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A Convergent Systems Approach to Food Loss and Waste in The Philippines

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Abstract

Food loss and waste (FLW) represent a critical sustainability challenge with profound implications for food security, environmental resilience, and economic stability. This study introduces a Convergent Systems Model (CSM) that integrates systems mapping, the Iceberg Model, and the Triple Bottom Line (TBL) sustainability framework to capture both surface-level events and deep systemic drivers of FLW. Unlike earlier studies that treat these analytical tools separately, this approach offers a multi-layered understanding of interactions, feedback loops, and root causes in a scalable format. It focuses on the Philippines, an emerging economy with fragmented agricultural systems, logistical constraints, entrenched socio-cultural norms, and gaps in policy implementation, reconceptualising FLW as an emergent property of interdependent subsystems. Data were gathered through an extensive review of peer-reviewed literature, government reports, sustainability indexes, and national surveys. Findings identify strategic leverage points, including targeted food literacy campaigns, expanded cold chain infrastructure, standardized labelling, community-based recovery systems, and digital innovations for surplus redistribution. The TBL analysis highlights significant social impacts, including hunger and malnutrition, environmental pressures from greenhouse gas emissions and resource depletion, and economic losses resulting from inefficiencies across the value chain. By integrating diagnosis and intervention design, the CSM bridges analytical gaps and provides a transferable framework for reducing FLW in complex, evolving food systems of emerging economies. This study advances the achievement of Sustainable Development Goals (SDGs) 2 (Zero Hunger) and 12 (Responsible Consumption and Production) by promoting equity-based, cross-sectoral, and sustainability-integrated strategies.

Keywords: Food Loss and Waste, Philippines, Sustainability, Systems Thinking, Triple Bottom Line.

Introduction

Food loss and waste (FLW) present one of the most critical sustainability challenges of the 21st century, with profound implications for food security, environmental resilience, and economic stability. Globally, approximately one-third of all food produced, equivalent to about 1.3 billion tons, is either lost or wasted annually, contributing significantly to greenhouse gas emissions, natural resource depletion, and persistent hunger (1-3). Southeast Asia collectively generates substantial food waste, with estimates indicating that the region loses up to 30% fruits and vegetables before reaching markets due to inadequate postharvest handling and logistics (4). Regional analyses further highlight common drivers such as rapid urbanization, weak waste management infrastructure, and cultural norms of abundance during festivals (5). Positioning the Philippine case within this regional trend underscores the urgency of tackling FLW not only as a national issue but also as part of Southeast Asia's broader sustainability and food security agenda. Emerging economies, such as the Philippines, are compounded by the interaction of agricultural vulnerabilities, infrastructural deficiencies, socio-cultural dynamics, and fragmented governance structures

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(6-7). In the Philippine context, FLW worsens food insecurity, environmental degradation, and financial losses for households and government institutions (8-9). It persists despite legislation such as the Ecological Solid Waste Management Act (Republic Act No. 9003) and proposals like the Food Waste Reduction Act (10). Previous research on FLW has often been fragmented, with studies focusing on single elements of the food system, such as postharvest losses, consumer behaviour, or policy analysis, without accounting for the interconnected feedback loops and systemic drivers that sustain inefficiencies (11-13). Most have relied on singular methodological approaches, whether technical, behavioural, or policy-oriented (14-16). This study employs a Convergent Systems Model, integrating systems mapping, the Iceberg Model, and the Triple Bottom Line (TBL) sustainability framework. By combining dynamic visual mapping, root-cause analysis, and sustainability assessment, this study captures both surface-level events and deeper systemic structures that influence FLW in the Philippines (17-19).

This study has three interrelated objectives: 1. diagnostic – to map systemic interactions and hidden drivers that reinforce FLW in the Philippines; 2. prescriptive – to identify leverage points for targeted, sustainable interventions across actor and subsystems; and 3. evaluative – to assess the social, environmental, and economic implications of FLW using the Triple Bottom Line framework. Together, these objectives clarify that the contribution is not only analytical but also action-oriented. By reconceptualising FLW as an emergent systemic property, this work advances Sustainable Development Goals 2 and 12 and offers a replicable framework for other emerging economies (20-21).

This study's Convergent Systems Model (CSM) also builds on established systems thinking traditions such as the Socio-ecological Systems (SES) framework, food system resilience approaches, and the circular economy paradigm. SES emphasizes the interdependence of human and ecological subsystems, highlighting the value of understanding how resource management and governance influence food outcomes (22). The food systems resilience framework underscores adaptive capacity, redundancy, and inclusivity in responding to shocks such as climate variability or market disruptions (23). Circular economy principles, in turn, advocate closing of resource loops through reuse, recovery, and redistribution (24). By weaving these traditions, the CSM adapts global systems thinking to the Philippine context, amalgamating diagnostic depth with intervention-oriented analysis for sustainable FLW reduction.

Methodology

Research Design

A qualitative systems-thinking approach was used to examine the multi-dimensional dynamics of FLW in the Philippines. Given the complex and adaptive nature of food systems, linear analysis alone is insufficient (25, 26). The Convergent Systems Model (Figure 1) integrates three complementary frameworks: Systems Mapping, Iceberg Model Analysis, and the Triple Bottom Line (TBL) Sustainability Framework. This combination allows a comprehensive understanding of surface events, underlying structures, behavioural drivers, and sustainability impacts (27).

In this study, the systems approach was employed primarily as a heuristic and diagnostic lens rather than a formal quantitative model. Systems mapping and causal loop diagrams were used to trace interactions and feedback loops. At the same time, the Iceberg Model provided layered root-cause analysis. The TBL framework enabled evaluation of social, environmental, and economic impacts. However, no formal system dynamics simulations or network analyses were conducted. The emphasis was on qualitative mapping and integrative diagnosis, allowing the framework to remain scalable and transferable to other emerging economy contexts.

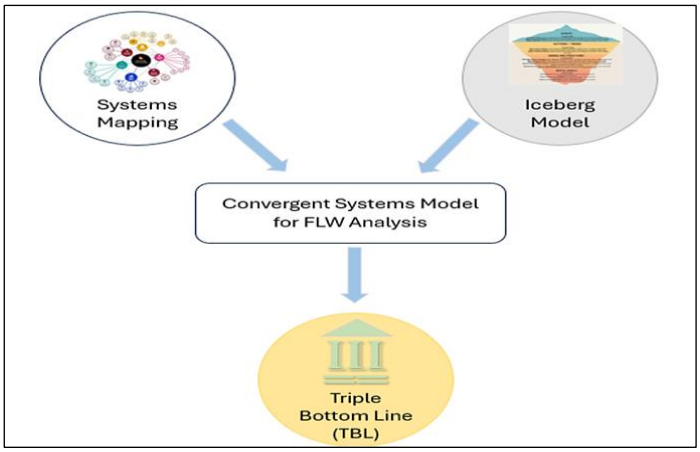

Figure 1: Convergent systems model for Philippine FLW analysis

Table 1: Comparative analysis of frameworks utilized in the study: understanding FLW in the Philippine context

Framework	Focus	Strength	Limitation	Type of Result
Systems Thinking	Interconnections, feedback	Identifies system-wide leverage points	Abstract without concrete indicators	Systems map, causal loops
Iceberg Model	Root causes, mental models	Diagnose deep causes	Not quantitative	Layered root-cause analysis
Triple Bottom Line	Sustainability outcomes	Measure impact across three domains	It does not explain systemic persistence	Quantified social, environmental, and economic metrics

Table 1 highlights how each framework contributes distinct but complementary insights. A system thinking offer a holistic view of interconnections but requires operationalization through mapping tools. The Iceberg Model deepens diagnosis by surfacing root causes, while the TBL framework quantifies impacts across social, environmental, and economic domains. Together, they justify the use of the Convergent Systems Model as an integrated framework tailored to the Philippine FLW context. Data collection was based on an extensive secondary review of peer-reviewed literature, government reports, sustainability indexes, NGO assessments, and official Philippine food security and nutrition surveys. Key sources included the Food and Agriculture Organization, the United Nations Environment Programme, the Department of Science and Technology's Food and Nutrition Research Institute, and the World-Wide Fund for Nature (8, 9, 28, 29).

Systems Mapping

Systems mapping was used to visualize the network of interactions among key FLW actors (producers, intermediaries, retailers, consumers, government agencies, and NGOs) within the Philippine food system. Causal loop diagrams helped identify reinforcing and balancing feedback loops across production, distribution, consumption, and waste (30). This mapping enabled the identification of systemic bottlenecks and leverage points (31).

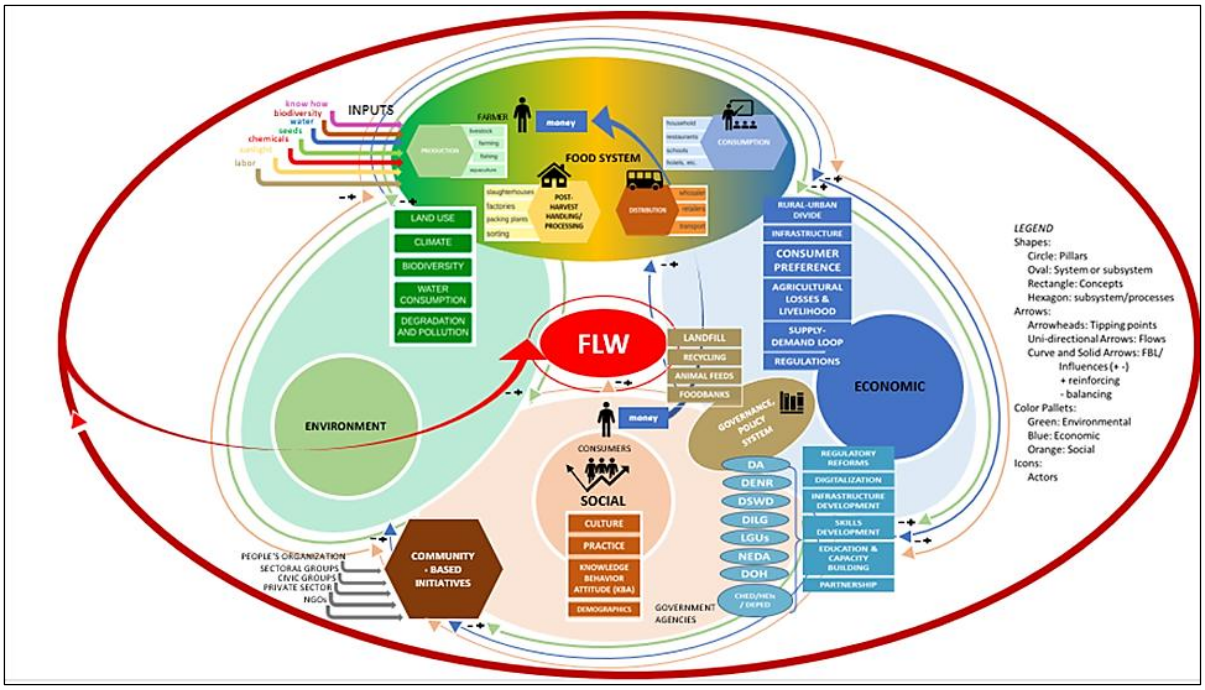

Figure 2: Philippine Food Loss and Waste Systems Map

Figure 2 illustrates how FLW emerges from complex interactions across the value chain. Notably, the reinforcing feedback loops, such as overproduction triggered by aesthetic standards which demonstrate how localized decisions accumulate into systemic inefficiencies. The map also underscores the pivotal role of weak cold chains and limited policy enforcement, which act as structural bottlenecks.

Iceberg Model Analysis

Building on the systems map, the Iceberg Model framework was applied to unpack four layers of systemic analysis:

- Visible Events: Observable manifestations of FLW, such as household waste and surplus dumping.
- Patterns and Trends: Recurring behaviors (e.g., waste spikes during festive seasons).
- Systemic Structures: Institutional and infrastructural arrangements enabling waste (e.g., limited cold chain logistics).
- Mental Models: Deep-seated cultural beliefs (e.g., preference for aesthetic perfection).

This framework facilitates a shift from symptom-based analysis to root-cause diagnosis, as validated by systems-thinking experts (25, 32, 33).

Triple Bottom Line Sustainability Framework

To assess the broader consequences of FLW, the study employed the TBL framework, which evaluates impacts across three sustainability dimensions:

- People (Social Impact): Hunger, malnutrition, and inequities.
- Planet (Environmental Impact): Greenhouse gas emissions, land degradation, and water overuse.
- Profit (Economic Impact): Financial losses and missed economic opportunities.

Previously, Triple Bottom Line's integration across sustainability dimensions was discussed and it was cited in the Elkington's 1997 proposal (34) and further refined by others (35-36), provides an integrated perspective essential for sustainable planning.

Analytical Flow

The Convergent Systems Model employed a three-phase analytical flow:

- Mapping: Structural mapping of FLW actors and processes.
- Diagnosis: Iceberg Model analysis of underlying structures and drivers.
- Sustainability Assessment: TBL Framework Categorization and Quantification of Impacts.

This integrative methodology provides a deep, actionable understanding of how FLW occurs and persists within emerging economy contexts (27).

Results and Discussion

Systems Mapping of the Philippine Food Loss and Waste

The systems map of food loss and waste of the Philippines (Figure 2) captures a highly interdependent network of actors, processes, and feedback mechanisms across the food value chain, from production to consumption and disposal. This systems map illustrates the following key components:

Inputs: Natural resources (land, water, biodiversity), energy, human labor, and agricultural inputs (e.g., seeds, fertilizers).

Actors: Farmers, intermediaries, retailers, consumers, government agencies (e.g., DA, DENR, LGUs), NGOs, and private logistics companies.

Processes: Agricultural production, postharvest handling, transportation, food processing, marketing, retailing, consumption, and waste management.

Feedback Loops: Overproduction responds to market demand, consumer preference for aesthetics leads to waste, weak cold chain systems exacerbate spoilage, and limited enforcement of food waste policies.

At the macro level, external drivers such as climate change, socio-economic disparity, market liberalization, and cultural food norms dynamically influence the system (37).

Interlinked Subsystems and Sectoral Insights

Food loss and waste (FLW) in the Philippines is systemic, emerging from the complex interactions across production, processing, logistics, retail, and consumption subsystems. These interconnected systems, each with distinct dynamics, contribute cumulatively to food loss.

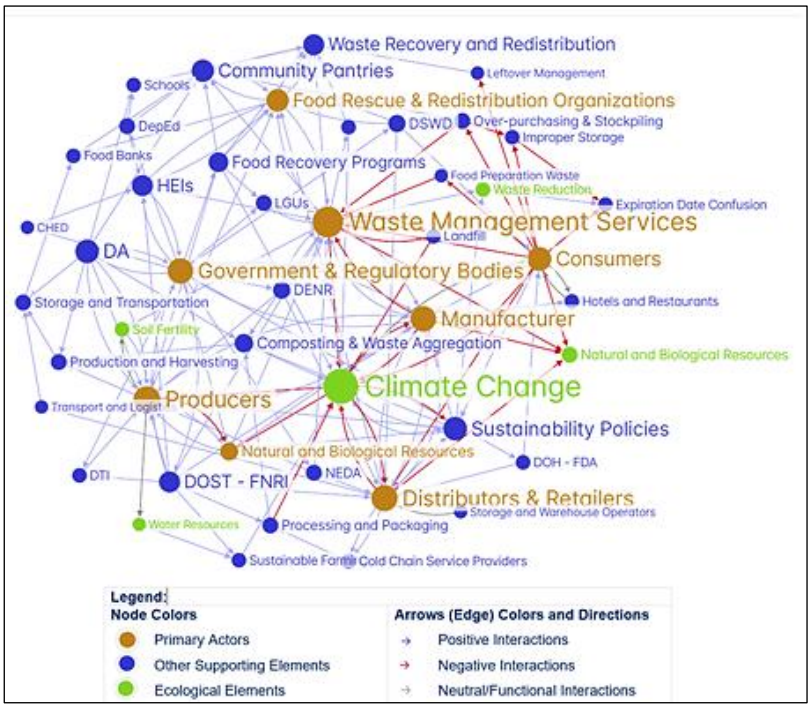

Figure 3: Systemic Interaction of Philippine FLW. Created by Sheila Mae Carungay with the Assistance of Graph Commons (38)

Figure 3 shows the interdependence of subsystems, making visible how shocks in one area (e.g., environmental degradation) cascade into others (e.g., reduced agricultural productivity and higher economic losses). This systemic interaction reinforces the need for cross-sectoral interventions rather than isolated technical fixes.

Agricultural Subsystem

Inefficient production practices, inadequate infrastructure, and vulnerability to extreme weather conditions contribute to high loss rates (39, 40). Overproduction without sufficient storage often results in wastage (41). Smallholder

farmers face persistent challenges accessing markets and preservation technologies (39).

Environmental Subsystem

Soil degradation, water scarcity, and biodiversity loss further reduce productivity (42, 43). FLW contributes to methane emissions and exacerbates climate change (44). Agricultural runoff and deforestation also impair environmental resilience (45, 46).

Socio-Cultural Subsystem

Cultural practices, such as over-preparation and rejecting imperfect produce, contribute to waste (47, 48). Misunderstandings about date labeling and biases against leftovers are widespread (49).

Economic Subsystem

Market incentives and supply chain gaps exacerbate FLW. Retailers frequently reject produce failing to meet cosmetic standards (50). Logistics costs, lack of cold storage, and overproduction for profit worsen inefficiencies (51-53).

Governance Subsystem

Despite legislation (Republic Act No. 9003) and policies such as the Food Waste Reduction Act, enforcement remains inconsistent (10, 54, 55). Fragmented governance structures and limited incentives for donation or recovery constrain progress (56).

FLW Drivers and Structures

Production inefficiencies, infrastructure deficits, retail standards, socio-cultural norms, policy gaps, and environmental shocks all reinforce systemic waste (39, 40, 47, 50, 54, 57). For example, perishable crops such as onions and mangoes routinely exhibit loss rates of 30–50% (38). Limited cold chains and fragmented transport networks compound these losses (51, 52).

The Iceberg Model of the Philippine FLW

Applying the Iceberg Model reveals:

- Surface-Level Events: Observable waste in households, surplus dumping (39, 58).
- Patterns: Seasonal waste spikes and a correlation between economic growth and higher waste (59, 60).
- Systemic Structures: Fragmented supply chains, misaligned incentives, lack of segregation infrastructure (40, 44, 56).
- Mental Models: Cultural emphasis on abundance, aesthetic biases, low perception of impact (48, 49, 61).

Intervening only at the surface level (e.g., awareness campaigns) is unlikely to generate transformative change without addressing these deeper structures and mental models (32, 33, 62). Table 2 summarizes leverage points derived from this analysis.

Table 2: Iceberg Model-Derived Leverage Points

Leverage Axis	System Layer Targeted	Description
Educational Campaigns	Mental Models	Reframe perceptions of food aesthetics and leftovers
Cold Chain Investment	Systemic Structures	Expand rural cold storage infrastructure
Subsidy Reform	Patterns and Trends	Align incentives with sustainable production
Public-Private Partnerships	Systemic Structures	Support recovery and redistribution programs
Standardized Labelling	Patterns and Trends	Clarify "best before" and "use by" date distinctions

These leverage points are especially relevant to the Philippine context. For instance, educational campaigns directly address cultural norms such as food abundance and aesthetic preferences that drive avoidable waste. Cold chain investment is crucial, given the country's tropical climate and frequent postharvest losses in fruits and vegetables, which sometimes reach 30-50 percent. Standardized food labeling helps address consumer confusion that can lead to premature disposal. Aligning these interventions with the corresponding system layers, such as mental models, structures, and patterns, reveals how small, targeted changes could generate outsized systemic impacts.

Triple Bottom-Line Analysis and Implications

People: Social Impact

FLW exacerbates food insecurity and malnutrition. In the Philippines, three out of five households

experience food insecurity, while plate waste averages 76 grams daily (8, 28, 63). The triple burden of malnutrition persists, with undernutrition and micronutrient deficiencies being widespread (29, 64).

Planet: Environmental Impact

Globally, FLW contributes 8–10% of greenhouse gas emissions (2, 65). In the Philippines, unsustainable resource use and limited waste segregation infrastructure compound environmental pressures (66). Every unit of wasted food represents a squandered resource of water, fertilizer, and energy (67).

Profit: Economic Impact

FLW incurs significant costs for producers, consumers, and governments. High logistics expenses, productivity losses, and missed economic opportunities are prevalent (51, 68). Reducing FLW could enhance resilience and competitiveness (69).

Strategic Leverage Points

Education and Awareness: Promote food literacy and value-based consumption (47, 61).

Public-Private Partnerships: Strengthening Cold Chains and Logistics (52, 70).

Policy Reform: Enforce existing legislation and implement new regulations (54, 55).

Community-Based Recovery: Scale composting and redistribution (56, 71).

Digital Innovations: Use apps and platforms to match surplus and demand (72).

Incentives: Provide subsidies or tax breaks for sustainable practices (73).

Table 3: Strategic leverage points for FLW reduction in the Philippines

Leverage Point	Key Focus Area	Proposed Actions	Expected Impact
Education and Awareness Campaigns	Consumer behavior, cultural, and mental models	Promote food literacy, value-based consumption, and discourage aesthetic bias.	Reduce household and retail food waste.
Public-Private Partnerships (PPPs)	Logistics, supply chain management	Strengthen cold chains, improve postharvest handling, and share tech innovations.	Minimize postharvest and distribution losses.
Policy Reform and Enforcement	Governance and regulation	Strengthen the enforcement of RA 9003, operationalize the Food Waste Reduction Act, and enhance monitoring.	Institutionalize food waste reduction practices.
Community-Based Recovery Systems	Grassroots initiatives, local governance	Support LGU-led composting, food banks, surplus donations (e.g., Rise Against Hunger, WWF Philippines)	Diverting edible surplus enhances the circular economy.
Farmer Cooperatives and Associations	Agricultural production efficiency	Improve farm-to-market linkages and postharvest tech access to promote sustainable farming.	Reduce losses at the farm level of production.
Labeling Standardization and Packaging Innovations	Retail and consumer sector practices	Clarify "best before" vs. "use by" dates, promote sustainable packaging	Prevent premature disposal, optimize consumer use
Digitalization of Food Systems	Technology integration	Use apps for surplus food redistribution to improve real-time inventory tracking.	Match supply and demand to minimize waste efficiently.
Incentivizing Sustainable Practices	Economic drivers	Provide tax breaks/subsidies for food recovery businesses and sustainable retailers.	Encourage sector-wide adoption of FLW-reducing innovations.

Each proposed action carries unique opportunities and barriers (Table 3). For example, private-public partnerships are feasible due to ongoing collaborations between the Department of Agriculture and the DOST. Still, they require more substantial incentives to attract logistics companies. Policy reform is politically challenging but essential to operationalize the proposed Food Waste Reduction Act. Community-based recovery systems, while effective, depend on local government capacity and sustained funding. Digital innovations offer scalability but face limitations in rural areas with weak connectivity. By elaborating on these sectoral considerations,

the result underscores that the FLW reduction requires not only technical fixes but also governance reforms, social buy-in, and context-sensitive implementation.

Comparative studies across Southeast Asia reveal both similarities and divergences with the Philippine context. For instance, Vietnam experiences high postharvest losses in rice due to inadequate drying and storage facilities, while Indonesia faces significant household-level food waste linked to urbanization and changing consumption habits (59, 60). The Philippine case aligns with these countries in terms of infrastructure gaps, weak cold chains, and socio-cultural drivers, but diverges in its governance challenges, as fragmented policy enforcement is pronounced. Such comparative framing suggests that while many lessons are regionally transferable, such as investment in cold storage, labeling literacy, and food redistribution systems, context-specific adaptations are necessary to address cultural and institutional particularities.

Reflections

FLW in the Philippines is an emergent property of systemic interaction. Addressing it requires cross-sectoral, adaptive, and complexity-aware strategies (32, 62, 74). Recognizing the interdependencies between agriculture, logistics, consumption, and governance is crucial for making meaningful progress toward SDGs 2 and 12 (20, 21).

A limitation of this study is that it primarily relied on secondary data sources, including surveys, government reports, and sustainability indexes, which has to be acknowledged. While these sources provide breadth and reliability, they do not fully capture the perspectives of underrepresented actors such as informal food vendors, waste pickers, and smallholder farmers. As such, certain dynamics, such as informal sector practices or real-time consumer behavior, could not be directly observed. Furthermore, the qualitative systems approach provides diagnostic and prescriptive insights but does not quantify system dynamics or simulate policy scenarios. These underrepresented actors experience FLW most acutely but are often excluded from policy discussions. Incorporating their lived experiences would help avoid a top-down perspective and enrich systemic analysis with grounded realities. Future research should prioritize participatory approaches that amplify these voices to strengthen equity and inclusivity in food system governance. Integrated primary fieldwork with farmers, informal vendors, and households can capture underrepresented perspectives and employ system dynamics modeling to test the long-term impacts of proposed interventions.

Conclusion

The Convergent Systems Model is appropriate for emerging economies like the Philippines, where diverse production-to-consumption landscapes operate within complex systems marked by unique social, economic, and environmental contexts (75). This study fills a critical gap by reconceptualising food loss and waste (FLW) as an emergent property of interdependent subsystems comprising agriculture, the environment, socio-cultural norms, economic drivers, and governance structures (14, 30). This perspective shifts the analytical lens beyond isolated "hotspots" and underscores how systemic interactions sustain inefficiencies (16, 17).

By integrating Systems Mapping, the Iceberg Model, and the Triple Bottom Line sustainability framework, the study identified leverage points with the highest potential for impact, including targeted food literacy campaigns, improved cold chain logistics, community-based recovery systems, and digital platforms for surplus redistribution (47, 49, 70).

Addressing FLW in the Philippines requires strategies that move beyond technical fixes toward transformative, cross-sectoral interventions aligned with SDGs 2 and 12 (20, 21). Only through complexity-aware, equity-based, and sustainability-integrated approaches can food loss and waste be reduced in ways that promote resilient, inclusive, and sustainable food systems.

Based on the findings, three concrete recommendations are proposed. First, institutionalize standardized food labeling and consumer education campaigns to reduce household and retail-level waste. Second, prioritize public-private partnerships to expand cold chain infrastructure, particularly in rural agricultural areas. Third, support community-based recovery systems and digital platforms to ensure edible surplus is redistributed rather than discarded. These targeted actions, if implemented collaboratively across government, industry, and

civil society, could significantly reduce FLW and enhance the resilience of the Philippine food system.

Abbreviations

CSM: Convergent Systems Model, FLW: Food Loss and Waste, LGU: Local Government Unit, NGO: Non-Governmental Organization, RA: Republic Act, SDG: Sustainable Development Goals, TBL: Triple Bottom Line.

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Author Contributions

Maria Celia Mateo-Fernando: conceptualization, manuscript writing, Elaida R. Fiegalan: methodology design, Sheila Mae E Carungay: prepared the Systemic interaction of Philippine FLW using Graphcommons, Gretchen Enarle: literature review, analysis, Sheena Marie M Marjolino: literature review, analysis, Jerome M Adriano: prepared the systems mapping and figures, Girlie Rueda: prepared the systems mapping and figures, Ian Junelord Invierno: prepared the systems mapping and figures, Kim Irvin Protacio: data synthesis, policy review, Leo Mendel Rosario, Ricardo Bagarinao, and Rodelio F. Subade: performed technical review.

Conflict of Interest

The authors declare that they have no conflicts of interest in the conduct and reporting of this study.

Declaration of Artificial Intelligence (AI) Assistance

As the principal author of this paper, I hereby declare that we used AI **only** for the following purpose/s: finding information about the literature used and checking grammar and syntax. I acknowledge that the work I submitted is largely the result of our own intellectual efforts, building from collective research work undertaken with my co-authors.

Ethics Approval

No human participants or animals were involved in this study; therefore, ethics approval was not required.

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