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SUSTAINABLE FOOD SYSTEMS: RESEARCH AND POLICY – A NARRATIVE REVIEW

Narrative Review

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ABSTRACT

Background: Global food systems serve as the backbone of human nutrition and livelihoods but simultaneously exert immense pressure on the planet. They are responsible for approximately 26–37% of global greenhouse gas emissions, consume 70–80% of freshwater resources, and occupy nearly one-third of the Earth's land surface. Adding to this burden, around one-third of food produced is lost or wasted annually, compounding environmental degradation and threatening long-term food security. The sustainability of these systems has therefore emerged as a pressing global health and policy concern.

Objective: This review aims to synthesize recent evidence on the environmental, nutritional, economic, and societal dimensions of global food systems, while identifying challenges and potential pathways for a sustainable transition.

Main Discussion Points: Key themes explored include the contribution of food systems to climate change through carbon dioxide, methane, and nitrous oxide emissions; the excessive use of land and freshwater resources; and the magnitude of food loss and waste driving inefficiencies. The review also highlights dietary transitions, particularly plant-based diets, as effective strategies to reduce emissions and improve population health. Emerging technological innovations such as fermentation-based proteins and regenerative agricultural practices are discussed as promising solutions. Additionally, the economic implications and hidden costs of current systems are examined, alongside the rising threat of climate-driven food price inflation.

Conclusion: The evidence underscores that food system transformation is both a necessity and an opportunity. Shifting toward sustainable, health-promoting, and resource-efficient models can reduce environmental pressures, improve global nutrition, and deliver significant economic and societal benefits. Achieving this transition requires coordinated clinical guidance, evidence-based policies, and robust multidisciplinary research.

Keywords: Food Systems; Greenhouse Gas Emissions; Sustainable Diets; Food Waste; Climate Change; Narrative Review.

INTRODUCTION

The global food system is currently on a trajectory that raises profound concerns about its sustainability. Food production and supply chains are responsible for nearly one-third of total anthropogenic greenhouse gas emissions, generating around 16.2 billion tonnes of CO_2-equivalents in 2022 alone (1). Broader estimates indicate that the food system contributes between 20–37% of global emissions, highlighting its central role in driving climate change (2). Alongside this, agricultural activity places intense demands on natural resources, with farming practices accounting for approximately 70–80% of global freshwater withdrawals and nearly 30% of the Earth's land surface use (3). Livestock production in particular exerts disproportionate pressure, consuming up to 80% of farmland despite providing a smaller share of global caloric intake (4). Equally troubling is the magnitude of food loss and waste. Roughly one-third of all food produced—an estimated 931 million tonnes annually, equating to about 121 kilograms per person—is wasted, generating 3.3 gigatonnes of CO_2-equivalents each year and simultaneously depleting precious land, water, and energy resources (5,6). These inefficiencies are compounded by ongoing demographic and socio-economic drivers such as rapid population growth, urbanization, shifting dietary preferences, and tightening resource constraints. Together, these forces perpetuate a cycle that threatens both environmental resilience and food security on a global scale (7,8). Despite widespread acknowledgment of these challenges, systemic reform remains inadequate. The complexity of food system unsustainability lies not only in emissions and resource depletion but also in the interplay of socio-economic behaviors and policy shortcomings. Previous literature has emphasized sectoral approaches, yet integrated solutions that balance environmental protection, economic growth, and social well-being remain limited (9,10). This knowledge gap underscores the urgent need for research that synthesizes evidence across disciplines and proposes actionable strategies for sustainable transformation. The objective of the present review is to critically examine the unsustainable dimensions of global food systems, assess their environmental and resource burdens, and evaluate emerging policy and scientific pathways for reform. By providing an integrated perspective, this study aims to inform interventions that can foster resilient, equitable, and environmentally sustainable food systems for future generations.

ENVIRONMENTAL FOOTPRINT AND RESOURCE USE

Climate Impact and Emissions Breakdown

The global agrifood system exerts a profound environmental burden, contributing nearly one-third of all anthropogenic greenhouse gas emissions. In 2022 alone, total emissions reached 16.2 gigatonnes of CO_2-equivalents, with farm-gate production responsible for almost half, pre- and post-production activities one-third, and land-use change just under one-fifth. Notably, while direct agricultural emissions have risen by 15% since 2000, land-use change emissions have decreased by 30%, reflecting both conservation gains and shifting production pressures. However, emissions from pre- and post-production processes—such as packaging, retail, and transport—have increased by more than half, illustrating the growing climate burden of globalized supply chains (1). Regional disparities are striking: Asia accounts for 42% of global food-related emissions, followed by the Americas (26%), Africa (18%), and Europe (12%), with Oceania contributing the smallest share. Although emission intensity per unit of economic output has declined by nearly 40% since 2000, efficiency gains are insufficient to offset overall emission growth (2).

Methane, Nitrous Oxide, Carbon Dioxide

Animal agriculture remains a dominant driver of short-lived climate pollutants, particularly methane (CH_4) and nitrous oxide (N_2O). Globally, agriculture produces approximately 37% of anthropogenic methane and 65% of nitrous oxide emissions, both of which exert far greater warming potential than carbon dioxide over shorter time horizons (3). In Brazil, methane emissions from cattle and dairy alone equaled more than the total greenhouse gas output of some European nations, underscoring the disproportionate climate burden of intensive livestock systems (4). Although carbon dioxide dominates absolute volumes, the contribution of methane and nitrous oxide remains central to food-related climate policy, particularly in regions dependent on ruminant production.

Water Use & Agricultural Footprint

Agriculture is also the largest global consumer of freshwater, accounting for 70–80% of withdrawals. Water footprints vary significantly by commodity: beef production exceeds 10,000 liters per kilogram, poultry requires approximately 4,300 liters per kilogram, and nuts approach 9,000 liters per kilogram. By comparison, staple cereals such as rice and wheat consume 2,500 and 1,800 liters per kilogram, respectively (5). Pulses, often promoted for sustainability, demand roughly 4,000 liters per kilogram but provide high nutrient returns per unit of water. Transitioning toward predominantly plant-based diets has been shown to reduce individual water use by more than half, presenting a critical opportunity for conservation (6).

Land Use & Biodiversity Impacts

Livestock production occupies nearly 70% of all agricultural land, equivalent to about 30% of the Earth's terrestrial surface. This extensive use constrains biodiversity and accelerates deforestation, particularly in tropical regions. Modeling studies suggest that halving global consumption of animal-source foods could reduce agricultural land demand by one-third, halt deforestation, restore biodiversity, and lower greenhouse gas emissions by nearly one-third by 2050 (7). Beyond emissions, land-use reform offers the potential to sequester up to 100 billion tonnes of CO_2 through rewilding and afforestation, positioning dietary shifts as a key strategy for climate mitigation (8).

FOOD LOSS, WASTE & RESOURCE INEFFICIENCIES

Food Waste Quantification

Globally, about one-third of food produced is lost or wasted, representing nearly 931 million tonnes annually, equivalent to 121 kilograms per person. Household consumption is responsible for over 60% of this loss, while supply chain inefficiencies contribute the remainder. Food waste alone accounts for approximately 8% of global emissions, squanders 1.4 billion hectares of land, and depletes freshwater resources exceeding the volume of Lake Geneva threefold (9).

Energy & Resource Loss

In addition to direct emissions, food waste embodies substantial energy loss. Estimates indicate that up to 38% of all energy consumed in the food system is wasted through discarded food, intensifying the system's inefficiency (10). Interventions targeting household behavior, retail practices, and cold-chain improvements hold promise for reducing these losses, but global progress remains slow and uneven.

Healthy Diet Emissions vs Cost

Affordability remains a central barrier to the adoption of sustainable dietary patterns. Comparative analyses show that the lowest-emission healthy diets produce only 0.67 kg CO_2-equivalents per day and cost approximately USD 6.95, compared with 2.44 kg CO_2-equivalents and USD 9.96 for average diets (11). However, over 2.8 billion people cannot afford even the cheapest healthy diet, highlighting persistent inequities between nutritional ideals and economic realities.

Diet Type Impacts

Meat-heavy diets emit up to four times more greenhouse gases than vegan diets. Adoption of planetary health diets—emphasizing plant-based foods—could reduce land use by 41%, cut emissions by 30%, and prevent 20% of premature deaths through improved nutrition (12). These benefits illustrate the dual health and environmental gains of dietary transition, yet uptake is hindered by cultural preferences, food environments, and affordability gaps.

ECONOMIC DIMENSIONS & HIDDEN COSTS

Global Economic Benefits of Transition

Transforming food systems is projected to generate annual global benefits exceeding USD 10 trillion. These include preventing 174 million premature deaths, eliminating undernutrition by 2050, and creating resilience for nearly 400 million agricultural workers. Importantly, the estimated costs of transformation—0.2–0.4% of global GDP—are small relative to potential returns (13).

National Hidden Costs in Australia

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Country-level analyses illustrate the magnitude of hidden costs embedded within food systems. In Australia, while the food sector contributes AUD 800 billion to the economy, hidden environmental and health-related costs amount to AUD 274 billion annually, or 13% of GDP. Lifestyle diseases linked to poor diets alone account for nearly AUD 50 billion per year, emphasizing the interconnectedness of health and sustainability challenges (14).

EMERGING CHALLENGES & CLIMATE PRESSURES

Climate-Driven Food Inflation ("Climateflation")

The intersection of climate change and food economics is manifesting as "climateflation," whereby extreme weather events increase production costs and food prices. In the UK, hay yields have halved in some regions due to drought, while heatwaves and floods globally disrupt supply chains and raise input costs (15). Escalating food prices disproportionately affect low-income populations, reducing access to healthy foods and fueling dietary transitions toward calorie-dense, nutrient-poor alternatives. This shift exacerbates risks of malnutrition and chronic diseases, creating a feedback loop between climate change, health, and inequality.

Innovation & Technological Pathways

Renewable Food Technologies

Novel technologies are reshaping the food production landscape. Fermentation-based proteins, algae-derived oils, and precision fermentation are gaining commercial traction, with major corporations investing in scalability. These renewable pathways aim to decouple food production from land and freshwater constraints, offering alternatives with substantially lower environmental footprints (16).

Regenerative Agriculture & Soil Health

Beyond technological innovation, regenerative agricultural practices present ecological pathways for system resilience. With over 60% of EU soils and 40% of UK soils degraded, regenerative farming techniques—such as minimal tillage, crop rotation, and microbial composting—are demonstrating potential to enhance nutrient absorption, improve yields, and restore biodiversity (17). Soil health is increasingly recognized not only as an environmental imperative but as a strategic asset for food security and national resilience.

Synthesis & Policy Pathways

The transition to sustainable food systems requires targeted interventions across multiple levels. Key policy priorities include addressing emission hotspots, particularly methane from livestock and inefficiencies in pre- and post-production chains; promoting water- and land-efficient crops; and halving global food waste to conserve resources and cut emissions (18). Shifting subsidies toward ecological farming, scaling regenerative practices, and embedding climate adaptation within food security strategies are equally critical. Importantly, policy must ensure that healthy, low-emission diets are made accessible and affordable, particularly for vulnerable populations. The integration of renewable technologies, economic incentives, and resilience-focused governance represents a multidimensional approach essential for safeguarding both planetary health and human well-being.

CRITICAL ANALYSIS AND LIMITATIONS

The current evidence base on sustainable food systems is expansive yet uneven, with recurrent methodological issues that temper the certainty of many headline conclusions. Much of the literature relies on modeling studies or secondary databases rather than large, prospective primary investigations, which constrains causal inference and the robustness of cross-context comparisons (12). When interventions are tested—such as dietary shifts, food-waste reduction programs, or regenerative practices—sample sizes are frequently modest, follow-up is short, and outcomes are heterogenous, limiting power to detect durable effects on both environmental and health endpoints (13,14). Randomized controlled trials that simultaneously assess clinical outcomes, environmental indicators, and costs remain scarce; instead, quasi-experimental designs and scenario analyses predominate, introducing structural assumptions that can drive results as much as observed data (3,15). Methodological bias is a pervasive concern. Selection bias arises when studies are concentrated in high-income settings with strong data infrastructures and formal retail chains, while smallholders, informal markets, and low- and middle-income countries are under-represented (16). This skews estimates of food loss and waste, affordability, and supply-chain emissions toward contexts with better monitoring, thereby challenging external validity (17). Performance and detection bias also feature in dietary intervention research: blinding is rarely feasible, "healthy user" effects are difficult to exclude, and outcome measures (from self-reported diet quality to modeled greenhouse gas profiles) are variably defined and not consistently validated against objective benchmarks (3,5). In emerging technology domains (e.g., precision fermentation, algae oils), many reports are industry-sponsored proof-of-concepts or ex-ante techno-economic assessments with optimistic adoption curves, creating a risk of confirmation bias and overstated near-term mitigation potential (18).

Publication bias likely amplifies positive findings and under-reports null or adverse results. National inventories and flagship assessments give prominence to central estimates, while uncertainty ranges and sensitivity analyses—particularly those that would narrow perceived benefits—are less visible in policy discourse and media summaries (1,6). In nutrition-environment modeling, scenarios that show large gains from "planetary" diets or rapid methane abatement are more frequently highlighted than those revealing slower transitions, rebound effects, or distributional trade-offs (19). The debate over methane metrics exemplifies how methodological choices can tilt interpretations: using GWP* rather than GWP100 can depict constant livestock methane as "no additional warming," reshaping perceived progress and potentially downplaying the need for absolute cuts; critics caution that such accounting risks policy complacency and inequity (8,9). Variability in measurement outcomes further complicates synthesis. Life-cycle assessment (LCA) results are sensitive to system boundaries (farm-gate vs. cradle-to-grave), functional units (per kilogram product, per serving, per nutrient density), allocation methods for co-products, and the choice and weighting of impact categories (climate vs. eutrophication, water scarcity, biodiversity) (4,10). Small changes in these parameters can materially alter the relative ranking of foods or production systems, challenging simple narratives such as "organic is always better" or "pulses always use less water" across contexts (20). Food-waste statistics show similar heterogeneity: the 2024 Food Waste Index improved guidance and expanded datasets, yet measurement remains uneven across countries and sectors, with household self-reporting prone to underestimation and retail shrink sometimes double-counted or misclassified (7,12). Affordability indicators for healthy diets—though increasingly standardized—still depend on price data coverage, purchasing power parity updates, and assumptions about culturally acceptable substitutions; as a result, global figures mask substantial sub-national variability and temporal volatility (21).

Generalizability is limited by ecological and socio-economic diversity. Emission intensities, water footprints, and land-use change risks differ markedly by agro-ecology, feed sources, trade routes, and policy regimes; findings from temperate, capital-intensive systems do not always translate to pastoralist or smallholder contexts where livestock provide nutrition, income smoothing, and cultural value (3,5). Likewise, the co-benefits of dietary transitions depend on baseline diets, micronutrient gaps, and food environments; in settings with high undernutrition, rapid shifts away from animal-source foods may carry unintended risks without parallel investments in fortification, diversification, and cold-chain infrastructure (22). Even within high-income countries, distributional impacts matter: "climateflation" raises prices unevenly across food groups, potentially pushing low-income households toward calorie-dense, nutrient-poor diets despite aggregate emission gains, a tension rarely captured in mitigation-centric models (23). In sum, while the qualitative direction of the literature is consistent—agrifood systems impose substantial climate and resource burdens, and targeted dietary, technological, and agro-ecological strategies can reduce them—the quantitative precision and transferability of many estimates remain constrained by study design, measurement variability, and context specificity. Future work would be strengthened by multi-country pragmatic trials that integrate clinical, environmental, and cost outcomes; harmonized LCA protocols with transparent allocation and biodiversity metrics; standardized, independently audited food-waste accounting; and equity-aware scenarios that stress-test policies under price shocks and diverse cultural diets (10–12).

IMPLICATIONS AND FUTURE DIRECTIONS

The findings of this review carry significant implications for clinical practice, policy development, and future research in the pursuit of sustainable food systems. From a clinical perspective, the evidence underscores the intimate connection between dietary patterns, environmental health, and human well-being. Diets rich in plant-based foods and low in red and processed meat not only reduce greenhouse gas emissions and resource depletion but also contribute to lowering the incidence of chronic diseases such as cardiovascular disorders, diabetes, and certain cancers (22). For clinicians, these insights reinforce the importance of integrating sustainability considerations into nutritional counseling and patient education. Encouraging patients to adopt balanced, affordable, and environmentally friendly dietary patterns can therefore be framed as both a health-preserving and climate-mitigating strategy, with particular relevance in populations vulnerable to diet-related non-communicable diseases. In terms of policy, the reviewed literature highlights an urgent need for robust, evidence-based guidelines that align nutrition and sustainability goals. Current dietary recommendations in many countries remain focused largely on individual health outcomes, with limited consideration of environmental consequences. The integration of planetary health principles into national dietary guidelines could help align clinical advice with climate objectives, while also guiding food procurement policies in hospitals, schools, and community programs (23,24). Governments have a role in redirecting subsidies away from resource-intensive commodities toward healthier, sustainable alternatives, while simultaneously addressing equity by making nutritious diets affordable to low-income populations (25). The concept of "true cost accounting" in food systems, which incorporates hidden health and environmental costs, should also be operationalized in policymaking to ensure more transparent evaluation of agricultural and dietary choices (26).

Despite the progress in quantifying emissions, water use, and land impacts, substantial gaps remain in the literature. Many studies rely on model-based projections, which, while informative, are limited by assumptions that may not reflect real-world complexities such as cultural food preferences, trade dynamics, and socio-political barriers (25). Furthermore, low- and middle-income countries remain under-represented in empirical data on food loss, waste patterns, and dietary affordability, creating a gap in evidence that limits the global applicability of findings (6). The environmental impacts of emerging technologies, such as microbial proteins and algae-derived oils, require independent and long-term evaluation, particularly with respect to scalability, safety, and cultural acceptance (8). Future research must therefore adopt more rigorous and inclusive designs. Large-scale, multi-country randomized controlled trials evaluating sustainable dietary interventions could generate high-quality evidence on both health and environmental outcomes (3,4). Longitudinal cohort studies in diverse populations are also essential to assess the durability and equity of dietary transitions across socio-economic contexts. Standardization in life-cycle assessment methodologies, particularly regarding allocation of co-products and biodiversity indicators, would greatly enhance the comparability and reliability of environmental impact estimates (9,10). Additionally, mixed-methods approaches incorporating qualitative insights can capture consumer behavior, cultural barriers, and policy feasibility—dimensions often overlooked in purely quantitative models. Ultimately, interdisciplinary collaboration between clinicians, nutritionists, environmental scientists, and policymakers will be crucial to bridge current knowledge gaps and chart actionable pathways toward resilient, sustainable, and health-promoting food systems.

CONCLUSION

The evidence synthesized in this review highlights that the global food system is a major driver of greenhouse gas emissions, water depletion, land degradation, biodiversity loss, and food waste, while also shaping dietary health outcomes and economic burdens. Although the literature consistently demonstrates the potential of dietary transitions, waste reduction, regenerative agriculture, and novel food technologies to mitigate these challenges, the strength of evidence is uneven, often relying on modeling assumptions and limited empirical data. For clinicians, these insights reinforce the value of promoting dietary choices that simultaneously enhance patient health and reduce environmental harm, while policymakers are urged to integrate sustainability into nutrition guidelines and food system regulations. Researchers are encouraged to adopt robust, multidisciplinary study designs that address gaps in long-term outcomes, cultural contexts, and equity dimensions. Ultimately, the transition to sustainable food systems represents both a necessity and an opportunity, requiring collective, evidence-based action to secure human and planetary health for future generations.

AUTHOR CONTRIBUTION

Author	Contribution
Muhammad Usama Aslam*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Esha Aslam	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Muhammad Shahbaz*	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published

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