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Valorization of food loss and waste: Sustainability practices to support circular economy

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Abstract: One-third of global food that is specifically produced for human consumption is lost and wasted along the food supply chain. This has become a global issue as its amount is projected to increase following the growth of the world population. FLW contains valuable components that can be valorized into a range of products for various applications. Managing FLW through valorization is considered one of the pathways to reduce the burden on the environment and support circularity in food systems. Thus, the development of innovative methods to capture the FLW value has received much attention. This review aims to provide an overview of various studies on FLW valorization to date. An attempt has also been made to explore the best practices and challenges of valorization to support the circular economy. The FLW valorization studies have progressed rapidly, including the innovation to produce bio-based materials, food ingredients, nutraceutical products, compost, and bioenergy. As combined with an economic model, the valorization of FLW can also broadly impact the economic and social aspects; thus, contributing to the transition toward the circular economy. Thereafter, several studies have also addressed challenges to valorizing FLW in the circular model; among them are the access to FLW availability data, investment, logistics, policy and regulation, and customer acceptance toward secondary material-based products.

Keywords: Circular economy, food loss, food waste, valorization.

1. Introduction

Enormous food loss and waste (FLW) is generated daily and is considered a substantial contributor to overall waste generation. In the global scope, one-third of food is estimated lost and wasted throughout the supply chain [1]. Food is defined as any edible substance, either processed, semi-processed, or raw, aimed for human consumption [2]. Correspondingly, FLW refers to food that is removed from the food supply chain due to the reduction in its quantitative or qualitative value [3-4]. Furthermore, FLW can be differentiated based on the stage within the food supply chain. Food loss typically occurs during production, post-harvest, storage, and processing stages, whereas food waste occurs at the retail and consumption stage [5]. Food loss represents the unintended result (e.g., discarded, lost, or degraded) during the process of producing food. Meanwhile, food waste results from negligence or a deliberate decision to discard the food deemed fit for human consumption [4]. Food removed from the supply chain due to mechanical damage, spilled or spoiled due to inefficient processes or management, degraded by pests or diseases, and off-grading products are among examples of food loss. While foods that are discarded by consumers or retailers due to their expiry dates, unused or leftover foods, and foods that spoiled during storage, are some examples of food waste [4-5].

Approximately 14% of food is lost in the global food system and around 17% is wasted [1, 6]. In addition, global food production is projected to increase by approximately 25%-70% to meet the demands of the world population of 10 billion people by 2050 [7], which certainly becomes a concern as the FLW will increase accordingly. FLW indicates burden on the environment and inefficient use of resources. Improper disposal of FLW could lead to environmental problems such as air and water pollution, resource depletion, and biodiversity loss [1]. It is also estimated that FLW contributes to 8-10% of global greenhouse gas emissions [6]. Thus, managing FLW is necessary to reduce the negative impact on the environment.

FLW contains valuable components that can be valorized into new products for various applications, such as biobased materials, bioenergy, food ingredients, and compost [8]. Valorization through recycling and recovery are part of FLW management, which the innovation receiving much attention and continuing to develop. The valorization option also plays a role in supporting the circular economy since it aims to give a new life to FLW. One of the concepts of circular economy is substituting the linear economy pattern of production and consumption by adopting circularity strategies. With the proper implementation of the circular economy concept, FLW generated in the food supply chain could be valorized and is strived to be the secondary resource input for other economic activities and kept in closed loops as long as possible. Moreover, transitioning to a circular economy through FLW valorization may also benefit economic and social aspects by giving opportunities for innovative economy, jobs, and livelihood [9-10].

This review article aims to provide a review on the various studies of FLW valorization. In theory, several studies have addressed how innovation on FLW potentially create various added-value products. However, in practice, transition to circular economy through FLW valorization is arduous due to its complexity.

Therefore, an attempt was also made to provide information related to successful cases of valorization initiatives along with the challenges encountered in supporting the circular economy.

2. Hierarchy of Food Loss and Waste Management

The waste management hierarchy shows the preferred order of actions to manage waste. As the interest in tackling FLW increases, the management hierarchy has also been adapted. Figure 1 presents the hierarchy of FLW management that has been summarized from several sources [11-17]. There are several types of hierarchy in FLW management using different terms. Nevertheless, this article refers to the widely known pyramid ranks for solid waste management, starting with prevention, reuse, recycling, recovery, and disposal [11, 14, 16-17].

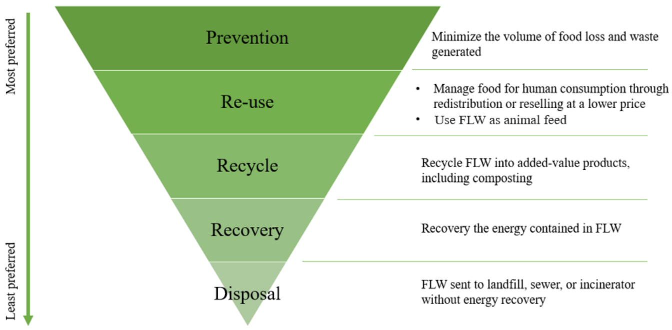

Figure 1. Food loss and waste hierarchy.

Prevention is placed at the top of the pyramid as it is the most desirable action, favoring the prevention of FLW generation throughout the food supply chain [11-17]. The prevention actions include developing better logistics, research, and development for efficient production or innovative packaging, and management to support efficient production or through educational campaigns to encourage sustainable consumption [14-15].

The second tier is re-use, which represents action to manage food that is still fit for human consumption to be consumed in its original form. Re-use primarily aims to keep edible food edible and provide those in need access to food. This action includes redistribution to food donations or shelter and reselling food at lower prices [18]. However, in several sources, re-use also includes using certain FLW as animal feed [14, 16-17]. Due to the nature of the food, which is easily contaminated and degraded, re-use is strictly subjected to safety and hygiene policies that are exclusively acceptable for human consumption. Similarly, FLW should meet animal feed safety regulations if re-using as animal feed becomes an option.

Recycle is placed at the third tier of the hierarchy. Recycle in FLW management can be described as an action to maintain the high value contained in the FLW through certain processes and transform it into products with additional value [17]. FLW can be re-processed to create products such as biomaterial, bio-chemicals or others that can be used in different fields of industry. In several sources, processes such as composting and anaerobic digestion without energy recovery are included in recycling options [11, 13-14]. Another source, however, uses the term nutrient recovery to describe the recovery of substances contained in FLW for low added value uses through composting and anaerobic digestion [15, 17].

The fourth tier of the FLW hierarchy represents a recovery of energy contained in FLW through the process such as incineration, anaerobic digestion, and fermentation. In this pathway, bioenergy and biofuel, such as biogas, heat, and bioethanol, are desired to be produced.

The final and least preferable option in the management of FLW is disposal. In this option, FLW will either be disposed to a landfill, incinerated without energy recovery, or go to the sewer [12-14].

3. Valorization of Food Loss and Waste

While keeping the edible food edible through prevention and reuse is the priority in FLW management [15], however, FLW will still be generated nevertheless. FLW management through recycling or recovery becomes another option that is preferred to choose. Moreover, some factors, such as management limitations or strict safety and hygiene standards, often make the options of valorization, i.e., recycling and recovery, become more viable. Thus, many studies have attempted to show the potential of transforming FLW into valuable products through various methods and technologies. Furthermore, the inedible parts of FLW (e.g., seed, peels, bones, pit), which become an integral part of FLW in certain cases, also shows potential to be valorized and are thus is included in this section. Table 1 summarizes the pathways of FLW valorization.

3.1 Recycling Food Loss and Waste

FLW consists of high value components, one of which is biomolecules, i.e., polysaccharide (cellulose, starch, chitin, chitosan, pectin), protein (collagen, keratin, gelatin), and lipid. These biomolecules contained in food products offers several potential benefits, including the production of biobased and biodegradable polymer [20-24]. The study of biopolymer derived from biomass are increasingly gaining importance and attention, especially in their application as food packaging. The starch contained in cereals (maize, wheat, or rice) and tubers (cassava or potato), for example, have been investigated in several studies as prospective raw materials in edible films and coatings preparation and their benefit as food packaging [25-26]. In one study, heterogeneous food waste collected from a cafeteria also showed potential in the production of bioplastic through microbial fermentation, i.e., polyhydroxyalkanoates (PHA) [27]. Furthermore, the inedible part of FLW also shows potential to be converted into biomaterial. For instance, muscles, skin, and scales of fish have shown potential as a material for food packaging as the extracted proteins (i.e., stromal and myofibrillar) are reported to have the ability to form a biodegradable film [20, 28]. Interest is also growing in utilizing minerals (calcium) contained in food products for bioceramics production. Fish bones, for example, show potential applications in the medical industry as the luminescent calcium phosphate (CaP) contained in the bones has similar features to the apatite compound that can be treated as bioceramic [29]. In addition, eggshells which are the inedible part of egg, combined with dicalcium phosphate dihydrate or calcium pyrophosphate, also show potential in the application as calcium phosphate bioceramics [30]. Besides biomaterial, eggshells in powder form can also be utilized in construction materials applications, for example as cement replacement, soil stabilizer, or alkali-activated binder [31].

Furthermore, numerous studies have also investigated the potential of producing specific extracted proteins, bioactive compounds, and dietary fibers from food products. Protein extracted from several plant sources such as oil crops (olive) [32], cereals (wheat, maize, and rice) [33-35], and legumes (soybean) [36] have been widely studied and reported to have potential use in various application, e.g., food, feed, plastics, textiles, and adhesive. Besides plants, animal-based proteins have also been reported to offer applications in industries. For instance, protein extraction from egg white and egg yolk has been investigated extensively and is claimed to have several beneficial properties. The egg white protein has several features, including foaming, gelling, and emulsifying, that can be applied to produce aerated food products [37]. Additionally, the protein isolated from egg yolk granules, a fraction obtained from centrifugal separation can also be used in several applications, such as a foaming and emulsifying agent, source of folate, material of edible films, or as encapsulating agent [38]. The extraction of protein from food loss generated in livestock and poultry industry, such as pork lungs, beef lungs, and mechanically deboned chicken meat also have been investigated and examined using a method that is easy to scale up [39]. The extracted protein was also reported to exhibit better functional properties than some commercialized products. Furthermore, there is a growing trend in functional and nutraceutical products marketed for bioactive compounds. Using various extraction techniques, bioactive compounds can be recovered from the inedible parts of vegetable and fruit, such as peels, pomace, trims, stems, and seeds. Tomato skin and pomace, for example, contain carotenoids that can be extracted through various methods [40]. Some studies also evaluated the extraction performance of carotene and pectin contained in carrots using water-induced hydrocolloidal complexation, a green and simpler method, and showed a promising result [41]. Besides bioactive compounds, carrot peel can also be utilized as an antioxidant high dietary fiber powder through drying and blanching [42]. The potential extraction of other bioactive compounds, such as essential oil and flavonoids derived from citrus (i.e., mandarin, sweet orange, lemon, grapefruit) peels, also have been widely studied [43-44]. In recent studies, however, essential oils are also explored as additional agents in active food packaging production [45]. The essential oils work as natural antimicrobial hydrophobic substances to increase the function of edible film and coating in preserving food quality [46].

Another valorization pathway is also explored in the meat supply chain through the rendering process. The fatty animal tissue in meat can be processed into saleable products such as edible fats and proteins (e.g., lard, edible tallow), which often used to make gelatins or cosmetics [47]. The rendering process could also process inedible parts of meat such as bones and blood into inedible tallow, grease, blood meal, or bone meal. The inedible tallow and grease can be used as feed or for soap production [48].

Table 1. Overview of food loss and waste valorization options.

Valorization Option	End Product	Source	Method	Reference
Recycling	Biopolymers (bioplastic)	Starch from cereals (maize and rice)	Starch extraction and casting	[25]
		Starch from tubers (cassava and potato)	Starch extraction, polymerization, molding	[26]
		Food scraps from cafeteria	Fermentation	[27]
		Muscle, skin, and scales of fish	Chemical extraction, solution castings or compression molding	[20, 28]
		Pineapple leaves	Fiber extraction, coating and pressing for textile	[62]
	Bio-ceramics	Fish bones	Thermal calcination	[29]
		Eggshell	Solid state reaction produced by heat treatment	[30]
	Protein	Oil crops (olive)	Chemical extraction	[32]
		Cereals (wheat, maize and rice)	Chemical extraction	[33-35]
		Legumes (soybean)	Physical, enzymatic, alkaline extraction	[36]
		White egg	Physical, enzymatic, alkaline extraction	[37]
		Egg yolk granule	High hydrostatic pressure extraction, depolymerization and delipidation by ultrasound	[38]
		Slaughterhouse byproducts	Conventional extraction	[39]
		Meat scraps, bones, blood	Rendering	[47-48]
	Fats	Meat scraps, bones, blood, feather	Rendering	[47-48]
	Dietary Fibers	Carrot peels	Blanching and drying	[42]
	Bioactive Compounds:			
	Carotenoids	Tomato skin and pomace	Conventional extraction	[40]
	Carotene and Pectin	Carrot	Water-induced hydrocolloidal complexation	[41]
	Essential Oil	Citrus	Extraction and purification	[43]
	Flavonoids	Citrus	Conventional extraction, Ultrasound assisted extraction, Supercritical fluid extraction	[44]
	Upcycled Food:			
	Beers	Bread	Brewing	[49]
	Condiment	Tomato, apple	Food preservation in a solution (e.g., vinegar)	[50]
	Dried Product	Fruit and vegetables	Drying/freeze drying	[51]
	Compost and Fertilizer:			
	Compost	FLW collected from entire FSC	Composting	[75]
	Fertilizer	Food waste anaerobic digestate effluent	Anaerobic digestion	[53]
		Food waste biogas slurry	Anaerobic digestion and solid liquid separation	[54]
Energy Recovery	Biogas	Canteen food waste	Anaerobic digestion	[56]
		FLW collected from entire FSC	Anaerobic digestion	[75]

The production of upcycled food from FLW is another concept that has also been explored. Bread that is lost and wasted throughout its supply chain can be utilized as the main ingredient to produce beer [49]. There have also been attempts to use FLW as ingredients in condiments, like apple chutney made from unaesthetic apples and tomato relish made from tomatoes lost in the production stage [50]. The production of dried snacks made from fruits and vegetables that are slightly bruised, overripe, or otherwise imperfect can also be an alternative for FLW management [51].

Another pathway of FLW valorization is by recovering the nutrients through composting and anaerobic digestion. Even after all the actions have been made to valorize FLW for industrial uses, some edible and inedible parts will still exist and need to be managed. FLW as an organic material can be easily decomposed into high-quality compost. In composting, microorganisms use the organic components in food waste and degrade them into short-chain chemicals. Organic waste could be composted through several methods, such as in-vessel, conventional static, turned heap, and windrow composting [52]. Meanwhile, in anaerobic digestion, the process creates digestate effluent with potential benefits. Digestate effluent generated from canteen food waste, for example, has been investigated and shown promising potential as fertilizer [53]. Another study also reported the use of biogas slurry from food waste anaerobic digestion as fertilizer [54].

3.2 Energy Recovery from Food Loss and Waste

FLW has considerable potential for biomethane production due to its organic matter content [55-57]. The biological treatment technologies, including anaerobic digestion and microbial fermentation, have been long studied to generate bio-fuels from FLW. Such techniques have been known to effectively handle high moisture content in FLW and generate minimum emissions [58]. The methane potential of some specific sources such as fruit and vegetable, fat-oil-grease, FLW generated from the slaughter house industry, dairy industry, restaurants, and households have been investigated in numerous studies [59]. In addition, the methane yield is reported to be higher than common anaerobic digestion substrates such as animal manure and sewage sludge in some studies. Furthermore, organic fractions in municipal solid waste could also be used as secondary material for biogas production [55]. Additionally, bioenergy can also be generated from organic material through incineration. However, this technology is less preferable since the important functional groups may be removed from the treated feedstocks.

4. Food Loss and Waste Valorization and Circular Economy

A circular economy is an economic paradigm that aims to minimize pollution and waste by extending the product life cycle [60], with the environmental, economic, and social aspects being the main impact areas. In relation to the circular economy, valorization is known as one of the pathways that enables FLW to return to the agri-food system. By valorizing FLW, there are income prospects from new markets and brand value improvement. As described in the previous section, the opportunities to create various added-value products from FLW are numerous. But in practice, moving towards a circular economy needs execution through innovative business models, a collaboration between agri-food value chain actors, also certain investment and incentive structures to open economic and social growth.

The concept and the shift to a circular economy requires a mindset and business processes that seem daunting to many. Transitioning to a circular economy also means tailoring the valorization pathways to local contexts where the business is developed, including the availability of FLW, government regulations, and demand for particular added-value products. Creating a desired circular system is arduous, and more efforts are needed to transition from conceptualization to implementation. Despite these hurdles, several reports have provided information about the evolving FLW valorization in practice and its progress toward a circular economy.

For example, one company in Australia has successfully transformed dumped bananas into gluten-free flour, resistant starch dietary fiber, and anti-bacterial, anti-fungal, and anti-inflammatory ointment [14]. This innovation has turned 500 tonnes of unmarketable bananas per week in Australia into profitable products. To make the business viable, the company develops their own machine and technology [61]. The business also evolves into a new market for banana growers as another marketplace for their produce. In the United Kingdom, a start-up company adds economic value to pineapple leaves by transforming them into a non-woven material [62]. An effort to gain environmental and social benefits is also made by using non-hazardous chemicals, applying fair trade principles, and creating job opportunities for the local farming community.

Successful implementation of circular economy principles by producing upcycled food is done by a start-up company in the United Kingdom (UK) that uses surplus bread as replacement of barley to produce brewing beers [49]. Approximately 44% of bread made in the UK are wasted and the company is reported able to salvage over 2 million pieces of it. To make the business work, the company make a collaboration with delis, bakeries, and sandwich makers to supply their unused bread and pay them with fair price. Furthermore, one company based in the United States turns food loss into dried fruit and able to sell them in the global market [63]. By doing this, the company claims to avert over 74,500 kg of fruit from being lost. The company also tries to strengthen the local communities by working with smallholder farmers and providing them with additional income and on-the-job training.

Another circular economy practice is shown by EU-27, Norway, Switzerland, and UK through valorizing bio-waste, which include FLW, into compost [64]. Around 66% of bio-waste is treated through composting and the products are circulated with economic value. The composting sector was also found to employ 11,000-18,000 full-time equivalents with an estimated contribution of USD 80 per tonnes to the gross domestic product. Furthermore, Smart Prosperity Institute also reported numerous successful practices toward circular economy in the recycling sector [65]. One company in Canada, for example, reportedly uses food waste as feed for black soldier flies, then the flies is converted into products such as microbiome for soil, liquid biofertilizers for aquaponic, and feedstocks. Using the same method, one company in South Africa also produces nutrient-rich compost and feed. Furthermore, a company in South Australia also reported successfully processing food waste generated from hotels, restaurants, schools, and manufacturers around Australia into a valuable source that can be added to soil conditioners, compost, and biofuels [14].

5. Challenges of Food Loss and Waste Valorization for Circular Economy

Although businesses and initiatives worldwide are progressing in developing a circular economy, transforming the food systems towards circularity is challenging. It requires innovative business models, effective coordination and strong commitment among stakeholders, and certain incentive systems [66-67]. Failure to create a circular food system can happen due to several barriers immanent in economic, social, policy, and technological aspects [68]. To summarize, Table 2 presents the challenges in implementing a circular economy through the valorization pathway.

Many innovations in FLW valorization have been analyzed, yet the application is mainly at the laboratory scale [69], with only a few levels up to the pilot scale, limiting the projection on the commercial level. Numerous studies also found to focus more on the technical aspect with less discussion on the environmental, economic, and social aspects; thus, the sustainability performance has yet been assessed comprehensively. In practice, lack access to new technology is often encountered by initiative actors and become an issue [70]. Acquiring quality of FLW that meets the standard for valorization is also addressed as another issue encountered in practice. FLW can deteriorate very quickly, requiring a proper handle to meet specific standards as raw material, especially if the end-product is intended for human consumption. Hence problems such as deficiencies in transportation and logistics aspects [71], and a lack of knowledge of procedures for handling the FLW could significantly undermine the quality of FLW. Additionally, recycling FLW into new products is considered a more complex task since some pathways need a specific type of FLW with standardized quality. As an example, by-product from plant foods is said to have not been fully utilized as phenolic compounds sources by the industry due to concerns about microbiological safety, toxins produced from fungi and bacteria, and potential pesticide residues [72]. In this regard, strict hygiene and safety issues are also strongly related to the utilization of FLW as materials. Similarly, microbial contamination has become a significant issue for seafood products that may affect their potential use [73-74]. Furthermore, general FLW composition is highly heterogeneous; thus, segregation and collection systems could play a significant role in the valorization practices that require particular types of FLW [75]. In the case of composting, the hassle of removing food from its common contaminant, such as packaging, may influence profitability due to the cost spent on pre-and post-processing [75-76].

Furthermore, in the business aspect, the lack of transparent information on FLW availability also becomes another barrier that could hinder the future development of FLW valorization on a larger production scale. In this regard, a standardized form of generating and sharing specific data among stakeholders, including the total amount of FLW, is needed [66]. Some innovations also require extensive funding because of high investment and commercial production costs [77]. Unfortunately, in several cases, funding opportunities are still limited, which makes the circular economy practices hard to implemented or remain mainly on a small scale [78]. In addition, the technology risk remains, especially for innovations that require new technology despite being fully scalable.

Regulations and policies are also one of the challenges encountered. This aspect is known to have a significant role in advancing the circular economy. They can, for example, change the supply and demand of materials and the production requirements [79] or simplify administrative procedures across institutions to encourage investment. However, in practice, many organizations feel the policies and regulations still lack enforcement to put pressure on the demand for circular economy solutions [79]. Nevertheless, there are some compelling regulation examples that have been implemented in several countries to induce more circularity actions in the context of FLW management, such as stricter regulation on gate fees or disposal bans of organic materials to landfills [79-80]. Furthermore, the lack of well-structured incentive schemes by the government becomes another critical challenge for circular economy adoption [81]. Introducing incentives that drive circularity on all policy levels could effectively stimulate the motivation of the actors involved. Favor environmental labeling and certification, modulation of Extended Producer Responsibility (EPR) fees, tradable recycling credit schemes, and subsidies, among others, are examples of incentives that have been implemented to boost the circular economy [82]. Furthermore, in the case of energy recovery innovations, the low price of fossil fuels could obstruct the renewable energy market. Thus, regulations to decrease the price of secondary materials, such as taxation on unsustainable materials or energy, are desired.

Another challenge encountered is determining factors such as the market price that influence the profitability of the valorization initiative [83]. Furthermore, the shift to circular models also needs solid public consensus to make it viable [84]. Public awareness of the full benefit of secondary material-based products is important to increase acceptance and demand [85]. Perception of product quality also becomes another issue, mainly if it is marketed as food. The commercial success of upcycled food, for instance, is said to depend strongly on consumer perception. A study found that many consumers still have concerns and are reluctant to consume food made from discarded ingredients despite full awareness of the benefit [86]. Hence, initiatives are required to enhance the perception of quality, which can be

Table 2. Challenges in creating a circular food system

Aspect	Challenges	References
Innovations and Technologies	• Innovation viability for the commercial aspect • Access to technology	[69-70]
Infrastructure and Logistics	• Adequate collecting and segregation system, and infrastructure • FLW handling procedure • Strict hygiene and health considerations	[69], [73-76]
Business Development	• Transparent information on FLW availability • High investment • Access to funding	[66], [67] [70], [77], [78]
Policy and Regulation	• Policies to support and develop circular economy • Less enforcement of legislation and regulations • Lack of policy harmonization	[79-82]
Market	• Public perception, awareness and acceptance towards secondary material-based products • Market price that influences the profitability of the valorization initiative	[70], [83-86]
Collaboration Between Stakeholders	• Level of engagement between stakeholders • Platform for information exchange between stakeholders	[66], [82]

accomplished such as through marketing communication and the presence of a certification label [86].

Defining and implementing a new circular model through FLW valorization also requires significant commitment, coordination, and communication among stakeholders [66]. For instance, developing long-term partnerships with FLW producers is essential to secure continuous raw material supply. Enhancing partnerships that share investment, risks, and rewards is another example of the collaboration needed in practice. Furthermore, due to the high connectivity and interdependencies of actors within the food system, ineffective communication among stakeholders can easily happen. Hence, the availability of a platform for exchanging information and technology is also important to ensure the ease and flexibility of circular practices. In this regard, platforms for sharing assets and for increasing other relevant information flow across the value chain need to be provided. One example, the European Commission and the European Economic and Social Committee creates the European Circular Economy Stakeholder Platform, a joint initiative for stakeholders that are active in the circular economy to share opportunities and scale up solutions [82].

6. Conclusion

FLW valorization is considered one of the pathways to design circularity in food systems. Numerous studies have been conducted to find various innovative options that can capture the FLW value, such as by producing biomaterials, extracting organic compounds, and molecules for the pharmaceutical, cosmetic, medical, food industries, producing compost, fertilizer and bioenergy. Valorization is an example of sustainable practice as it reduces the dependence on non-renewable resources and minimizes waste generated in landfills. As it combines with the economic model of circular economy, the FLW valorization could drive new revenue streams and gain social benefits. Numerous cases have shown how FLW valorization are evolving and positively in supporting circular economy. Therefore, practicing FLW valorization for circular economy is challenging since it relies on significant commitment, coordination, communication among stakeholders, and new business models. Several barriers are immanent in economic, social, policy and regulation, collaboration, and technological aspects. Policies and regulations that can support businesses to develop innovative business models, as well as the system and infrastructure to secure the quantity and quality of FLW, a high engagement between stakeholders, and acceptance of customers toward products derived from secondary materials, are some challenges addressed.

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