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Food Loss and Waste: Magnitude, Nutritional Implications, Environmental Consequences, and Strategies for Reduction — A Narrative Review with Special Reference to Indonesia

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ABSTRACT

Background: ood loss and waste (FLW) represent a critical yet underappreciated challenge to global food and nutrition security, environmental sustainability, and economic development. An estimated 13% of food produced globally is lost along the supply chain. Indonesia ranks among the world's largest contributors to food waste, generating 53–84 kg per capita per year, with households responsible for approximately 80% of this volume. This narrative review synthesizes current evidence on the magnitude, drivers, nutritional implications, environmental consequences, and effective reduction strategies for FLW, with particular attention to the Indonesian context.
Methods: A non-systematic literature search was conducted in PubMed, Web of Science, and Google Scholar for systematic reviews, meta-analyses, policy reports, and contextual studies published between 2016 and 2026.
Results: FLW imposes a triple burden: nutritional, through the loss of macro- and micronutrient-dense foods; environmental, through greenhouse gas emissions, water depletion, and land use; and economic, disproportionately affecting smallholder farmers and food-insecure households. Behavioural interventions, including education and choice architecture nudges, demonstrate moderate effectiveness in reducing consumer-level waste. Policy instruments such as date labelling reform, fiscal measures, and food redistribution systems show promise but remain inconsistently implemented, particularly in low- and middle-income countries including Indonesia.
Conclusion: Achieving SDG 12.3's target to halve per capita food waste by 2030 requires coordinated multisectoral action combining measurement, behavioural, regulatory, and technological strategies, adapted to the national and local context.

Keywords: food insecurity; food loss; food systems; food waste; nutrition security

A. BACKGROUND

The global food system produces more than enough calories to nourish every person on earth, yet approximately one in eleven people remain affected by hunger and a third of the global population is unable to afford a healthy diet[1]. This paradox is partly explained by the staggering scale of food loss and waste (FLW) throughout the food supply chain. According to the most recent Food Waste Index Report published by the United Nations Environment Programme (UNEP) in 2024, an estimated 1.05 billion tonnes of food were wasted at the household, food service, and retail level globally in 2022, equivalent to nearly one fifth of all food available to consumers, while a further 13% of global food production is estimated to be lost along the supply chain before reaching the retail stage[1,2]. Collectively, FLW represents one of the most consequential systemic failures of contemporary food systems, with cascading consequences for nutrition, climate, ecology, and economic equity.

The distinction between food loss and food waste, while often used interchangeably in public discourse, carries important technical and policy implications. Food loss refers to reductions in the quantity or quality of food along supply chains from post-harvest to, but not including, the retail stage, and arises from deficiencies in storage infrastructure, transportation logistics, cold chain capacity, and post-harvest handling practices[2,3]. Food waste, by contrast, refers to food discarded or otherwise removed from the food supply chain at the retail, food service, or consumer level, and is driven primarily by consumer behaviour, retail overordering, aesthetic quality standards, and ambiguous date labelling[1,2]. This distinction matters because the drivers, consequences, and optimal interventions differ markedly between the two: food loss in low- and middle-income countries predominantly occurs at the production and storage stages and demands infrastructure investment, while consumer-level food waste in both high-income and transitioning economies calls for behavioural, regulatory, and logistical responses[3,4].

Reducing FLW has been explicitly embedded in the international sustainable development agenda through Sustainable Development Goal (SDG) 12.3, which calls on countries to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses, by 2030[5]. Despite growing political commitment, global progress toward SDG 12.3 remains insufficient: the 2025 Champions 12.3 Progress Report concluded that the world is not on track to achieve this target, with the majority of countries still lacking baseline FLW data capable of tracking progress[5]. Indonesia presents a particularly salient case study, given its status as the fourth most populous nation, a major agricultural producer, and simultaneously one of the world's

highest per capita contributors to food waste, having been ranked second globally in food loss and waste at approximately 300 kg per person per year by the Economist Intelligence Unit in a widely cited 2017 assessment[6].

This narrative review aims to: (1) describe the magnitude and distribution of FLW globally and in Indonesia; (2) analyse the nutritional implications of FLW for food and nutrition security; (3) examine the environmental and economic consequences of FLW; (4) synthesize evidence on the determinants of food waste behaviour; (5) evaluate the effectiveness of behavioural and structural interventions for FLW reduction; and (6) discuss policy implications, with particular attention to the Indonesian context and the path toward achieving SDG 12.3.

B. METHODS

This article was prepared as a narrative literature review. A non-systematic search was conducted in PubMed/MEDLINE, Web of Science, and Google Scholar for articles published between 2016 and 2026, supplemented by targeted searches of reports from the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), the Champions 12.3 coalition, and the World Resources Institute, using combinations of the keywords "food loss," "food waste," "food loss and waste," "food and nutrition security," "nutrient loss," "greenhouse gas emissions," "SDG 12.3," "behavioural intervention," "nudge," and "Indonesia." Priority was given to systematic reviews and meta-analyses of intervention studies, authoritative global monitoring reports, country-specific epidemiological and measurement studies, and landmark policy analyses. Studies published as conference abstracts only or without available full text were excluded. Findings were thematically synthesized around magnitude and distribution, nutritional and environmental consequences, determinants of food waste behaviour, intervention effectiveness, and implications for Indonesia.

C. RESULT AND DISCUSSION

The evidence reviewed here demonstrates that food loss and waste impose a triple burden on humanity: a nutritional burden through the loss of macro- and micronutrient-dense foods; an environmental burden through greenhouse gas emissions, water and land use; and an economic burden disproportionately affecting smallholder farmers and food-insecure households in low- and middle-income countries[1-5]. These burdens are interconnected, and

effective policy responses must address all three dimensions simultaneously if SDG 12.3 and related sustainable development goals are to be achieved.

1. Global and Indonesian Magnitude of Food Loss and Waste

At the global level, FAO estimated in 2019 that approximately 14% of food produced for human consumption is lost between harvest and the retail stage, predominantly in supply chain activities including post-harvest handling, storage, processing, and distribution[3]. A further 17-19% of food available to consumers is wasted at the household, food service, and retail level, as consistently reported across successive UNEP Food Waste Index assessments[1,2]. In absolute terms, the UNEP 2024 report estimated that 1.05 billion tonnes of food waste were generated in 2022 alone, amounting to 132 kilograms per capita, of which the household sector contributed approximately 60%, food service 28%, and retail 12%[2]. Crucially, the 2024 report found that food waste per capita levels are more uniform across income groups than previously assumed, with high-, upper-middle-, and lower-middle-income countries differing by only 7 kg per capita, definitively dispelling the earlier assumption that food waste is predominantly a high-income-country problem[2].

Within Indonesia, the food waste burden is substantial and growing. A longitudinal analysis covering the period 2000 to 2019 found that the proportion of food wasted rose from approximately 39% to 55% of food produced, equivalent to 5 to 19 million tonnes per year, with households generating approximately 80% of total food waste and approximately 44% of household waste consisting of edible food[6]. A more recent direct measurement study conducted across urban and rural households in Indonesia, employing a rigorous diary and waste sorting methodology, provided the first detailed composition data on household food waste in the country, finding that cooked and prepared foods accounted for the largest proportion of wasted edible food, followed by fresh fruits and vegetables[7]. The UNEP Food Waste Index 2024 estimated Indonesia's food waste generation at 53 kg per capita per year at the household and food service level, while the National Development Planning Agency (Bappenas) estimated a substantially higher figure of 80.3 to 84 kg per capita per year when broader definitions and higher household contributions are applied[8]. Taken together, Indonesia's scale of food waste imposes significant burdens on food security, nutrition, and the environment, and positions the country as a critical focus for FLW policy action in the Asia-Pacific region.

2. Nutritional Implications of Food Loss and Waste

The nutritional consequences of FLW extend far beyond caloric loss. Because nutrient-dense food groups, including fruits, vegetables, seafood, and dairy products, are

disproportionately lost and wasted relative to their share of caloric production, FLW amplifies dietary inadequacy for both macro- and micronutrients[9,10]. A landmark study quantifying the nutritional content of food wasted at the retail and consumer levels in the United States estimated that wasted food in 2012 contained approximately 1,217 kilocalories, 33 grams of protein, 5.9 grams of dietary fibre, 1.7 micrograms of vitamin D, 286 milligrams of calcium, and 880 milligrams of potassium per capita per day, with dietary fibre, calcium, potassium, and vitamin D among the nutrients wasted in quantities exceeding current dietary gaps in the population's actual intake[9]. A global analysis of 151 countries similarly found that daily per capita food waste contained vitamin C, K, zinc, copper, manganese, and selenium equivalent to 25-50% of their respective dietary reference intake values, with cereals, fruits, and vegetables identified as the three major food groups contributing most to wasted nutrient loss[10].

In food-insecure settings, including Indonesia, the nutritional implications of FLW are particularly acute because wasted food is unlikely to be replaced from alternative sources by low-income households lacking adequate financial resources, meaning that food discarded at any stage of the supply chain represents a genuine and irreplaceable nutritional loss for the households and communities that needed it most[11]. A study examining household food waste generation and its associated caloric and nutrient losses in Lebanon found that an average of 451 kilocalories, 37.5 grams of carbohydrate, 14.9 grams of protein, 2.9 grams of dietary fibre, and substantial quantities of calcium, potassium, and vitamin D were embedded in household food waste per capita per day[12]. These nutrient losses are particularly concerning in the context of Indonesia's ongoing double burden of malnutrition, in which micronutrient deficiency and undernutrition coexist with rising rates of overweight and obesity, and where nutrient-dense foods are already underconsumed relative to dietary recommendations[13]. Reducing food waste in this context therefore carries a dual nutritional dividend: directly increasing the availability of nutrient-dense foods for food-insecure households, and indirectly reducing demand pressures that drive up the price of nutritious foods for all consumers.

Further complicating the nutritional dimensions of food waste is the paradox that, in higher-income settings, consumer-level food waste frequently includes foods already overconsumed in the diet, such as those high in saturated fat, sodium, and added sugar, meaning that preventing all food waste at the consumer level would not automatically improve overall diet quality[14]. This observation reinforces the need for targeted, food-group-specific waste reduction strategies, with priority given to reducing losses of fruits, vegetables, legumes, and

other nutrient-dense food groups, rather than uniform waste minimization without regard to nutritional profile.

3. Environmental Consequences of Food Loss and Waste

Food loss and waste generate an environmental footprint that is extraordinary in scale. The full life-cycle greenhouse gas (GHG) emissions embodied in globally lost and wasted food have been estimated at approximately 3.3 gigatonnes of CO2 equivalent per year when land use change is excluded, and between 8 and 10% of total annual global GHG emissions when the complete supply chain from production to disposal is considered, making FLW one of the single largest anthropogenic drivers of climate change[15,16]. This figure is nearly five times the annual GHG emissions of the entire global aviation sector[16]. The principal emission sources include methane released from decomposing organic matter in landfills and open dumps, carbon dioxide generated throughout production, transport, and processing of food that ultimately goes uneaten, and nitrous oxide from agricultural production activities, particularly from the application of synthetic nitrogen fertilizers to crops that are never consumed[15].

Beyond GHG emissions, FLW also represents a profound misuse of finite natural resources. Globally, the water embedded in wasted food is equivalent to approximately three times the volume of Lake Geneva, with fruit, vegetable, and cereal production being particularly water-intensive[16,17]. FLW also occupies an estimated 1.4 billion hectares of agricultural land annually -- nearly a third of the world's total agricultural area -- contributing to deforestation, biodiversity loss, and soil degradation when land is cleared to produce food that is ultimately not consumed[15,17]. In Indonesia, where the decomposition of food waste in landfills releases methane at a rate 25 times more potent than carbon dioxide over a 100-year time horizon, and where municipal solid waste management infrastructure remains severely strained in many provinces, the environmental consequences of food waste are compounded by inadequate disposal systems that maximize methane generation rather than directing organic waste toward composting or anaerobic digestion with energy recovery[8,13].

4. Economic Consequences and Food Security Linkages

The economic cost of FLW is staggering. The FAO estimated that the direct economic value of food lost and wasted globally amounts to approximately USD 940 billion to 1 trillion per year, to which environmental externality costs of approximately USD 700 billion and social costs of approximately USD 900 billion must be added to obtain the full societal burden[17]. These figures disproportionately affect low- and middle-income countries through two distinct pathways: on-farm and supply chain losses reduce the marketable output and income of smallholder farmers, who account for a large share of food producers in developing countries

and are frequently among the most food-insecure and nutritionally vulnerable populations; while consumer-level food waste imposes financial burdens on households that are often least able to absorb the cost of discarding food they could have consumed[11,17].

In Indonesia, economic losses from food waste are compounded by infrastructure gaps in cold chain logistics, post-harvest storage, and waste management systems that have historically limited the government's ability to prevent losses between the farm gate and the consumer[8]. A policy brief on scaling up FLW reduction programmes in Indonesia highlighted that 29 local governments have implemented FLW policies, but that the vast majority are in the form of non-binding circular letters rather than enforceable legislation, and that national budget allocations for FLW measurement and reduction remain insufficient to achieve the government's ambitious 75% reduction target by 2045, as outlined in the 2024 Bappenas FLW Roadmap[8]. The broader food security implications are also direct: analyses suggest that even a 25% reduction in global food waste could generate enough food to nourish all 821 million chronically undernourished individuals[4], reinforcing the case that FLW reduction is a critical lever for achieving zero hunger and food and nutrition security targets alongside climate and sustainability goals.

5. Determinants of Food Waste Behaviour

Understanding the behavioural and structural drivers of food waste is essential for designing effective reduction strategies. At the household level, food waste is influenced by a complex interaction of attitudinal, normative, and situational factors. A systematic review of household food waste behaviour applying the Theory of Planned Behaviour found that attitudes toward waste, subjective norms, and perceived behavioural control collectively and significantly predicted food waste generation and intentions to reduce it, but that the strength of these associations varied substantially across cultural, socioeconomic, and geographic contexts[18]. In Indonesia specifically, a structural equation modelling study of urban households found that attitude, subjective norm, and perceived behavioural control were all independently and significantly associated with food management behaviour and intentions to reduce food waste, suggesting that multi-component interventions addressing attitudes, social norms, and enabling environmental conditions are more likely to be effective than single-focus approaches[19].

Additional drivers identified across the literature include household income, with higher-income households generally wasting more food in absolute terms; household size, with larger households exhibiting lower per capita waste rates; meal planning behaviour and shopping practices, with impulsive purchasing and lack of meal planning consistently associated with

higher waste generation; and ambiguous date labelling practices ("best before" versus "use by"), which are among the most commonly cited drivers of premature food disposal at the consumer level in studies across multiple high- and middle-income country settings[18,20]. At the food service and retail level, aesthetic quality standards, overstocking practices, short shelf life policies, and limited food redistribution infrastructure contribute substantially to upstream waste generation[2,3]. These structural drivers are particularly important because they cannot be addressed by consumer behaviour change alone and require upstream interventions targeting procurement, production, and retail practices.

Among Indonesian young consumers, a study employing the Extended Theory of Planned Behaviour found that environmental attitude, food knowledge, subjective norms, and moral norms were the most significant predictors of intention to reduce food waste, while perceived behavioural control and religious values also played meaningful roles, suggesting that food waste reduction campaigns targeting Indonesia's large youth demographic should emphasize environmental consequences and social norms alongside practical food management skills[20]. The close connection between food waste reduction and Islamic values of avoiding israf (extravagance and waste), observed in religious discourse across Indonesia's majority Muslim population, represents a culturally embedded pathway for motivating waste reduction behaviour that complementary public health messaging could leverage.

6. Behavioural Interventions for Food Waste Reduction

A growing body of intervention research has sought to quantify the effectiveness of behavioural strategies for reducing food waste at the consumer and food service level. A meta-analysis of 58 food waste reduction intervention studies involving 26,533 participants, published between 2011 and 2021, found that behavioural interventions produced a moderate overall effect size ($z = 0.22$) on food waste reduction, with education programmes demonstrating the highest effect size, followed by social norms-based messaging and structural environmental modifications, while informational feedback alone produced the weakest effects[21]. The review further found that interventions conducted in elementary and middle school settings marginally improved overall effect sizes, suggesting that early-life food literacy education may offer population-level returns on investment by establishing food management habits and waste-reduction norms before adult dietary patterns are established[21].

A more recent and comprehensive machine-learning-assisted systematic review and meta-analysis of 306 effect sizes drawn from 110 articles covering more than 2.4 million observations assessed the effectiveness of demand-side food waste interventions across multiple intervention types[22]. The overall effect size for food waste interventions was Cohen's

d = 0.39 (reduced to 0.27 after adjustment for publication bias), indicating a small but meaningful aggregate effect. Among specific intervention types, choice architecture strategies targeting the organization of the food environment -- including default option changes, availability modifications, and portion size adjustments -- consistently outperformed information-based and persuasion-focused approaches[22]. Incentive-based approaches, including financial rewards for waste reduction, also showed promise in reducing food waste, with effect sizes comparable to strong choice architecture interventions[22]. Nudge-based approaches produced an overall Cohen's d of 0.38, with behaviourally oriented nudges (altering the physical or choice environment) outperforming cognitively oriented nudges (providing information and appeals)[22,23].

In the food service setting, a systematic review and meta-analysis examining plate food waste across hospital, school, and commercial food service environments found substantial variation in waste rates across settings, with school and institutional catering consistently producing higher plate waste than commercial food service, partly reflecting differences in consumer autonomy, menu flexibility, and the acceptability of food on offer[24]. Structural interventions such as tray-less cafeteria design, smaller default portion sizes, and enhanced food presentation have demonstrated meaningful reductions in food service waste across multiple controlled trials, often without compromising reported consumer satisfaction or nutritional adequacy[23,24].

7. Structural and Policy Interventions for Food Loss and Waste Reduction

Beyond behavioural interventions targeting individual consumers, effective FLW reduction requires coordinated structural, regulatory, and technological responses across the supply chain. One of the most evidence-supported and cost-effective upstream interventions involves reform of food date labelling systems. The proliferation of multiple date formats, particularly the conflation of "best before" (quality-based) and "use by" (safety-based) labels, is consistently identified as a primary driver of premature food disposal across consumer studies in Europe, North America, and increasingly in Asia[3,20]. Standardizing and clarifying date label formats, and shifting away from highly conservative quality-based labels, has been proposed as a high-leverage, low-cost regulatory intervention with potential to substantially reduce household food waste without requiring changes in consumer attitudes or additional infrastructure[3,17].

Cold chain infrastructure investment is among the most impactful structural interventions for reducing supply chain food loss in low- and middle-income countries. A 2024 study from the University of Michigan estimated that inadequate cold chain infrastructure is responsible

for up to 620 million metric tonnes of food loss globally, with tropical countries including Indonesia facing particularly high post-harvest losses of perishable crops due to inadequate refrigerated storage and transport capacity[1]. Investments in small-scale cold storage at the farm gate, rural market storage facilities, and refrigerated transport networks have demonstrated measurable reductions in post-harvest losses in multiple developing country contexts, with the co-benefit of increasing smallholder farm incomes by improving market access for perishable commodities[3,17].

Food redistribution systems, including food banks, community fridges, and surplus food recovery platforms, represent a complementary approach to reducing end-of-chain waste. A case study analysis of a food bank network in Navarra, Spain, found that the food bank's activities prevented approximately 4,715 tonnes of CO2 equivalent from being emitted annually while simultaneously redistributing food to food-insecure households, demonstrating that food redistribution can simultaneously address food security, nutritional equity, and environmental goals[25]. Fiscal instruments, including levies on food waste disposal in commercial settings, tax incentives for food donation, and extended producer responsibility schemes, have been piloted in a small number of high-income countries with early evidence of positive effects on food business waste reduction practices, though the transferability of these models to middle-income country contexts with different regulatory infrastructure and enforcement capacity remains to be established[22].

8. Indonesia's Policy Context and Path to SDG 12.3

Indonesia's commitment to FLW reduction has been codified through a progressively strengthened policy framework. In 2024, the National Development Planning Agency (Bappenas) published a national FLW Roadmap setting an ambitious target of reducing food loss and waste by 75% by 2045, and a draft presidential regulation (Peraturan Presiden) focused on FLW management was under development to establish a comprehensive regulatory framework for FLW prevention and handling across sectors[8]. Despite this political commitment, significant implementation gaps persist. A 2025 policy brief examining Indonesia's FLW reduction programmes found that the majority of currently active local government FLW policies take the form of non-binding circular letters (surat edaran) rather than enforceable legislation, and that national budget allocations remain insufficient to support the data infrastructure and programmatic delivery needed to meet the 2045 target[8].

Strengthening FLW measurement infrastructure represents a prerequisite for evidence-based policy in Indonesia. The most recent direct measurement study of household food waste in Indonesia, conducted by Martianto and colleagues at IPB University in 2024, provided

important composition and volume data, finding that cooked and prepared foods constituted the largest share of household food waste and that urban households generated modestly higher waste volumes than rural households, with important implications for where and how reduction programmes should be targeted[7]. A complementary study examining the association between household food insecurity and food waste found that food-insecure households in Indonesia did not necessarily waste less food than food-secure households, complicating assumptions about the relationship between economic status and waste behaviour, and underscoring the importance of direct measurement over reliance on proxy indicators[26].

Future research priorities should include establishing nationally representative, standardized FLW baselines using validated direct measurement methodologies, conducting lifecycle analyses of nutrient losses embedded in Indonesian food waste by food group, and rigorously evaluating the effectiveness of locally adapted behavioural and structural interventions for FLW reduction in both urban and rural Indonesian settings. The broader implications of FLW reduction for Indonesia's nutrition and public health agenda are substantial. Indonesia's ongoing national commitments to reducing stunting, improving dietary quality, and achieving universal food security are directly undermined by a food system in which a significant proportion of nutritious foods are lost before reaching the households that need them most. Integrating FLW reduction into national nutrition policy for example, by prioritising the reduction of losses in nutrient-dense food groups such as fruits, vegetables, fish, and legumes, and by strengthening food redistribution pathways that channel surplus food toward food-insecure communities could generate synergistic gains for nutrition security, sustainability, and economic equity simultaneously[4,13,17].

D. CONCLUSION

Food loss and waste represent a systemic failure of global food systems with profound and interconnected consequences for nutrition security, environmental sustainability, and economic equity. Globally, FLW accounts for 8-10% of annual greenhouse gas emissions, embeds the nutritional value of hundreds of millions of healthy diets in discarded food, and costs the global economy approximately one trillion USD per year. Indonesia, as one of the world's most significant contributors to food waste in absolute and per capita terms, faces both a pressing challenge and a meaningful opportunity: translating its 2024 national FLW roadmap into enforceable policy, robust measurement systems, and evidence-based programming that reaches households, food businesses, and supply chain actors alike. Effective FLW reduction requires the integration of behavioural interventions targeting consumer attitudes, norms, and

choice environments; structural reforms encompassing date labelling, cold chain investment, and food redistribution systems; and regulatory frameworks that incentivize and enforce FLW reduction across the supply chain. Progress toward SDG 12.3 will require not only political commitment but also sustained investment in data, innovation, and multisectoral collaboration, with nutrition security firmly embedded as a core rationale and outcome measure of FLW reduction efforts.

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