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Food Waste Valorization: Leveraging Singapore's Zero Waste Master Plan and 30-by-30 Goal

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Abstract: Singapore, being a land-scarce country, imports more than 90% of the food supply, which poses a challenge in ensuring food security. In the last five years, Singapore, with a population of 5.9 million, generated approximately 759 tonnes of food waste on average, thus further deepening food security challenges and imposing enormous pressure on the country's food and land resources. The Zero Waste Plan and the 30-by-30 food security goal initiated by the Singapore government focus on reducing waste and improving resource efficiency and encourage the collective efforts from the local agri-food businesses to sustainably provide 30% of Singapore's nutritional requirements by 2030. In recent years, valorizing food waste streams into higher-value products has been an increasing trend in tackling food wastage and offering a new source of food ingredients. Food wastes such as okara, spent barley grains, and fruit and vegetable wastes have been successfully valorized into a variety of prototypes by local research and development capabilities for food and agricultural applications. However, food waste valorization faces various challenges, i.e., infrastructure development, economy viability, consumer awareness, collaborative partnership, regulatory support, and data management. This review serves as a reference for other countries in ensuring food security and achieving sustainable development goals.

Keywords: food waste; valorization; food security; sustainability; zero waste



Citation: Heng, K.; Tan, K.; Chan, A.; Lee, C.C.C. Food Waste Valorization: Leveraging Singapore's Zero Waste Master Plan and 30-by-30 Goal. *Sustainability* **2024**, *16*, 7321. <https://doi.org/10.3390/su16177321>

Academic Editor: Angeliki Maragkaki

Received: 10 June 2024

Revised: 31 July 2024

Accepted: 19 August 2024

Published: 26 August 2024



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1. Introduction

The generation of food waste is a constant global concern to the environment, economics and food security. When large amounts of food are wasted and thrown into the landfill to wait for incineration, methane, which is an extremely potent greenhouse gas, is produced. As the food demand continues to rise, more energy is required to produce the food wastes that were lost, thereby increasing carbon emissions and contributing to climate change and global warming. One of the greatest contributors to climate change is the production of meat-based foods, including livestock feed, which emits twice the greenhouse gases than that of plant-based sources [1]. Economically, the costs spent to produce, process and transport the food, such as water, land and energy resources, are eventually wasted, leading to financial losses. Additional costs to reproduce the food also certainly increase the financial burden on the food industry. In the context of food security, the production of food waste increases the country's dependency on imported foods as it decreases the amount of food available to be consumed. In hopes of combating the negative effects that are caused by food wastage, this paper aims to shed light on food waste valorization and how it plays a role in reducing food waste and offering a new source of food ingredients.

The Zero Waste Master Plan and the 30-by-30 Goal have been implemented by the Singapore government as important measures to tackle environmental sustainability and

ensure food security. Singapore's Zero Waste Master Plan is the nation's inaugural strategy to achieve zero waste status [2]. The plan presents essential tactics for building a nation that is both sustainable and resource-efficient while also being resilient to climate change. A circular economy strategy is implemented for managing waste and resources, which helps to shift towards more sustainable methods of production and consumption. The Master Plan established ambitious waste reduction objectives for Singapore. As a target, the amount of waste sent to Singapore's only landfill (Semakau) on a daily basis should be decreased by 30 percent by the year 2030. This objective will aid in prolonging the lifespan of this landfill beyond the year 2035.

Considering that the bulk of Singapore's food is imported from other countries, it is crucial to prioritize local production in order to decrease reliance on food imports. The 30-by-30 key strategy aims at enhancing food security in Singapore. The objective of the 30-by-30 initiative is to enhance the capability and efficiency of the local agri-food sector in order to sustainably provide 30% of Singapore's nutritional requirements by 2030 [3]. This objective is also embedded in the Singapore Green Plan 2030, which will actively contribute to fostering a more robust and sustainable food future. In order to accomplish this objective, the Singapore Food Agency (SFA) has initiated a comprehensive strategy for the Lim Chu Kang area to enhance food production and expand sustainable fish farming in the deep southern waters of Singapore. This plan includes implementing various strategies, such as providing financial assistance for innovative research projects focused on creating sustainable food production systems.

This paper reviews food waste valorization in Singapore and the strategic move of incorporating the utilization of food waste into Singapore's Zero Waste Plan and 30-by-30 objective. It facilitates the redirection of organic waste away from landfills, thus prolonging the operational duration of current waste disposal facilities and minimizing the impact on the environment. The act of upcycling food waste can result in the production of higher-value products to promote food sustainability. With all the inventive and financially beneficial sustainable technologies, the transformation of food waste into valuable resources serves as a catalyst for economic growth and fortifies Singapore's standing in the global marketplace. The objectives of this paper are to highlight the food waste generated, disposed of and recycled in Singapore; to explore different applications, technologies and prototypes in food waste valorization, supported by local case studies from various food waste streams; to discuss the challenges associated with food waste valorization; and to review and evaluate Singapore government schemes and incentives in addressing the challenges identified. The content in this review includes food waste status in Singapore subsectioned into food wastage statistics, food waste recycling and food waste valorization; food waste valorization case studies in Singapore subsectioned into okara, spent barley grains and fruit and vegetable wastes; challenges in food waste valorization subsectioned into infrastructure development, economy viability, consumer awareness, collaborative partnership, regulatory support and data management; government schemes and incentives subsectioned into legislation and initiatives supporting food waste management.

Internationally, the 17 Sustainable Development Goals (SDGs) proposed during the United Nations Conference set universal goals that help to address the urgent environmental, political and economic challenges [4]. The case studies on food waste valorization showcase actual examples where Singapore made efforts to achieve SDG 2: 'Zero Hunger'; SDG 11: 'Sustainable Cities and Communities'; and SDG 12: 'Responsible Consumption and Production', which are related to the concept of food waste valorization, helping to reduce waste and save landfill space. The environmental benefits derived from food waste valorization contribute to SDG 13: 'Climate Action'.

2. Food Waste Status in Singapore

2.1. Food Wastage Statistics

Food waste constitutes approximately 10% of the total waste stream in Singapore, making it a significant portion of the overall waste generated. In the year 2020, approxi-

mately 665 thousand tonnes of food waste were produced, with almost half of it coming from households [5]. Singapore has made the recycling of food waste a top priority in its sustainability efforts, as it acknowledges the need to reduce waste and move towards becoming a Zero Waste Nation.

The integration of food waste recycling aligns with Singapore's overarching goal to improve food security and achieve self-sufficiency. To achieve the ambitious 30-by-30, it is crucial to investigate innovative methods of managing resources. This includes the utilization and integration of food waste into the food processing industry. Singapore's practice of valuing food waste reduces waste and its negative effects on the environment, at the same time enhancing the durability and sustainability of its food supply chain.

The National Environment Agency (NEA) is currently undertaking the next phase of development for the Tuas Nexus Integrated Waste Management Facility (IWMF) in order to achieve these objectives [6]. This phase involves the construction of a modern Food Waste Treatment Facility (FWTF) that can process 400 tonnes per day of food waste, as well as an 800-tonnes-per-day Sludge Incineration Facility (SIF). Singapore's infrastructural investments showcase its dedication to embracing state-of-the-art technologies and infrastructure to facilitate the sustainable handling of organic waste. This progress propels Singapore's pursuit of a circular economy and a more resilient, self-sustaining future.

2.2. Food Waste Recycling

Figure 1 shows the food waste generated, disposed of and recycled in Singapore from 2018 to 2023 [5]. There is a fluctuation in the total amount of food waste generated over the years: from 763,000 tonnes in 2018, which dropped to 665,000 tonnes in 2020 and ended up with 755,000 tonnes in 2023. This trend suggests that despite efforts to reduce food waste, consumption patterns and population growth continue to drive up the overall amount of food waste produced in Singapore.

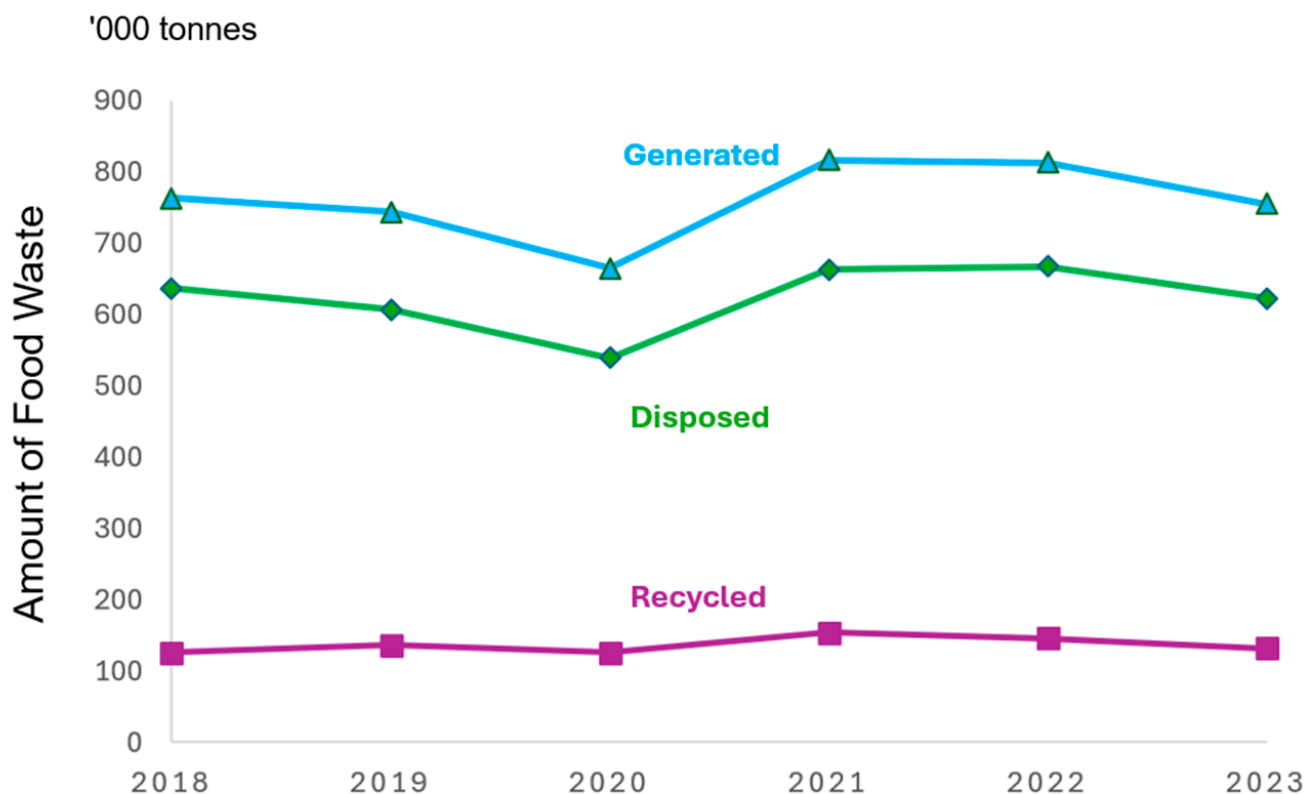


Figure 1. Total food waste generated, disposed of and recycled in Singapore (2018–2023).

There has been some fluctuation in the amount of food waste disposed of and recycled: the recycling rate has remained relatively stable, hovering around 17% to 19% over the years. This indicates that while there have been efforts to increase food waste recycling, they are not sufficient to significantly impact the overall recycling rate.

Furthermore, the amount of food waste recycled has shown a slight increase over the years, from 126,000 tonnes in 2018 to 132,000 tonnes in 2023. This suggests that there may be growing awareness and initiatives in place to encourage food waste recycling in Singapore. However, the recycling rate still remains relatively low compared to the total amount of food waste generated. Unrecycled food wastes are likely to end up in and compete for limited landfill space in Semakau Island, which is expected to be completely occupied by 2035 or even earlier [7].

Overall, the data highlight the ongoing challenge of managing food waste in Singapore and the need for continued efforts to improve waste reduction, recycling and resource recovery initiatives. The key strategies for improving food waste management and achieving higher recycling rates will likely include the following: (a) Intensification of research on the valorization of food waste; (b) raising of public awareness; (c) implementation of effective policies; and (d) investment in infrastructure for the recycling of food waste.

2.3. Food Waste Valorization

Food waste valorization is the deliberate process of transforming leftover or excess food materials into valuable products that enhance and support the food supply chain (NEA, 2023) [8]. The processing flow encompasses treatment, bioreaction, extraction, purification, dehydration or concentration, and formulation. Treatment can be in the form of heat, chemical or mechanical, such as alkaline treatment and microwave-assisted ultrasonication. Enzymatic fermentation is a common bioreaction that utilizes the mechanism of the enzymatic pathway to break down a specific substrate in a controlled environment. Firstly, extraction can be done through treatments and bioreactions, and purification will follow up to ensure that the targeted compound is pure and isolated. Dehydration or concentration is usually carried out to maintain its original state and to prolong the shelf-life of the sample. Lastly, the dehydrated sample or powder can be utilized to formulate and innovate a food product. The efforts effectively cut greenhouse gas emissions, encouraging the conservation of resources while providing alternatives to food ingredients. Furthermore, they provide prospects for generating income and creating employment, contributing to economic durability and sustainability. By diverting food waste from landfills, the higher-value products obtained through the process of food waste valorization have a wide range of uses, each serving different parts of the food industry and meeting various societal requirements.

Singapore's strategy for managing food waste is multifaceted and forward-thinking. It serves as a comprehensive guide for policies and initiatives aimed at minimizing food waste generation. The key objectives are to promote sustainability and reduce the overall environmental impact of discarded food. Singapore places prevention at the forefront of its approach, emphasizing better inventory management, portion control, and awareness campaigns. When prevention is not feasible, the country focuses on converting food waste into valuable resources through methods like composting and anaerobic digestion. Edible surplus food is redirected to human and animal consumption, addressing both waste reduction and food insecurity. Landfill disposal is considered the least desirable option due to its environmental impact. The products can be classified into four primary categories: (a) animal nutrition; (b) food ingredients; (c) nutraceutical and functional foods; and (d) bioactive compounds from plants.

The use of food waste as a raw material for animal nutrition is a valuable method of enhancing its value. The treated waste can be converted into feed formulations that are appropriate for aquaculture and poultry, thus providing additional sources of feed and decreasing the environmental consequences linked to livestock farming [9]. This approach involves converting food waste into high-quality animal feeds, which reduces waste and improves resource efficiency in the agricultural sector.

The process of food waste valorization also enables the extraction and purification of valuable elements from discarded food materials, including proteins, fats, and natural colorings. The recovered components can be reincorporated into the food manufacturing cycle, functioning as eco-friendly substitutes for traditional sources. By utilizing these recovered resources, manufacturers can reduce their dependence on new materials, address vulnerabilities in their supply chain and foster circularity within the food industry [10].

Food waste research has also focused on the extraction of bioactive compounds from food waste with the potential to provide health benefits, such as antioxidants, dietary fiber and prebiotics [11,12]. These extracts obtained from food sources that were previously not fully utilized or overlooked can be added to dietary supplements and pharmaceutical formulations. By harnessing the nutritional value of discarded food, besides improving human health and well-being, this method also stimulates innovation in discovering and formulating new nutraceuticals. Functional foods that contain beneficial bioactive components can also be developed from leftover or excess food materials [13]. These products are developed to provide targeted health benefits that go beyond basic nutrition in a normal dietary intake. They include a variety of formulations that are customized to meet the different preferences and dietary requirements of consumers. Manufacturers can address the increasing demand for healthier and more sustainable food choices, as well as reduce waste in the supply chain, by using functional ingredients derived from food waste.

Multiple studies have shown that bioactive compounds obtained from food waste are effective in controlling pests, improving soil quality and increasing crop productivity [14,15]. Utilizing food waste to obtain bioactive compounds for agricultural use offers an environmentally friendly solution that is in line with sustainable resource management principles. By adopting the applications of these natural compounds, manufacturers and farmers not only decrease the negative impact of food waste on the environment but also decrease the dependence on synthetic chemicals in agriculture, which will encourage a more sustainable and eco-friendly farming method.

3. Food Waste Valorization Case Studies in Singapore

Table 1 is a summary of case studies conducted in Singapore from 2018 to 2024, focusing on the utilization of food waste for human consumption and agricultural applications. The selected studies are derived from a combination of scholarly journal publications and media reports.

Table 1. Food waste valorization studies in Singapore (2018–2024).

Food Waste Stream	Prototype	Technology	Features	References
Okara	Probiotic beverage	Solid-state fermentation with microbes; enzymatic reaction	Contains live probiotics, dietary fiber, free isoflavones and amino acids; nutritious, non-dairy alternative	[16]
	Biscuits	Solid-state fermentation with microbes	Higher amino acid content than conventional biscuits	[17]
	Okara soy cheese	Solubilization and formulation	Functional soy cream cheese, healthier alternatives of soy cream soup and soy sliced cheese	[18,19]
	Plant biostimulant	Processing, extraction and purification	Promoted plant growth; improved crop yield and quality; anti-fungal	[20]

Table 1. Cont.

Food Waste Stream	Prototype	Technology	Features	References
Spent barley grains	Functional noodles	Formulation of dried spent barley grain into a paste-like dough	Zero glycemic response; high in fiber; good source of protein; low in calories	[21]
	Protein powder	Solid-state fermentation by microbes	Acts as plant-based emulsifier with strong antioxidative properties	[22]
Vegetable wastes	3D-printed food	Pureeing and 3D food printing	Creative 3D-printed food	[23]
Orange peel wastes	3D-printed food toppings, soup bowl and biscuits	Sonication and 3D food printing	Increased bioflavonoids and antioxidant content in snacks	[24]

3.1. Okara

Okara, a residual product of soybean processing, is one of the largest food waste streams in Singapore. Four studies involving okara valorization are identified and reviewed. Shan et. al. converted okara into a nutritious and sustainable alternative to dairy-based drinks using solid-state fermentation with a combination of microbial action and enzymatic reaction [17]. The final drink prototype contains live probiotics, which promote gut health, in addition to beneficial nutrients such as dietary fiber, free isoflavones and essential amino acids. The novel method tackles the issue of food waste while supporting Singapore's wider sustainability objectives by decreasing dependence on conventional dairy production and advocating for the use of plant-based ingredients.

Razali (2022) reported on the formulation of biscuits from okara undergoing solid-state fermentation, which increases the amino acid content of the biscuits [18]. The digestibility of okara after fermentation was enhanced by reducing the presence of anti-nutrients and releasing free amino acids. However, a postprandial blood amino acids study showed that the consumption of biscuits containing fermented okara does not alter postprandial amino acid responses in middle-aged and older Singaporeans. Incorporating fermented okara into biscuit manufacturing offers a chance to expand the market for plant-based snacks, appealing to health-conscious and environmentally conscious consumers who are looking for more sustainable options.

In addition to beverages and biscuits, a group of researchers from Republic Polytechnic, Singapore has solubilized okara and formulated it into three prototypes of soy cheese—soy cream cheese, soy cream soup and soy sliced cheese [19]. These soy cheese options have higher levels of protein, dietary fiber and antioxidants than their commercial dairy-based counterparts, providing consumers with a healthier and more environmentally friendly choice. The introduction of soy cream soup and sliced cheese made from okara-based ingredients showcases the adaptability of these ingredients in food innovation, appealing to a wide range of consumer tastes and dietary requirements. This initiative enhances the value of okara and further contributes to the expanding market for plant-based substitutes.

A further processing on the solubilized okara by the research group has developed a novel okara-based plant biostimulant [20]. This biostimulant has been shown to promote leafy vegetables' and melons' growth as well as increasing their crop yield and quality. When administered to strawberry plants, it prevented and mitigated powdery mildew disease, concurrently enhancing flowering and fruiting processes. This novel method emphasizes the interdependence between the upcycling of food waste and the promotion of sustainable agriculture, highlighting the capacity of circular economy models to generate favorable environmental and economic results.

3.2. Spent Barley Grain

Spent barley grain (SBG) is another main food waste stream that is rich in fiber, protein and other valorizable nutrients. Barley grains are typically used in the beer-making process commonly known as malting. During malting, the grains are soaked, cooked to ferment, and then mashed to extract beer, which contains protein, sugar and nutrients from SBG [25]. After malting, SBG is the most abundant byproduct of the brewing process, accounting for 85% of the total brewing waste material produced [26]. In Singapore, there are more than 75,000 tons of SBG produced yearly, making it a sustainable food waste stream for valorization [27]. SBG has been transformed into protein and fiber-rich ingredients in the form of paste-like dough [21]. The ingredient was used to formulate starchless noodles with a minimal glycemic response in healthy individuals. The starchless noodles derived from spent barley grains exhibited comparable sensory characteristics as conventional starch-based noodles but with enhanced cohesiveness and chewiness. The noodle is a rich source of nutrients, including protein and dietary fibers.

In another study, protein was recovered from SBG using a solid-state fermentation by *Rhizopus oligosporus* [22]. The isolated fraction has a protein content ranging from 61% to 66%, with higher emulsifying abilities, foaming properties and water/oil binding capacities compared to the unfermented sample. The fermented SBG protein extract also exhibited greater antioxidative properties. In application, when used in a mayonnaise recipe, the extract exhibited superior emulsion stability in relation to creaming, microstructure and viscosity. The author concluded that fermented SBG protein has the potential to be used as a plant-based emulsifier in the fields of food, pharmaceuticals and cosmetics.

3.3. Fruit and Vegetable Wastes

Fruit and vegetables, despite being one of the most vulnerable foods to food spoilage, generally contain high amounts of dietary fiber, vitamins, minerals and bioactive compounds such as antioxidants. Their wastes from food processing trap the nutrients, making the wastes potentially valorizable. A group of students at local junior colleges and polytechnics in Singapore were engaged in valorizing kale and spinach wastes [23]. The vegetable waste samples were chilled, rinsed, chopped, boiled and pureed. The obtained purees were used to formulate the inks for three-dimensional food printing. They were tasked to innovate dishes based on these two wastes that looked good and were tasteful, which addressed consumers' reluctance to embrace food waste as a valid food option. This approach tackles the issue of food waste, encourages advancements in food technology and provides new opportunities for sustainable food production and consumption methods.

In another study, orange peel waste was transformed into nutritious snacks using three-dimensional printing technology [24]. The researchers formulated rheology-modified inks derived from orange peels to print three-dimensional food products. It was also found that the orange peel waste contains bioflavonoids and demonstrates antioxidant activity. Thus, this study demonstrated a practical approach to repurposing food waste into valuable food products, thereby promoting food sustainability and circularity in food waste management through the utilization of 3D food printing as a technological tool.

These research and development initiatives to utilize food waste demonstrate the inventive nature and cooperative actions that are propelling Singapore's shift towards a more sustainable and resilient food system. However, it is necessary to conduct additional research and evaluation to assess the long-term sustainability and socio-economic consequences of these initiatives. Obstacles such as the ability to handle increasing demands, gaining widespread approval from consumers, and establishing appropriate rules and regulations continue to be major challenges that need to be addressed.

4. Challenges in Food Waste Valorization

Figure 2 shows potential challenges in food waste valorization research and development that researchers and manufacturers commonly encounter in Singapore.

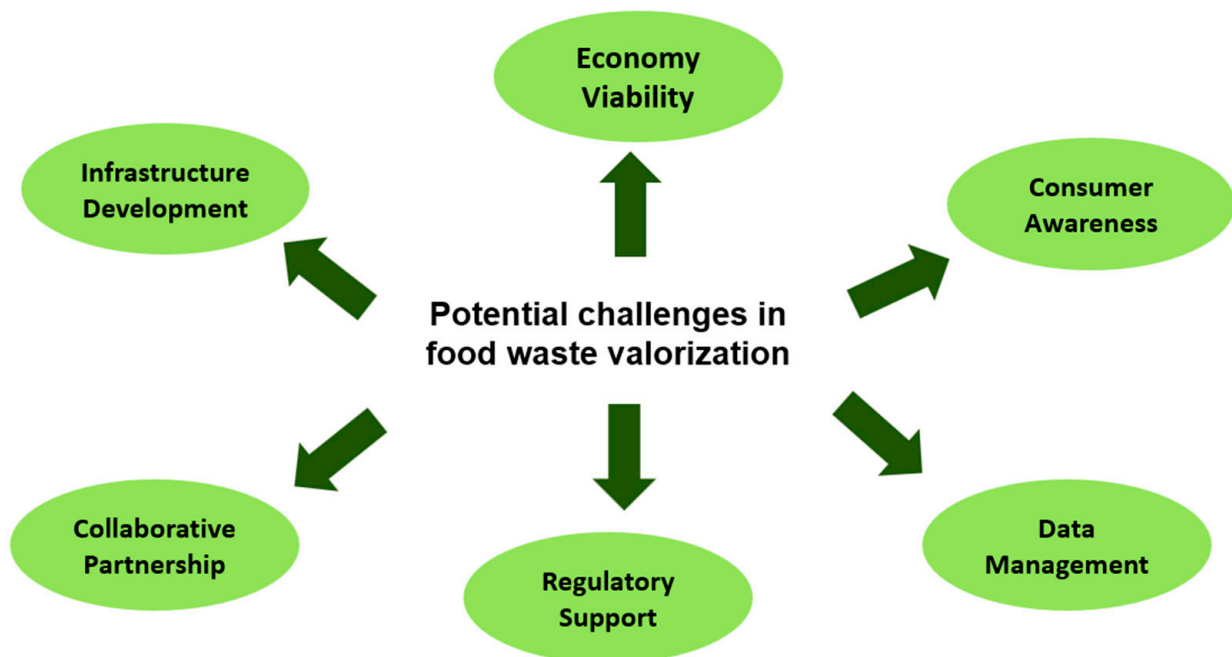


Figure 2. Potential challenges in food waste valorization research and development.

Food waste presents a substantial global challenge with negative consequences for environmental sustainability, economic effectiveness and social well-being. Efforts to capitalize on food waste have gained momentum as a result, with the goal of extracting value from resources that would otherwise be discarded. Nevertheless, many obstacles hinder the widespread acceptance and efficiency of food waste valorization initiatives. This section analyzes and tackles these challenges, suggesting strategies to overcome them and promote a more sustainable and efficient food system.

4.1. Infrastructure Development

The establishment of a robust infrastructure for the treatment, bioreaction, extraction, purification, dehydration, concentration or formulation of food waste is necessary in order to facilitate the efficient valorization of food waste. There are many different types of food waste, and in order to accommodate them all, it is necessary to make significant investments in specialized facilities and equipment. The significant risk associated with investing in research without guaranteed returns hinders the advancement and acceptance of valorization technologies [28].

Singapore has established a wide array of specialized facilities focused on the conversion of food waste into valuable resources. The NEA Tuas Nexus, managed by the National Environment Agency (NEA) and Singapore's National Water Agency, is a prominent facility dedicated to the treatment of food waste using anaerobic digestion technology [29]. The plant processes 40 tonnes of wastewater sludge and food waste from 23 locations on a daily basis. The combination of wastewater sludge and food waste is subjected to anaerobic digestion, a biological process that decomposes organic substances without the presence of oxygen, in order to generate biogas for energy production. The findings revealed that the combined digestion of used water sludge and food waste leads to a significant boost in biogas production, with an increase of up to 40% compared to when the two inputs are digested separately.

A Singapore-based company, ecoWise, engages in the investment, development and management of renewable energy projects that provide substantial environmental, social and economic advantages to the local community in which it operates [30]. The group is among the pioneering companies in Singapore that specialize in the development of biomass power plants. The group's initial biomass co-generation power plant became fully

operational in 2005. Subsequently, in 2011, a second biomass tri-generation power plant was commercially ready for operation under a public–private partnership contract with Gardens by the Bay—Singapore for a fifteen-year concession period. The company also operates a biomass co-generation power plant to produce electrical and thermal energy from food waste. Agricultural and food waste were dehydrated and repurposed as animal feed ingredients.

Although Singapore has made substantial progress in the valorization of food waste, it is imperative to increase the capacity of current facilities or create new ones in order to handle the increasing amount of food waste. Enhancements are required in the collection and sorting mechanisms for food waste at its origin. Although Singapore has successfully enforced the compulsory segregation of food waste in specific areas, such as commercial and industrial establishments, ensuring widespread adherence in other sectors continues to be a difficult task. Improving the collecting infrastructure, such as implementing specialized vehicles and storage facilities for temporary storage, will simplify the logistics of managing food waste.

In order to overcome limitations in capacity, Singapore can contemplate the expansion of current anaerobic digestion facilities. This extension would enhance the overall processing capacity for food waste and enable more extensive waste diversion from landfills. Allocating resources to pilot projects focused on advanced technologies such as pyrolysis or hydrothermal processing has the potential to open up new opportunities for utilizing food waste. These technologies provide increased energy recovery efficiency and generate valuable byproducts such as biochar or biofuels, which can be utilized in diverse industrial applications or as sources of renewable energy [31].

A major financial obstacle in developing food waste valorization infrastructure is the substantial upfront expenditure needed to construct and outfit facilities such as anaerobic digestion plants or composting facilities. These facilities frequently utilize intricate technology and infrastructure to effectively treat and manage organic waste.

In addition to the original capital costs, the operational charges and continuing maintenance provide considerable financial obstacles. These expenditures encompass expenses related to garbage collection, processing, energy generation and adherence to environmental rules.

Obtaining scientific evidence to support initiatives that aim to make use of food waste often requires expensive research, which can be a major obstacle for food manufacturers. Therefore, ongoing research and development are crucial for improving the efficiency and effectiveness of food waste valorization processes at lab-based and pilot-scale production levels before the processes are upscaled to mass production. Some manufacturers may opt to engage Original Equipment Manufacturers (OEMs) or contract manufacturers in the process of developing and implementing valorization technologies, which can expedite the pace of mass production by reducing the risk of installing huge infrastructure that involves a huge direct investment [32]. Facilitating collaborations between government institutions, such as the NEA in Singapore, and private investors can harness the assistance and knowledge of the public sector along with the funding capabilities of the private sector. Public–private partnerships (PPPs) have the ability to distribute risks, reduce the costs of financing, and expedite the establishment and growth of infrastructure for the valorization of food waste.

4.2. Economic Viability

To secure long-term investments and ensure sustainability, it is critically important to determine if the transformation of waste into valuable commodities is economically feasible. It is necessary to identify the specific volumes of food waste that are critical in order to achieve economies of scale and effectively manage logistics costs [33]. In Singapore, at least 30 tonnes of okara and 55 tonnes of spent barley grains are generated daily [34]. These are the two food processing side streams that are commonly upcycled, as both have

a more sustainable local supply, which allows for a scalable approach once the valorization method is established.

The incorporation of food waste valorization into supply chains is encouraged by the adoption of a model consistent with a circular economy. The implementation of a closed-loop system and the repurposing of waste resources are two ways in which the industry can reduce its reliance on new materials and improve its production sustainability. By evaluating the economic viability of various valorization techniques and exploring market potential, stakeholders can make informed decisions that promote both environmental stewardship and financial prosperity. Exploring the market potential for products derived from food waste valorization is essential to attract investment and foster economic growth in this sector. Singapore provides a unique case where innovative solutions have successfully captured market demand. For instance, bioethanol production from food waste has gained traction due to favorable government policies supporting renewable energy initiatives. Similarly, biochemicals derived from food waste have found niche markets in cosmetics and pharmaceuticals, leveraging Singapore's strategic location as a hub for biotechnology and chemical industries [35].

4.3. Consumer Awareness

Consumer awareness refers to the level of knowledge and understanding that individuals have about their rights and responsibilities as consumers [36]. It involves being informed about product quality, safety, pricing and the various laws and regulations.

It is crucial to make deliberate attempts to inform consumers about novel functional ingredients and products that are made from food waste in order to promote their acceptance and usage. According to Hellali et al. (2023), the demand for circular food products is lower compared to their conventional counterparts [37]. Individuals who are averse to taking risks are willing to pay a lower price for these products compared to individuals who are more inclined to take risks. Positive information presented within an environmental or health framework has a more significant impact on the willingness to pay for upcycled foods compared to information focused on the economy.

Therefore, disseminating information to the general public, including the use of social media, regarding the significance of reducing and utilizing food waste promotes modifications in behavior towards conscientious consumption and waste control [38]. Community involvement and engagement campaigns are crucial in promoting awareness to create a consumer market that is friendly to food waste valorization. Having this in place is especially important in order to complete a supply chain loop.

Consumer awareness is crucial in promoting food waste valorization efforts in Singapore. Consumer engagement that is effective can have a substantial impact on how the public perceives and behaves towards using items made from food waste.

Zero Waste SG, a not-for-profit and non-governmental organization in Singapore, has implemented the Save Food Cut Waste campaign to address the issue of food loss [39]. This project focuses on decreasing wastage at all stages of the supply chain, with a particular emphasis on raising consumer awareness. The program utilizes various forms of media, community activities, and partnerships with food outlets to educate customers on the significance of reducing food waste.

4.4. Collaborative Partnerships

The key to success in converting food waste into valuable resources lies in a collaborative framework that unites various stakeholders. Research institutions are crucial in this ecosystem, as they utilize scientific expertise to create cutting-edge technologies and solutions. In Singapore, research institutions, including the Agency for Science, Technology and Research (A*STAR), universities and polytechnics, are at the forefront of innovative research in food waste valorization technologies. These institutions are investigating various methods, including advanced biotechnological processes and innovative product development, to optimize the upcycling of food waste.

However, cross-collaboration between institutions and industry can be enhanced to share resources and propel innovations. The networking initiatives supported by the European Union can be a reference for Singapore to facilitate joint research on the valorization of food waste and enhance the transfer of knowledge between different stakeholders [40]. Organized communication channels among research institutions, industrial partners, and government bodies can be formed to improve transparency and promote the flow of knowledge. It is critical that the private sector recognizes the importance of addressing environmental concerns as well as the economic opportunities associated with converting waste into valuable resources. Incubators and accelerators are essential in fostering the growth of startups and small-medium companies engaged in the process of converting food waste into valuable products. Resources such as mentorship, access to funding and business development support can assist in transforming research breakthroughs into commercially viable solutions.

A key aspect of Singapore's strategy for food waste management is actively involving the community. Singaporeans are encouraged to minimize waste generation, separate food waste for recycling and embrace sustainable consumption practices through public education campaigns, grassroots initiatives and community-led projects.

Schools, community centers and non-profit organizations actively contribute to raising awareness and fostering behavior change [41]. Composting workshops, urban farming projects, and food rescue programs are empowering individuals to actively participate in reducing food waste and promoting a more sustainable future. Regular meetings, workshops and webinars can be conducted on platforms to encourage conversations on research goals, technical difficulties and market demands.

4.5. Regulatory Support

It is of utmost importance to ensure the safety and quality of food products derived from waste. The safety and quality standardization of food waste for food applications refers to the process of transforming food waste into products that can be safely consumed by humans or used for other valuable purposes [42]. Regulatory authorities must establish precise standards and guidelines for the processing of food waste to ensure the production of safe and top-notch products. This encompasses factors such as hygiene protocols, measures to prevent contamination and the composition of the product. Standardization endeavors may encompass the establishment of thresholds for impurities, the implementation of processing methodologies and the enforcement of adherence to food safety management systems such as Hazard Analysis and Critical Control Points (HACCP).

The utilization of food waste can be hindered by regulatory obstacles such as limitations on health claims and labeling for food products derived from food waste when safety and toxicity are concerned [43]. This entails providing scientific evidence to support claims and establishing consumer comprehension and confidence. Well-defined criteria aid in distinguishing products in the market according to their health advantages, promoting consumer trust and enabling well-informed decisions.

Regulatory frameworks can have a significant impact on motivating businesses and individuals to embrace practices that reduce and make use of food waste. The Singaporean government plays a pivotal role in promoting the valorization of food waste by implementing policy interventions and regulatory frameworks. The National Environment Agency (NEA) works together with industry stakeholders to develop guidelines for waste management practices and encourage the use of sustainable technologies through incentives. Regulations and policies that are advantageous, such as tax incentives and waste diversion targets, can motivate businesses and individuals to embrace waste reduction and valorization practices [44].

In order to optimize the utilization of food waste in Singapore, it is possible to introduce targeted regulatory enhancements that will promote innovation, guarantee product safety and stimulate the expansion of the sector. Clear and specific standards and rules for the processing of food waste can be established to ensure the production of safe goods.

This encompasses rules for maintaining cleanliness, measures to prevent contamination and criteria for the composition of products. Precise criteria for pollutants and impurities in food waste-derived goods can be established to guarantee their safety and quality. The standards imposed by the European Union on the recycling of organic waste into compost or biogas have stringent thresholds for pollutants and pathogens to guarantee the safety of the end products. These regulations establish a precise structure for managing organic waste while upholding stringent safety criteria.

It is important to demand empirical proof to validate health claims for food products produced from food waste. This guarantees that any asserted health advantages are supported by reputable scientific studies. Labeling regulations should be established that provide customers with clear and comprehensive information regarding the source of substances (e.g., “derived from food waste”) and their safety advantages. Additionally, standards should be developed to authenticate and validate products derived from food waste, fostering customer confidence and enabling well-informed choices.

4.6. Data Management

The UN Department of Economic and Social Affairs advocates for the strategic utilization of big data to mitigate food loss and waste and foster sustainable growth [45]. By harnessing advanced data analytics techniques across the entire food supply chain, stakeholders can gain profound insights into patterns, inefficiencies and opportunities for improvement. This data-driven approach enables stakeholders to predict demand with greater accuracy, optimize inventory management and enhance logistical operations. Additionally, big data facilitates the identification of critical points where food loss occurs, allowing for targeted interventions to minimize waste. These interventions may include implementing innovative storage solutions, improving transportation logistics and optimizing distribution networks. Moreover, big data empowers stakeholders to track and trace food products more effectively, ensuring timely delivery and reducing the likelihood of spoilage [46]. Overall, leveraging big data in the fight against food loss and waste not only promotes environmental sustainability but also contributes to economic resilience by optimizing resource allocation and enhancing productivity in the food sector.

A similar big data model can be adopted for food waste valorization. Robust data collection and monitoring systems are crucial for effectively tracking progress and optimizing valorization processes. The process of digitalization can improve the effectiveness and precision of data management, thereby enabling well-informed decision-making in valorizing food waste [47]. A sustainable supply of food waste is crucial for long-term production operations using food waste as raw materials. Comprehensive data collection and monitoring systems on food waste produced from different sources help to identify a supply of raw materials for valorization, allowing more precise predictions on the volume of production.

5. Government Schemes and Incentives

5.1. Legislation

Food waste presents a substantial global challenge, impacting both the sustainability of the environment and the efficiency of the economy. The Singaporean government has made addressing food waste a priority due to the scarcity of land and resources in the country. In 2014, the NEA introduced the Mandatory Waste Reporting scheme to cover hotels and malls and extend it to industrial premises and convention and exhibition centers in 2010. Based on the findings, between 2021 and 2022, the recycling rate only increased for large hotels (8.6 to 10.5%) and decreased for large malls and industrial premises (12.6% to 11.6% and 55.1% to 54.4%, respectively) [48].

The Resource Sustainability Act (RSA) 2019 and Resource Sustainability (Amendment) Act 2023 aim to establish a structure to manage the inevitable food waste produced by large establishments. Since 2021, it has been mandatory for developers of new industrial and commercial developments generating large amounts of food waste to set aside space

for on-site food waste treatment in their factory layout plans, as Singapore will move to closed-loop management of food waste in 2024. From this year onward, the National Environmental Agency (NEA) requires owners and operators of establishments such as hotels, malls and large industrial developments to separate food waste for processing [49]. The occupier of the prescribed building will be liable to a fine should they dispose of food in a non-designated facility. In addition, the building manager will be liable to a fine or imprisonment should the prescribed does not enable the occupier to dispose of food waste separately from other types of waste. Finally, the RSA mandates that all food waste disposed of in the designated facility must be treated in the building; the building manager will also be accountable by a fine or imprisonment.

The scope of legislation primarily focuses on waste management, and this does not sufficiently address upstream factors, which are overproduction, supply chain efficiencies and consumer behavior. Additionally, though the legislation targets large commercial and industrial food waste generators, there should be more effort to reach out to small-scale industries and run more public awareness campaigns and educational programs on household food waste, encouraging efficient food purchase and good preparation habits to save money and reduce food wastage.

Compliance and accurate reporting are crucial for policymaking, but ensuring consistency and reliable data collection on food waste generation from different sources will be an ongoing challenge. The government can gradually implement mandatory food waste reporting in large-scale food industries before moving into medium- and small-scale businesses. Stringent enforcement of penalties can drive effective legislation but also may not be practical across all sectors. Therefore, to foster compliance, the legislation should be flexible to recognize the diversity of the food industry and be accommodating to different business sizes and types.

The installation and maintenance of on-site food waste segregation systems and treatment facilities can incur significant expenses. The large size of such equipment may pose challenges for small- or medium-sized establishments in terms of space constraints [50]. The space that could have been utilized for generating revenue has now transformed into a cost center for these companies. Operational disruptions may occur in the collection of food waste in manufacturing companies, requiring staff training. In addition to providing training, it is necessary to establish a new mindset that promotes the adoption of new operating procedures. This will require the company to allocate additional time and resources. To encourage smooth adoption to upcycle, recycle and reduce waste, NEA launched the 3R Fund, where they co-fund up to 80 percent of organizations' qualifying costs, capped at \$1 million per project or per applicant [51].

Food contamination concerns have led companies to implement stringent regulations regarding food safety and quality. Consequently, it is essential to provide training to the staff to ensure that they can hygienically handle food waste, particularly when the food waste is intended to be used as a source of food for human consumption. The implementation, optimization and maintenance of treatment systems may necessitate specialized technical knowledge. Smaller establishments may lack the internal capability or be unaware of where to locate such resources.

Admittedly, it is challenging to address all these gaps, as it involves collaboration between the trinity, government agencies, businesses and the public. Continuous monitoring and adaptation with some flexibility to the legislation is necessary to ensure an impactful outcome.

5.2. Initiatives Supporting Food Waste Management

The Singapore government has designated a \$1.76 million SGD Food Waste Fund to subsidize the expenses of food waste treatment solutions. The objective of this fund is to encourage organizations to implement efficient waste management strategies. The Food Resource Valorisation Awards were launched by the National Environment Agency (NEA) in 2021 with the aim of promoting active engagement from organizations. Three local

companies were honored with the merit award for their innovative methods of utilizing food waste [52].

The NEA, together with IPI, Enterprise Singapore, co-organized the annual Sustainability Open Innovation Challenge (SOIC) in 2021, inviting innovative ideas for the collaborative development of sustainable solutions [53] to establish resilient on-site food waste treatment systems that efficiently utilize limited space while producing valuable outputs [54]. A total of 16 corporates participated and submitted their challenge statements; 627 proposals were received, and 15 startups were awarded [55]. The startups were given the opportunity to discuss the development of the solutions. This initiative provides a maximum of \$2 million SGD to enhance the separation of food waste into different categories, including both uniform and non-uniform waste.

Another new initiative, The Hungry for Change Challenge, was launched in 2022 by the NEA and the Development Bank of Singapore (DBS) Foundation in collaboration. This challenge enables individuals to take control and lead efforts to implement solutions that are specifically designed to decrease or stop the occurrence of food waste in Singapore. Five startups in Singapore—Mottainai Food Tech, tHEMEat Company, ChangeX, Divert for 2nd Life and The Moonbeam Co—were awarded a total of \$125,000 to develop their solutions. Through promoting collaboration and stimulating creative ideas, these startups developed new food varieties, such as plant-based meats and spent coffee-ground cookies, providing many success stories to consumers [56].

The NEA and the Singapore Food Agency (SFA) collaborated extensively with the food industry to create resources, training programs and guidelines for optimal performance. Food manufacturers can consult the freely available online guidebook on food waste minimization prepared by the SFA as a reference. Establishments in Singapore benefit from collaborating with various startups to effectively navigate different technologies for treating food waste [57].

It is crucial to increase public consciousness regarding food waste management. The third 'Say YES to Waste Less' campaign was launched by the NEA in September 2021 [58]. The campaign advocates a sustainable lifestyle by purchasing an optimal quantity of food to reduce food wastage, reducing the use of disposable waste by deploying reusable containers to minimize packaging waste and businesses collaborating with the NEA to support this campaign. More than 140 companies supported this campaign through the collection of surplus food, the diversion of foods that are near 'best-before' dates, the reduction of single-use waste through a closed-loop reusable system and the upcycling of food side streams back into food production. A social enterprise, through the smart use of its proprietary AI technology, has diverted more than 600 tonnes of surplus food, helped partners save \$7.1 million and prevented 3114 tonnes of carbon emissions [59].

The Singapore government's extensive range of support initiatives, encompassing financial assistance and the promotion of innovation, aim to facilitate a seamless and economical transition, particularly for smaller enterprises. SOIC is now in its fifth edition, while DBS X Hungry for Change returns for the second time with more partners joining the initiative. The multiple runs from these events are testimonies to the importance of sustainability and food waste valorization in Singapore.

To reinforce existing initiatives, the NEA can consider strengthening the Food Valorization Award by having additional award categories, such as Most Innovative Solution or Most Scalable Solution, and developing a comprehensive and standardized index to measure food loss and waste across food supply chains with the data collected.

The government can tap into food waste management knowledge from countries to learn from their best practices and about the ecosystem these countries have developed for South Korea and China.

South Korea developed a 'Food Waste Reduction Masterplan' in 1996 for food establishments and households. They established a recycling program in 1998 and banned food waste from landfills by 2005. In 2010, the South Korean government introduced a volume-based food waste fee system (pay-as-you-throw model), where residents purchase

biodegradable bags to dispose of food waste and pay based on the weight of disposed waste. Strict enforcement with penalties is imposed for non-compliance, and this has significantly reduced Seoul's household food waste by nearly 47,000 tonnes in six years (2013 to 2019) and has increased food waste recycling from less than 2% in 1995 to 95% in 2019 [60]. Stringent measures have proven to be an effective method, and the Singapore government should consider these as they move to tackle the challenge of increasing involvement in managing food waste among Singapore residents [61].

China's anti-food waste law was implemented in 2021 as a need to address the challenges they face in food security for domestic food supply. The COVID pandemic, serious floods since 1998 and increasing agricultural imports in 2020 have triggered the government of the People's Republic of China to address food security and food waste reduction. The anti-food waste law targets mainly catering service providers and food producers, as these places generate the most food waste. This policy was adopted with sanctioning power due to non-compliance and negative consequences when there were no sanctions for the past 9 years. The approach was to motivate a change in cultural practices, such as 'face saving', where diners are less likely to pack their leftovers after a meal in a restaurant setting [62]. The government continues to lead changes through bottom-up actions by getting multiple parties such as commercial, social, the general public and the government themselves to establish the 'big food concept' of promoting food diversity on both ends—agricultural production and consumers—to change consumers' consumption patterns to buy only what they can finish and eat more white meat to save animal feed, and to protect the environment while meeting the nation's protein demand [63]. Various initiatives and systems to collect data directly from caterers and food producers have been implemented nationwide and will be consolidated.

Case studies have shown that for a food system to be sustainable and secure, the government, businesses, research institutions and individuals will have to contribute, either with a top-down or bottom-up approach. To ensure its longevity for future generations, a combination of a top-down approach to adhering to rules and regulations and a bottom-up approach to actively influencing and changing consumers' behavior is needed to reduce waste to the greatest extent possible.

6. Conclusions

The Zero Waste Plan offers a strategic structure for minimizing the creation of waste and maximizing the efficiency of resources, with a focus on reducing waste, recycling and implementing circular economy principles. Integrating food waste valorization strategies perfectly fits with this vision, providing opportunities to redirect food waste away from landfills, decrease greenhouse gas emissions and generate new food sources and resources that can enhance food production, such as urban farming in the country.

This review has indicated that although there have been attempts to enhance food waste recycling, they are inadequate to substantially influence the total recycling rate. Various methods, technologies, and prototypes used to convert food waste into valuable resources are highlighted. Case studies of different food waste streams in Singapore are reviewed, showing promising research and industry applications. Additionally, challenges in infrastructure development, economic viability, consumer awareness, collaborative partnerships, regulatory support and data management that are associated with food waste valorization are discussed. Government schemes and incentives related to food waste management, focusing on legislation and initiatives, are explained.

Food waste valorization is an excellent initiative that fits well with Singapore's 30-by-30 goal, which highlights the importance of improving food security by focusing on local production and innovation. By implementing a food waste valorization process, environmental concerns can be effectively addressed while simultaneously bolstering the food system's resilience and self-sufficiency. Incorporating the utilization of food waste into Singapore's Zero Waste Plan and 30-by-30 goal offers a comprehensive solution to urgent environmental and economic issues. Singapore can convert its food waste into

valuable resources and make progress towards its sustainability goals by utilizing advanced technologies and promoting partnerships between the government, research institutions, industry and communities.

Harnessing this potential necessitates collective endeavors to surmount the numerous challenges delineated in this paper. Stakeholders in Singapore can fully realize the advantages of food waste valorization and contribute to a more sustainable future by giving priority to infrastructure development, economic viability, consumer awareness, collaborative partnerships, regulatory compliance and data management. For policymakers, clearer and more comprehensive guidelines and standards for food waste valorization should be developed to better support more extensive food waste management in Singapore.

Ultimately, Singapore can effectively address environmental concerns, capitalize on economic prospects and enhance food security resilience by prioritizing the utilization of food waste. Future research can focus on exploring innovative technologies for scalable food waste valorization and improving data collection and management practices. By employing strategic planning, innovation and collective action from research institutions, industry players, government and communities, Singapore has the potential to lead the way towards a future that is both sustainable and resilient for future generations.

Author Contributions: Writing—original draft, K.H., K.T., A.C. and C.C.C.L.; Writing—review & editing, K.H., K.T., A.C. and C.C.C.L. All authors have read and agreed to the published version of the manuscript.

Funding: The research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Xu, X.; Sharma, P.; Shu, S.; Lin, T.-S.; Ciais, P.; Tubiello, F.N.; Smith, P.; Campbell, N.; Jain, A.K. Global Greenhouse Gas Emissions from Animal-Based Foods Are Twice Those of Plant-Based Foods. *Nat. Food* **2021**, *2*, 724–732. [CrossRef]
2. Zero Waste Masterplan Singapore. Available online: <https://www.mse.gov.sg/resources/zero-waste-masterplan.pdf> (accessed on 18 August 2024).
3. 30 by 30. Available online: <https://www.ourfoodfuture.gov.sg/30by30/> (accessed on 22 April 2024).
4. Background on the Goals. Available online: [https://www.undp.org/sdg-accelerator/background-goals#:~:text=The%20Sustainable%20Development%20Goals%20\(SDGs,economic%20challenges%20facing%20our%20world](https://www.undp.org/sdg-accelerator/background-goals#:~:text=The%20Sustainable%20Development%20Goals%20(SDGs,economic%20challenges%20facing%20our%20world) (accessed on 18 July 2024).
5. Food Waste Management. Available online: <https://www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/food-waste-management> (accessed on 22 April 2024).
6. Integrated Waste Management Facility. Available online: <https://www.nea.gov.sg/our-services/waste-management/waste-management-infrastructure/integrated-waste-management-facility> (accessed on 22 April 2024).
7. Semakau Landfill 20th Anniversary. Available online: <https://www.nea.gov.sg/corporate-functions/resources/publications/books-journals-and-magazines/envision-lite/june-july-2020/semakau-landfill-20th-anniversary> (accessed on 18 July 2024).
8. Food Waste Valorization. Available online: <https://www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/food-waste-management/food-waste-valorisation> (accessed on 22 April 2024).
9. Nath, P.C.; Ojha, A.; Debnath, S.; Sharma, M.; Nayak, P.K.; Sridhar, K.; Inbaraj, B.S. Valorization of Food Waste as Animal Feed: A Step towards Sustainable Food Waste Management and Circular Bioeconomy. *Animals* **2023**, *13*, 1366. [CrossRef] [PubMed]
10. Castillejo, N.; Martínez-Zamora, L. Bioactive Compounds from Fruit and Vegetable Waste: Extraction and Possible Utilization. *Foods* **2024**, *13*, 775. [CrossRef] [PubMed]
11. Pop, C.; Suharoschi, R.; Pop, O.L. Dietary Fiber and Prebiotic Compounds in Fruits and Vegetables Food Waste. *Sustainability* **2021**, *13*, 7219. [CrossRef]
12. Dikmetas, D.N.; Devcioglu, D.; Özünal, Z.G.; Demiroz, A.; Yavuz, E.; Sirkeci, C.B.; Karbancioglu-Guler, F.; Kahveci, D. From Waste to Remedy: Extraction and Utilization of Food Waste-Derived Bioactive Components in Wound Healing. *Trends Food Sci. Technol.* **2024**, *145*, 104347. [CrossRef]

13. Lau, K.Q.; Sabran, M.R.; Shafie, S.R. Utilization of Vegetable and Fruit By-Products as Functional Ingredient and Food. *Front. Nutr.* **2021**, *8*, 661693. [CrossRef] [PubMed]
14. Tian, X.; Li, Y.; Hao, N.; Su, X.; Du, J.; Hu, J.; Tian, X. The Antifeedant, Insecticidal and Insect Growth Inhibitory Activities of Triterpenoid Saponins from *Clematis aethusifolia* Turcz against *Plutella xylostella* (L.). *Pest Manag. Sci.* **2020**, *77*, 455–463. [CrossRef]
15. Mapelli, F.; Carullo, D.; Farris, S.; Ferrante, A.; Bacenetti, J.; Ventura, V.; Frisio, D.; Borin, S. Food Waste-Derived Biomaterials Enriched by Biostimulant Agents for Sustainable Horticultural Practices: A Possible Circular Solution. *Front. Sustain.* **2022**, *3*, 928970. [CrossRef]
16. National University of Singapore. NUS Food Scientists Create Healthy Probiotic Drink from Soy Pulp. Available online: <https://news.nus.edu.sg/nus-food-scientists-create-healthy-probiotic-drink-from-soy-pulp/> (accessed on 22 April 2024).
17. Shan Lee, D.P.; Yin Leong, G.X.; Liu, X.; Kim, J.E. Effect of Okara and Biovalorized Okara Biscuits Consumption on Postprandial Circulating Amino Acid Concentrations: A Crossover Randomized Controlled Trial. *Curr. Dev. Nutr.* **2022**, *6*, 447. [CrossRef]
18. Razali, N.A. Soy By-Product: Okara Could Be Upcycled into Plant-Based Cheese by Singapore Partnership. Available online: <https://www.foodnavigator-asia.com/Article/2022/08/15/soy-cheese-a-promising-plant-based-alternative-singapore-partnership> (accessed on 22 April 2024).
19. Yun, T.H. Republic Poly Students Turn Soya By-Product into Cheese. Available online: <https://www.straitstimes.com/lifestyle/food/republic-poly-students-turn-soy-by-product-into-cheese> (accessed on 18 August 2024).
20. Tan, N. Republic Polytechnic Researchers Turn Soya Pulp Meant for Landfills into Crop Booster. Available online: <https://www.straitstimes.com/singapore/republic-polytechnic-researchers-turn-soya-pulp-meant-for-landfills-to-a-crop-booster> (accessed on 18 August 2024).
21. Shi, P.; Ng Yuen Kai, R.; Vijayan, P.; Lim, S.L.; Bhaskaran, K. Valorization of Spent Barley Grains: Isolation of Protein and Fibers for Starch-Free Noodles and Its Effect on Glycemic Response in Healthy Individuals. *Front. Sustain. Food Syst.* **2023**, *7*, 1146614. [CrossRef]
22. Chin, Y.L.; Chai, K.F.; Chen, W.N. Upcycling of Brewers' Spent Grains via Solid-State Fermentation for the Production of Protein Hydrolysates with Antioxidant and Techno-Functional Properties. *Food Chem. X* **2022**, *13*, 100184. [CrossRef] [PubMed]
23. Pant, A.; Ni Leam, P.X.; Chua, C.K.; Tan, U.-X. Valorisation of Vegetable Food Waste Utilising Three-Dimensional Food Printing. *Virtual Phys. Prototyp.* **2022**, *18*, e2146593. [CrossRef]
24. Leo, C.H.; Lee, C.P.; Foo, S.Y.; Tan, J.C.; Tan, J.D.; Ong, E.S.; Hashimoto, M. 3D Printed Nutritious Snacks from Orange Peel Waste. *Mater. Today Proc.* **2022**, *70*, 12–16. [CrossRef]
25. JamieOliver.com. Spent Grain—Reducing Waste in the Beer Industry: Features. Available online: <https://www.jamieoliver.com/features/spent-grain-reducing-waste-beer-industry/#:~:text=WHAT%20IS%20SPENT%20GRAIN?,spent%E2%80%99%20as%20it%E2%80%99s%20been%20used> (accessed on 18 July 2024).
26. Nyhan, L.; Sahin, A.W.; Schmitz, H.H.; Siegel, J.B.; Arendt, E.K. Brewers' Spent Grain: An Unprecedented Opportunity to Develop Sustainable Plant-Based Nutrition Ingredients Addressing Global Malnutrition Challenges. *J. Agric. Food Chem.* **2023**, *71*, 10543–10564. [CrossRef]
27. Neo, P. Well Spent: Healthy Noodle Firm KosmodeHealth Seeking Spent Barley Partnerships with Major F&B Brands. Available online: <https://www.foodnavigator-asia.com/Article/2021/02/23/Well-spent-Healthy-noodle-firm-KosmodeHealth-seeking-spent-barley-partnerships-with-major-F-B-brands> (accessed on 18 July 2024).
28. Dou, Z.; Dierenfeld, E.S.; Wang, X.; Chen, X.; Shurson, G.C. A Critical Analysis of Challenges and Opportunities for Upcycling Food Waste to Animal Feed to Reduce Climate and Resource Burdens. *Resour. Conserv. Recycl.* **2024**, *203*, 107418. [CrossRef]
29. Co-Digestion Of Food Waste and Used Water Sludge Enhances Biogas Production for Greater Energy Generation. Available online: <https://www.nea.gov.sg/media/news/news/index/co-digestion-of-food-waste-and-used-water-sludge-enhances-biogas-production-for-greater-energy-generation> (accessed on 18 July 2024).
30. ecoWise Holding Limited. ECOWISE—Renewable Energy: To Yield Significant Environmental, Social & Economical Benefits. Available online: <https://www.ecowise.com.sg/en/our-businesses/renewable-energy> (accessed on 18 July 2024).
31. Lin, L.; Xu, F.; Ge, X.; Li, Y. Improving the Sustainability of Organic Waste Management Practices in the Food-Energy-Water Nexus: A Comparative Review of Anaerobic Digestion and Composting. *Renew. Sustain. Energy Rev.* **2018**, *89*, 151–167. [CrossRef]
32. Chen, Y.; Karamemis, G.; Zhang, J. A Win-Win Strategy Analysis for an Original Equipment Manufacturer and a Contract Manufacturer in a Competitive Market. *Eur. J. Oper. Res.* **2021**, *293*, 177–189. [CrossRef]
33. Sharma, V.; Singh, A.; Grenier, M.; Singh, V.; Thakur, M. Waste Valorization in Food Industries: A Review of Sustainable Approaches. In *Sustainable Food Systems*; World Sustainability Series; Springer: Cham, Switzerland, 2023; pp. 161–183. [CrossRef]
34. Brew a Better World—Turning Waste to Value. Available online: https://www.nea.gov.sg/docs/default-source/our-services/waste-management/turning-waste-to-value-to-brew-a-better-world-_22092021.pdf (accessed on 23 April 2024).
35. Pharmaceuticals & Biotechnology. Available online: <https://www.edb.gov.sg/en/our-industries/pharmaceuticals-and-biotechnology.html> (accessed on 18 July 2024).

36. Mishra, M.; Kushwaha, R.; Gupta, N.; Sinha, A.; Dwivedi, H. Survey Data to Evaluate Consumer Behaviour and Consumption Pattern of Sustainable Apparel: A Study on Consumer Awareness Level. *Data Brief* **2023**, *49*, 109350. [CrossRef]
37. Hellali, W.; Korai, B.; Lambert, R. Food from Waste: The Effect of Information and Attitude towards Risk on Consumers' Willingness to Pay. Available online: <https://www.sciencedirect.com/science/article/pii/S0950329323001398> (accessed on 27 April 2024).
38. Teoh, C.W.; Koay, K.Y.; Chai, P.S. The Role of Social Media in Food Waste Prevention Behaviour. *Br. Food J.* **2021**, *124*, 1680–1696. [CrossRef]
39. Zero Waste SG. Available online: <https://www.zerowastesg.com/about-us> (accessed on 18 July 2024).
40. Morone, P.; Falcone, P.; Tartiu, V. Food Waste Valorisation: Assessing The Effectiveness of Collaborative Research Networks through The Lenses of A COST Action. *J. Clean. Prod.* **2019**, *238*, 117868. [CrossRef]
41. Rut, M.; Davies, A.R.; Ng, H. Participating In Food Waste Transitions: Exploring Surplus Food Redistribution In Singapore Through The Ecologies Of Participation Framework. *J. Environ. Policy Plan.* **2021**, *23*, 34–47. [CrossRef]
42. Bárbar, S.-R.; Gerardo, Á.-R.; Alberto, V.; Elena, I.; Alejandro, C. Food by-products and food wastes: Are they safe enough for their valorization? *Trends Food Sci. Technol.* **2021**, *14*, 133–147. [CrossRef]
43. Vilas-Boas, A.A.; Pintado, M.; Oliveira, A.L.S. Natural Bioactive Compounds from Food Waste: Toxicity and Safety Concerns. *Foods* **2021**, *10*, 1564. [CrossRef]
44. Tsai, W.-T.; Lin, Y.-Q. Analysis of Promotion Policies for the Valorization of Food Waste from Industrial Sources in Taiwan. *Fermentation* **2021**, *7*, 51. [CrossRef]
45. Build Back Better: Using Green and Digital Technologies to Reduce Food Waste at Consumer Level. Available online: <https://www.unep.org/explore-topics/green-economy/build-back-better> (accessed on 22 April 2024).
46. Big Data to Reduce Food Loss and Waste for Sustainable Growth. Available online: <https://sdgs.un.org/partnerships/big-data-reduce-food-loss-and-waste-sustainable-growth> (accessed on 22 April 2024).
47. Annosi, M.C.; Brunetta, F.; Bimbo, F.; Kostoula, M. Digitalization within Food Supply Chains to Prevent Food Waste. Drivers, Barriers and Collaboration Practices. *Ind. Mark. Manag.* **2021**, *93*, 208–220. [CrossRef]
48. Mandatory Waste Reporting. Available online: <https://www.nea.gov.sg/our-services/waste-management/mandatory-waste-reporting#MWR8> (accessed on 18 July 2024).
49. Food Waste Segregation for Treatment by Large Commercial & Industrial Food Waste Generators to Be Mandatory from 2024. Available online: <https://www.nea.gov.sg/media/news/news/index/food-waste-segregation-for-treatment-by-large-commercial-industrial-food-waste-generators-to-be-mandatory-from-2024> (accessed on 22 April 2024).
50. Lee, K.; Oh, J.; Chu, K.; Kwon, S.; Yoo, S. Comparison and Evaluation of Large-Scale and On-Site Recycling Systems for Food Waste via Life Cycle Cost Analysis. *Sustainability* **2017**, *9*, 2186. [CrossRef]
51. 3R Fund. Available online: <https://www.nea.gov.sg/programmes-grants/grants-and-awards/3r-fund> (accessed on 18 July 2024).
52. Food Resource Valorisation Awards. Available online: <https://www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/food-waste-management/food-resource-valorisation-awards> (accessed on 22 April 2024).
53. Sustainability Open Innovation Challenge 2023. Available online: <https://sustainability.innovation-challenge.sg/> (accessed on 22 April 2024).
54. Call to Reduce Food Waste Disposal from Commercial Premises and Enhance Recycling. Available online: <https://www.nea.gov.sg/programmes-grants/grants-and-awards/call-to-reduce-food-waste-disposal-from-commercial-premises-and-enhance-recycling> (accessed on 22 April 2024).
55. Accelerate Innovation to Build a Sustainable Singapore. Available online: <https://www.openinnovationnetwork.gov.sg/success-stories/success-stories/accelerate-innovation-to-build-a-sustainable-singapore> (accessed on 18 July 2024).
56. Hungry for Change Challenge 2023. Available online: <https://www.dbs.com/foundation/community-impact/dbsf-nea-hungry-for-change> (accessed on 22 April 2024).
57. Food Waste Minimisation Guidebook for Food Manufacturing Establishments. Available online: <https://www.sfa.gov.sg/docs/default-source/default-document-library/food-waste-minimisation-guidebook-for-food-manufacturing-establishments-.pdf> (accessed on 22 April 2024).
58. More Partners Join The Say YES To Waste Less Campaign to Reduce Food Wastage and Disposables. Available online: <https://www.nea.gov.sg/media/news/news/index/more-partners-join-the-say-yes-to-waste-less-campaign-to-reduce-food-wastage-and-disposables> (accessed on 18 August 2024).
59. More Than 140 Partners Say Yes To Waste Less. Available online: <https://www.nea.gov.sg/media/news/news/index/more-than-140-partners-say-yes-to-waste-less#:~:text=D2L.sg%20collects%20all%20types,it%20was%20founded%20in%202021> (accessed on 18 July 2024).
60. South Korea Once Recycled 2% of Its Food Waste. Now It Recycles 95%. Available online: <https://www.weforum.org/agenda/2019/04/south-korea-recycling-food-waste/> (accessed on 18 July 2024).
61. Leg—South Korean Comprehensive and Successful Policy Mix Aiming at Food Waste Treatment and Recovery. Available online: <https://www.fao.org/platform-food-loss-waste/in-action/projects/project-detail/south-korean-policy-food-waste-treatment-and-recovery/en> (accessed on 18 July 2024).

62. Feng, Y.; Marek, C.; Tosun, J. Fighting Food Waste by Law: Making Sense of the Chinese Approach. *J. Consum. Policy* **2022**, *45*, 457–479. [[CrossRef](#)] [[PubMed](#)]
63. Brodie, J. Can Managing Food Waste Help China Meet Its Climate Goals? Available online: <https://focus.cbbc.org/can-managing-food-waste-help-china-meet-its-climate-goals/> (accessed on 18 July 2024).

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