



## Food science innovations and sustainable development: Trends in reducing greenhouse gas emissions under Agenda 2030-2050

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**Abstract:** This study evaluates current trends in food science and innovation, emphasizing the urgent need to achieve zero greenhouse gas emissions generated from food waste across supermarkets, households, markets, and industries, as well as to implement effective food loss mitigation strategies. Regardless of region, food waste and postharvest losses have become widespread issues. While some populations continue to face food insecurity, other parts of the world experience food abundance, where food security challenges have largely been resolved, resulting in surplus food supplies but also giving rise to health, environmental, and waste management problems. In nations with food surpluses, these challenges have been mitigated through extensive supply chain networks that ensure efficient movement of food from farm to fork, with products being properly processed, packaged, and distributed. Both processed and packaged foods, as well as fresh produce, are regulated by “use-by” and “expiry” dates. Once these dates are exceeded, such food becomes unfit for consumption and is classified as waste. Wasted food accumulates in large quantities, often destined for garbage incineration. Each year, vast amounts of prepackaged and processed foods are discarded in developed nations, while in developing countries, greater losses occur at the harvesting and processing stages. In recent years, sustainable strategies have been introduced to reduce postharvest losses and minimize food wastage at the household level.

**Keywords:** carbon footprints, innovations, wasted foods, food loss, food science, and strategies

### 1. Introduction

The right to food for all persons has necessitated the need to upcycle food waste to high-end, nutritious products, swap imperfect foods for a lesser fee, and donate unused perishable groceries to offset the carbon footprint (Todd & Faour-Klingbeil, 2024). In Japan, for instance, supermarket outlets have a price reduction policy. Once it clocks 7 pm, the price tags are automatically adjusted to avoid waste of perishables. A significant amount of food waste is accumulated annually from unsold and uneaten food products, which translates to 80million tons of wasted food (Kim, 2023). Food processing and storage are the least problematic for the Organisation for Economic Co-operation and Development Countries (Maye & Duncan, 2017). Irrespective of this research, other statistics have shown that with every tick of the clock, food is wasted. Certain indices from behavioral science have pointed to food waste from the angle of consumer science, including people’s perception, different lifestyle changes, health, diet-related issues, and nutritional transition (Borrello et al., 2017; Sharma & Deutsch, 2023).

The downside remains whether developed or developing countries, food is wasted; however, the numbers are different since the technical knowledge is different (Nogueira et al., 2021). Established evidence showed that food waste is evident from farm to retail for developing countries and from retail to consumers for extremely developed countries (Andam et al., 2020; Todd & Faour-Klingbeil, 2024).

The medium of food waste generation was best illustrated in Figure 1. The pattern of waste for developed nations differs with the adaptation of technology in every segment of the food system and food chain process; these applications have resulted in shelf-stable foods all year round (Ishangulyyev et al., 2019). As per supermarket policy, certain processed food groups, such as dairy or meat products, are discarded and declared unsafe to curb food poisoning of Salmonella, a certain microorganism. These safety precautions have been achieved, and safety with product recalls and food destruction (Koester, 2014). Home pantries are hoarded and

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packed with food to meet the needs of the household, which sometimes are discarded for health reasons by consumer choice, when past due date, infested by pests or rodents (Yılmaz & Günal, 2023). Restaurant policies are similar to supermarkets; celebrations such as birthdays and wedding ceremonies are accompanied by large food preparation and buffet. These are the means by which food is wasted. Research has shown that food festivals and waste are synonymous; one study showed that 150,000 tons of tomatoes are wasted annually in La Tomatina festival in Spain, Bavarian beer in Oktoberfest, and Brewfest in Miami. In addition to waste generated by organizers of these events, waste from food vendors that are unsold is estimated to be negligible, as these are redistributed as charities (Carvache-Franco et al., 2025; Rossetti et al., 2024; Zhang & Zhang, 2025).

Developing nations have the largest food waste issues from farm to table. The distance of farmlands is farther compared to slaughterhouses and fishing waterways. Purchasing power with prices of foodstuffs is determinant in food distribution to the bigger markets. These are excluding the likes of insecurities at the farm front of farmers by herdsmen, to interstate restrictions, and travel bans to certain regions, to finally losses in the market front (Rolker et al., 2022).

The practice of upcycling of comestibles helps make our food systems more sustainable, from waste reduction to lowered greenhouse gas emissions, with less pressure on the environment.



**Figure 1:** Illustration of food waste medium in developed nations versus developing nations

The idea of transforming imperfect foods into a high-end, nutrient-dense product has been termed an innovative approach in food systems (Wikström et al., 2019).

At present, eight billion people exist in the world (Live, 2023); according to the Ministry of Agriculture in India, fifty thousand worth of food goes to waste. The problem is not restricted to raw foods, but lavish weddings, hotels, restaurants, and large-scale events have all contributed to food wastage. The use of a sustainable management approach has been advocated to halt wasted food, whether in developed or developing countries. In this paper, a concise review of different sustainable practices has been presented as pertaining to wasted food policies, market strategies, and innovations, all geared towards Sustainable Development Goals of 2030 and beyond.



MDGs were largely successful globally, though the dearth of synergy among goals resulted in less interconnectivity with eco-friendly goals for the environment. SDGs have far greater improvement with more considerations on the planet's environmental and economic goals that are measurable; with greater push towards sustainable dimensions such as: housing, jobs, food, information, expertise, Artificial Intelligence, and technology ([Schiff, 2008](#)).

The question of why MDG failed in India, Nigeria, and other African countries with regard to hunger and food practices would help trigger solutions to achieving SDGs with food innovation practices in Asia and Africa at large.

Several factors contributed to the inability of many African countries to achieve the MDGs. Among the key factors were that: models adopted for MDG were all western inclined, weak governance, mismanagement of funds, poor synergy between parastatals, state, local government officers, and market traders, poor infrastructure, low-income earnings of consumers, weak institutions, and policies ([Oleribe & Taylor-Robinson, 2016](#)).

According to the United Nations, at the current rate of happenings, there is a likelihood of not enough food to feed the planet's teeming population. Food sustainability is very important; presently, food waste amounts to half of the processed product, excluding agricultural produce, of food loss. For a sustainable planet, economists, agricultural extension agents, banks, government bodies, farmers, food technologists, producers, and consumers must strive to ensure that half of the food produced is not wasted ([Niles et al., 2017](#)). This has become a food problem and requires specific tasks for food processors and distributors in the supply chain; and where food lapses are generated, efforts are seen to mitigate the food scraps into useful ingredients for meal preparations and ready-to-eat high-end products. Examples are nibbles from dried mangoes, bananas, and veggie chips, which are shelf-stable products of food waste.

Therefore, the use of postharvest simulations and technologies such as cell technology for cultivated foods from cells of crustacean, meats, fish, and insects helps to incorporate upcycled products during processing, thereby offsetting carbon print. These methods are efficient and innovative to cushion the effect of the rising population, while converting food waste into perfect food products ([Blomqvist, 2009](#); [Garcia-Gonzalez & Eakin, 2019](#)).

## 2. Solutions

### 2.1. Food waste programme

The establishment of measurable food waste programmes, ensuring the separation of waste for ease of processing. Application at the household level, grocery stores, restaurant chains, and large-scale for big food industries. Charging residents by the weight of the household waste generated, and vice versa for food industries. Intentionally, adhering to the first-in-first-out rule at the household level and for the supply chain department, raw materials are needed for product formulation. These transitioning campaigns for zero waste during continuous production, with established teamwork and planning among staff prior to shifts ([Borrello et al., 2017](#)).

### 2.2. Policy

Empowerment of farmers, processors, wholesalers, consumers, and cities to tackle food loss and wastage of food, thereby addressing food insecurity in the various associated systems. Continuous sensitization of pilot programs in schools for kids and teens on how to convert imperfect produce to delicious recipes, and the need to decipher that zero food waste possibilities exist for a better planet. Restaurant policies have been administered successfully in OECD countries, where leftovers and food scraps are directed to the food bank delivery system, always ensuring food for all ages ([Bharucha, 2018](#)). Advocacy policies also mandate supply chain distributors and grocery stores to send less-than-perfect groceries, truckloads of unsold food, and rejected foods for pickup. Established channels have been created online for online presence at a lesser price to be resold or stock up food banks. Examples are dropping off Happy Fridge in India, for residents to drop off food, as well as Second Harvest, Flash Foods, and Food Rescue in Canada, which operate towards mobilizing people to donate to those who do not have access to food regularly, and temperature-regulated vans are used to move cooked and imperfect products to certain homes and food banks ([Antle & Capalbo, 2010](#); [Schiff, 2008](#)).

### **2.3. Patronize sustainable agriculture**

The deliberate patronizing of farmers who use electric vans for food distributions is welcomed. Sourcing of ingredients from sustainable farmlands with innovative ideas like hydroponics that disrupt traditional farming, and supporting sustainable food suppliers that offset carbon emissions. These food producers find ways to remove carbon from the atmosphere by supporting and switching to farmers, distributors, brands, and advertising agencies that are accountable to the environment, and making continuous efforts to be socially responsible at the same time to offset the total amount of greenhouse gases generated daily. Patronizing insect farming as the farming requirements of less land use and water are sustainable ([Kuzmin, 2016](#); [Springmann et al., 2018](#)).

### **2.4. Adopting sustainable innovations**

A lot of food industry activities promote greenhouse gas emissions; there is a need to achieve zero emissions by 2030 and beyond. Food industries can decide to introduce the use of electric trucks, solar-powered forklifts, and mini electric vans that move through the motorable safety routes in the industry. The recycling of wastewater for washing and cleaning processes saves water and energy. Additionally, the measurable treatment of waste effluents prior to emptying into the municipal waterways ([Arcese et al., 2015](#)).

### **2.5. New companies and startups**

Establishment of new companies and start-ups that focus on plant-based food, feed, and more restaurants with plant-based recipes for a sustainable food system. New product development and upscaling of existing products could integrate edible insects in food production. These products are high in protein and omega-3 and omega-6 fatty acids. The production of carbon-negative spirits and vodka has been introduced to reduce greenhouse gas emissions, with less water use during production ([Mensi & Udenigwe, 2021](#); [Pettrini, 2009](#); [Springmann et al., 2018](#)).

Mergers and start-ups alike are encouraged to diversify into plant-based alternatives. The demand for red meat, white meat, and other animal by-products continues to grow. Laboratory-grown meat has cushioned the effect of production cost, less land use, and water consumption. Therefore, consumer acceptability of such products is advised through proper advertisement channels on the nutrition and safety status, including sensitization of the benefits of plant-based alternatives as food-based solutions with far less environmental impact ([Mylan et al., 2023](#); [Wood & Tavan, 2022](#)).

### **2.6. Food companies' sustainable ideas**

Every day, millions of single-use foils, cans, and trays used to bag goods, non-biodegradable containers, straws, and plastic cutlery used in food takeout and deliveries are wasted worldwide. Despite their convenience, some of the most fashionable food packaging materials are, however, harmful to the environment. Food companies' sustainable ideas may include the adoption of environmentally friendly packaging materials that readily decompose and are safe for the planet. Examples are adoption of technologies with avocado pits for making biodegradable products like spoons, forks, trays, straws, and containers; a sustainable beverage packaging example is Garson wines has used novel shaped bottles that are eighty-seven percent lighter than glass, thus packing bottles without additional packaging which ensures efficient use of space, allowing more product to be packed on a single shipping pallet. Thereby reducing loading time and cutting half of the carbon footprint emissions ([Earle, 1997](#); [Mensi & Udenigwe, 2021](#)).

Sustainable Cellulose bottles for wines, beers, and soups made of 95 percent recycled paper boards and weighing five times less than glass have been adopted by Frugal Pac Company. These cellulose bottles are alternatives to glass and plastic ([Kan & Miller, 2022](#)).

The use of sustainable corn starch-popcorn-mushroom-based containers or packages, this innovation has been reported as a good substitute for Styrofoam and plastic containers because of its biodegradable nature. This hundred percent plant-based agricultural waste is the new bioplastic that offers a viable, excellent insulating, and eco-friendly packaging material ([Sharma & Deutsch, 2023](#)).

Another similar sustainable packing material is the use of hemp herbs and mycelium mushrooms in the production of serving trays and packs like paper boards. The future of food packaging now includes bamboo



and cassava peels made by Bio Pak; these materials easily disintegrate in the soil three months after production. Thereby addressing the plastic waste catastrophe. The use of cleaning agents made from fruit scraps has been advocated for a safer planet. Pineapple fruit is one fruit high in digestive enzymes suitable for surface clean-ups. Effluent treatments are efficiently managed, resulting in less algae growth, with reduced synthetic detergent pollution ([Wikström et al., 2019](#)).

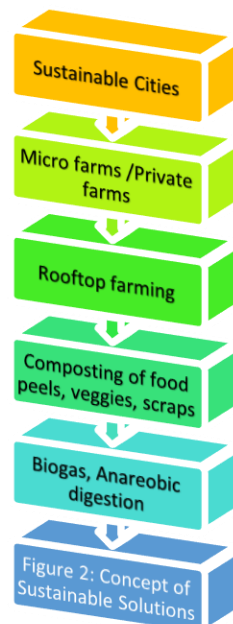
### 2.7. Market sensitization

This measurable sensitization scheme should be scheduled regularly to cause a shift in the learning participation of market traders of perishable produce in Nigeria and West Africa at large ([Aamir et al., 2018](#); [Kuzmin, 2016](#)). The urgency has stemmed from the huge amount of vegetable and fruit waste generated from the market trash places, which would have been otherwise sold for far less price or donated to charity. These traders need to know the consequences of hoarding perishables for better sales and throwing away unsold produce when a bargain is not profitable. From the transportation cost to labor wasted, land use, water and energy wasted, to the consequences to the Nigerian economy and environment at large ([Brown et al., 2017](#)).

### 2.8. Introduction of the integrated supply chain and waste system

The lack of an integrated whole supply chain system, still following the traditional way of produce distribution, causes a big chunk of fruits and vegetables to be lost during transportation, with inadequate packaging material (primary and secondary packages) to cushion the goods. Most fruit and vegetables are wasted due to gaps in packaging materials and the supply chain. Market traders should unlearn their traditional ways and adopt a proper supply chain route as taught by the government and private agencies ([Kim, 2023](#); [Nogueira et al., 2021](#)).

Market traders of perishables should be made to contribute their own quota to help eliminate food insecurities in the economy. Corporate social responsibility can be facilitated for community service by giving out perishables for far less than the market price to the less privileged, and to food banks that would otherwise be discarded. The enforcement of taxation on excess waste generated per person and or per grocery shop. Local Government partnership with market bodies and chairpersons in various provinces, territories, and states on cutting taxes for registered market traders of perishables that become accountable, who have unlearned and relearned sustainable practices. Establishment of measurable taxation systems to tax the amount of waste generated in marketplaces located in metropolitan cities, villages, suburbs, and other rural areas ([Aamir et al., 2018](#); [Brown et al., 2017](#); [Todd & Faour-Klingbeil, 2024](#)).



**Figure 2:** Concept of Sustainable Solutions

Figure 2 shows examples of applications of the solutions that are useful and replicable. The incorporation of the concept of trending cities would invariably translate to the availability of food material, such as veggies, and mini farmland in and around the community. Research has shown that a rooftop greenhouse farm with caged

poultry is manageable. The use of wilted leaves for rearing and the use of manure for the growing of veggies are termed sustainable.

A centralized system for composting waste food is practiced; however, the separation of waste has not been perfected in developing countries. Training on composting for animal feed, biogas production, and efficient waste separation measures using coded colored nylon should be adapted to communities and equivalent cities ([Shurson et al., 2023](#)). These sustainable practices, when channeled, have resulted in newer streams of income and, invariably, opportunities exist to create solutions to solving waste management issues in the environment and communities at large ([Um, 2025](#)).

### **2.9. Regulations Measures for Food Waste**

Universally, food waste regulatory measures have been adopted, and exist to checkmate and stand as a barrier with a buffer effect against food movement from farm to landfill. These are dependent on the establishment of a legislative framework, national laws, and binding rules that show clear and mandatory goals for reducing food waste across sectors of the supply chain. Examples are pay-as-you-dispose systems, where waste is charged per disposal to landfills; a ban on food and organic waste disposal with tax options; donation of food through price slashing, donation to homes, and food banks ([Baig et al., 2022](#)).

Additional global and regional regulatory measures include the following, but are not limited to; Republic of China in 2021 enacted an anti-food waste law, with consumers being levied with tax policies and regulations aimed at curbing excessive consumption in restaurants ([Shen et al., 2024](#)). Singapore has a resource sustainability act that mandates large commercial and industrial premises to segregate and treat food waste, with mandatory reporting requirements.

United Nations Sustainable Development Goal 12 has been summarized to mean accountable consumption and production, with the exact aim to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains by 2020 ([Manios et al., 2024](#)).

The European Union has decreed, as part of its circular economy package, to develop a food waste measurement methodology as well as a solid platform for food losses and food waste to facilitate action among member states. This anti-food waste law has been enacted in France, which mandates supermarkets to donate unsold food. For countries like Spain, food chain operators must have waste prevention plans ([Cahyani et al., 2022](#)).

### **3. Conclusions**

With 2030 around the corner, scientific hands are on the desk to birth a sustainable future free of wasted food and unwanted loss. A society where nothing goes to waste because the knowledge of food perishability is well taught, discussed, articulated, and advocated for the need to reuse food, and through food outreach. The use of sustainable practices by farmers, consumers, and stakeholders should be promoted and reinforced by the law governing the people and the environment. These whole possible development practices are all geared towards offsetting carbon footprints with a sustainable future of food security.

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Ijeoma Adaeze Nwaeze, Experiment and analyze data, Writing-original draft; editing, proofreading.

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The authors declare no conflict of interest.

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