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Heng Kiang Soon , Tan Kye Teng , Adeline Chan , Charles CC Lee *

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Food Waste Valorisation: Leveraging on Singapore's Zero Waste Masterplan and 30-by-30 Goal

Heng Kiang Soon [1], Tan Kye Teng [1], Adeline Chan [2] and Charles CC Lee [3,*]

[1] Republic Polytechnic
[2] Innovation Partners for Impact (IPI) Singapore
[3] University of Newcastle (Australia)
* Correspondence: charles.cc.lee@newcastle.edu.au

Abstract: Singapore, being a land-scarce country, is heavily dependent on imported food, which poses a challenge in ensuring food security. In addition, the substantial amount of food waste generated in Singapore further deepens food insecurity challenges, imposing enormous pressure on the country's food and land resources. In the recent years, valorising food waste streams into higher value products has been an increasing trend in tackling food wastage due to its economical and environmental benefits. This paper provides a thorough review on food waste valorisation in Singapore and summarizes critical information from the current food landscape to the food waste management strategies adopted. The review highlights the prototypes developed from food waste streams by the local research and development capabilities and the technological processing and techniques used for versatile applications ranging from food and nutraceuticals to urban agriculture. The challenges associated with the valorisation of food waste are also addressed. Two ambitious Initiatives by the Singapore government Zero Waste Plan and the 30-by-30 food security goal to encourage food waste valorisation are explored and presented. The review serves as a reference for other countries in ensuring food security and achieving sustainable development goals.

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

1. Introduction

The Zero Waste Master Plan and the 30-by-30 Goal has 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 [1]. 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 [2]. 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

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as providing financial assistance for innovative research projects focused on creating sustainable food production systems.

The paper reviews food waste valorisation 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.

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, approximately 665 thousand tonnes of food waste were produced, with almost half of it coming from households [3]. 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 [4]. 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 2022 [5]. There is a consistent increase in the total amount of food waste generated over the years, from 763,000 tonnes in 2018 to 813,000 tonnes in 2022. 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.

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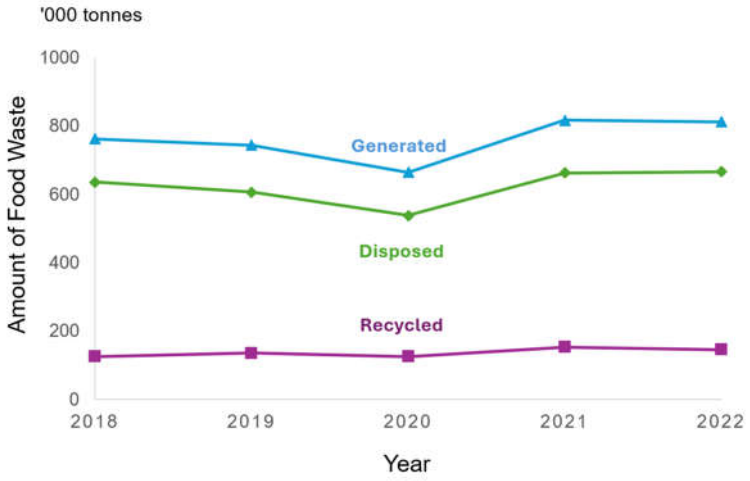

Figure 1. Total food waste generated, disposed of and recycled in Singapore (2018-2022) Reference source?

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 146,000 tonnes in 2022. 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.

Overall, the data highlights 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 valorisation of food waste; (b) Raising of public awareness; (c) Implementation of effective policies; and (d) The investment in infrastructure for the recycling of food waste.

2.3. Food Waste Valorisation

Singapore's strategy for managing food waste is multifaceted and forward-thinking. It serves as a comprehensive guide for policies and initiatives aim 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.

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 [6]. The processing flow encompasses treatment, bioreaction, extraction, purification, dehydration or concentration and formulation. The efforts effectively cut greenhouse gas emissions, encourage the conservation of resources while providing alternatives of 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. The products can be classified into four primary

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categories: (a) Animal nutrition,; (b) food ingredients,; (c) nutraceutical and functional foods,; and (d) bioactive compounds for 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 [7]. 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 [8].

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 [9,10]. These extracts obtained from food sources that were previously not fully utilised 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 [11]. 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 consumer. For manufacturers, they 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 [12,13]. 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 do 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 Valorisation 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 valorisation 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 fibre, free isoflavones and amino acids; nutritious, non-dairy alternative	[14]
	Biscuits	Solid-state fermentation with microbes	Higher amino acid content than conventional biscuits	[15]
	Okara soy cheese	Solubilization and formulation	Functional soy cream cheese, healthier alternative of soy	[16]

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			cream soup and soy sliced cheese	
Spent barley grains	Plant biostimulant	Processing, extraction and purification	Promoted plant growth; improved crop yield and quality; anti-fungal	[17,18]
	Functional noodles	Formulation of dried spent barley grain into a paste-like dough	Zero glycemic response; high in fibre; good source of protein; low in calories	[19]
	Protein powder	Solid-state fermentation by microbes	Act as plant-based emulsifier with strong antioxidative properties	[20]
Vegetable wastes	3D printed food	Pureeing and 3D food printing	Creative 3D-printed food	[21]
Orange peel wastes	3D printed food toppings, soup bowl and biscuits	Sonication and 3D food printing	Increased bioflavonoids and antioxidant content in snacks	[22]

3.1. Okara

Okara, a residual product of soybean processing is one of the largest food waste streams in Singapore. Four studies involving okara valorisation are identified and reviewed. Liu and Vong 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 [14]. 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.

Delia et al. formulated biscuits from okara undergoing solid-state fermentation which increases the amino acid content of the biscuits [15]. 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, Heng et al. solubilized okara and formulated it into three prototypes of soy cheese – soy cream cheese, soy cream soup and soy sliced cheese [16]. These soy cheese options have higher levels of protein, dietary fibre 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 showcase 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.

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A novel okara-based biostimulant was developed by isolating bioactive compounds from okara [17,18]. This biostimulant has been found to stimulate leafy vegetables' growth, increase their crop yield and quality and prevent and mitigate powdery mildew disease in strawberry plants. 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 grains (SBG) are another main food waste streams which are rich in fibre, protein and other valorisable nutrients. SBG were transformed into protein and fibre-rich ingredients in the form of paste-like dough [19]. 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 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* [20]. 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 unfermented sample. The fermented SBG protein extract also exhibited greater antioxidant. 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. Fruits and Vegetable Wastes

Students at local junior colleges and polytechnics were engaged in valorising kale and spinash wastes [21]. The vegetable waste samples were chilled, rinsed, chopped, boiled and pureed. The purees obtained were used to formulate the inks for the 3-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 3-demensional printing technology [22]. The researchers formulated rheology-modefied inks derived from orange peels to print 3-demensional 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 repurpose 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 valorisation research and development that researchers and manufacturers commonly encounter in Singapore.

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Figure 2. Potential challenges in food waste valorisation 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 response, 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 valorisation 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 valorisation 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 [23].

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 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 valorisation technologies which can expedite the pace of mass production by reducing the risk of installing huge infrastructure that involves a direct huge investment [24].

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 [25]. In Singapore, at least 30 tonnes of okara and 55 tonnes of spent barley grains are generated daily [25,26]. 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 valorisation method is established.

The incorporation of food waste valorisation 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

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repurposing of waste resources are two ways in which the industry can reduce its reliance on new materials and improve its production sustainability.

4.3. Consumer Awareness

Consumer awareness refers to the level of knowledge and understanding that individuals have about their rights and responsibilities as consumers [27]. 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., the demand for circular food products is lower compared to their conventional counterparts [28]. 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 [29]. Community involvement and engagement campaigns are crucial in promoting awareness to create a consumer market which is friendly to food waste valorisation. Having this in place is especially important in order to complete a supply chain loop.

4.4. Collaborative Partnerships

The key to the 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 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 valorisation of food waste and enhance the transfer of knowledge between research institutions [30].

Collaborations between research institutions and industry partners expedite the transfer of technology and hasten the process of bringing innovative solutions to the market. 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. Investing in advanced technologies and infrastructure to transform food waste by those in the food manufacturing and waste management sectors will ensure the successful implementation of food waste valorisation technology by the industry.

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

Schools, community centres and non-profit organizations actively contribute to raising awareness and fostering behavior change [31]. 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.

4.5. Regulatory Support

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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 [32]. 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 [33]. 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 valorisation practices [34].

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, fostering sustainable growth [35]. 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 minimise 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 [36]. 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 valorisation. Robust data collection and monitoring systems are crucial for effectively tracking progress and optimizing valorisation processes. The process of digitalization can improve the effectiveness and precision of data management, thereby enabling well-informed decision-making in valorising food waste [37]. A sustainable supply of food waste is crucial for a long-term operation of production using food waste as raw materials. Comprehensive data collection and monitoring systems on food waste produced from different sources help to identify supply of raw materials for valorisation, allowing more precise predictions on volume of production.

5. Government Schemes and Incentives

5.1. Legislation

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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. 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. Starting in 2024, 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 [38].

However, the installation and maintenance of on-site food waste segregation systems and treatment facilities can incur significant expenses. Furthermore, the large size of such equipment may pose challenges for small or medium-sized establishments in terms of space constraints [39]. The space that could have been utilised 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.

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.

5.2. Initiatives Supporting Food Waste Management

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 [40].

NEA initiated a call for proposals in 2021 as a component of the National Innovation Challenges, in partnership with other organizations. 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. The objective is to establish resilient on-site food waste treatment systems that efficiently utilize limited space while producing valuable outputs [41].

The annual Sustainability Open Innovation Challenge (SOIC), which was launched by Enterprise SG (ESG) in 2021, invites innovative ideas for the collaborative development of sustainable solutions [42]. Another new initiative, The Hungry for Change Challenge was launched in 2022 by 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. Through promoting cooperation and stimulating creative ideas, these initiatives enhance the development of a more sustainable ecosystem for managing food waste [43].

The NEA and the Singapore Food Agency (SFA) collaborate 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 start-ups to effectively navigate different technologies for treating food waste [44].

It is crucial to increase public consciousness regarding food waste management. The third ‘Say YES to Waste Less’ campaign was launched by NEA in September 2021 [45]. The campaign advocates for individuals to purchase an optimal quantity of food in order to minimise any unnecessary waste. They are encouraged to only acquire essential items to prevent an excess and deploy reusable containers to reduce packaging waste. Nevertheless, the exploration and promotion of upcycling

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food waste at the individual and household level should be examined and encouraged in order to optimize the utilization of food waste, given that the majority of food waste in Singapore originates from households.

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. The collaboration between the government, businesses, research institutions and individuals has the potential to establish a food system that is both sustainable and secure, ensuring its longevity for future generations. This is not solely focused on adhering to rules and regulations, but rather on actively influencing a future where we place importance on our resources and 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.

Food waste valorisation 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 the 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.

Ultimately, Singapore can effectively address environmental concerns, capitalize on economic prospects, and enhance food security resilience by prioritizing the utilization of food waste. By employing strategic planning, innovation and collective action, Singapore has the potential to lead the way towards a future that is both sustainable and resilient for future generations.

Conflicts of Interest: The author declares no conflict of interest.

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