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Seafood Restaurant Food Waste: Quantification, Causes, Valorization, and Circular Economy

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Abstract

Seafood restaurants generate significant food waste due to the high perishability of fish and shellfish, operational inefficiencies, and stringent quality standards. Globally, 30–35% of seafood is wasted, with 25–60% of raw mass discarded as heads, bones, viscera, and shells. The supply chain faces additional challenges, including rapid spoilage and cold-chain dependency, intensifying storage and preparation losses. Studies indicate that 45% of seafood restaurant waste occurs during preparation, 30–34% from plate leftovers, and 20–25% from poor storage management. The environmental impact is considerable, contributing to methane emissions and resource depletion, while, economically, seafood restaurants lose up to 54.5% of potential revenue due to poor waste management. Seafood waste holds valorization potential, such as chitosan from crustacean shells, gelatin and collagen from fish bones and scales, biodiesel from residual fish oil, and bio-nanocomposites for sustainable packaging. Emerging circular ecsonomy models integrate prevention, redistribution, and valorization, aligning with sustainable development goals. This review synthesizes over 50 studies, highlighting that integrated interventions—operational redesign, consumer nudging, staff training, policy incentives, and valorization technologies—can reduce seafood restaurant waste by 30–50%, while unlocking economic and environmental benefits.

Keywords: Circular Economy, Food Waste, Seafood Restaurants.

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INTRODUCTION

Food waste represents one of the most pressing challenges within the global food system, threatening food security, economic stability, and environmental sustainability. Globally, approximately 1.3 billion tons of food are wasted annually, generating an estimated 3.3 gigatons of CO_2-equivalent emissions—about 8% of total global greenhouse gas emissions (Kilibarda et al., 2019). Restaurants play a substantial role in this issue. In the United Kingdom, restaurants and catering services generate 1.6 million tons of waste annually, including 600,000 tons of food waste (Christ & Burritt, 2017). In the United States, restaurants discard an average of 33 pounds of food waste for every USD 1,000 in revenue, translating into an economic loss of USD 162 billion per year (Blum, 2020). In China, restaurant food waste reaches 40 million tons per year, while in Indonesia, food waste from restaurants, hotels, and catering services amounts to 20.9 million tons annually, equivalent to 4–5% of the nation's GDP (Maswadi et al., 2024).

Seafood is one of the most economically valuable and nutritionally rich food commodities, yet it is also among the most vulnerable supply chains to waste. FAO data indicate that global seafood production reaches approximately 178 million tons per year, of which 30–35% is lost or wasted along the supply chain—from post-harvest and distribution to restaurant consumption (Zhan et al., 2024). Unlike other commodities such as grains or vegetables, seafood is highly perishable, requiring complex cold-chain logistics, stringent food safety standards, and significantly faster stock rotation in restaurant kitchens. These characteristics make seafood restaurants culinary hubs and major food waste generators, particularly in coastal tourism areas. Seafood restaurants are the final link in the seafood distribution system, bridging fishermen's catches with end consumers. Unlike general restaurants, seafood establishments depend heavily on fresh daily catches, leading to fluctuating stock levels. Moreover, restaurants often reject fish or shellfish due to minor visual imperfections—despite being perfectly edible—causing additional waste at the raw material reception stage. Seafood preparation in restaurants produces two simultaneous waste streams: kitchen preparation waste, including fish heads, bones, scales, crustacean shells, and unused viscera; and plate waste from uneaten food left by consumers.

Seafood waste in restaurants is not merely a technical problem but also intersects with social, economic, and cultural dimensions. Environmentally, discarded seafood sent to landfills generates methane emissions, accelerates eutrophication in coastal waters, and wastes natural resources such as water, fuel, and fishing. Each kilogram of wasted seafood equates to the loss of three to five liters of water and the labor and energy

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expended in harvesting and distribution (Roy et al., 2023). Economically, seafood is a high-value source of protein; thus, waste in seafood restaurants significantly impacts business revenue. Studies focusing on seafood restaurants reveal that economic losses due to poor waste management can reach 42–54.5% of potential restaurant revenue (Theogene & Ernest, 2023). Socially, seafood is rich in essential nutrients, such as omega-3 fatty acids, crucial for human health. Ironically, these highly nutritious and valuable products are discarded while many coastal communities experience protein deficiencies and malnutrition. Unique risk factors also drive the vulnerability of seafood restaurants to generating waste. Seafood spoils extremely rapidly; fish and shellfish can deteriorate within hours if there are slight deviations in storage temperature. Their high moisture content accelerates microbial growth, requiring restaurants to enforce strict protocols for discarding unsafe materials. Hygiene and aesthetic standards—especially in premium seafood restaurants—further amplify waste volumes, as edible portions of fish are often discarded simply to achieve perfect fillet presentation. Additionally, consumer dining patterns in seafood restaurants, particularly buffet-style or all-you-can-eat formats, tend to encourage over-serving, resulting in significant plate waste.

Global policies addressing food waste reduction are evolving, but remain limited in specifically targeting seafood restaurants. In the European Union, the Circular Economy Action Plan promotes the utilization of seafood by-products, but these policies primarily focus on the processing industry rather than the restaurant sector. In China, the "Clean Plate" campaign aims to reduce food waste, yet the cultural tradition of large seafood banquets continues to generate substantial waste. Countries such as Indonesia and Thailand lack structured logistics, seafood donation, or recycling regulations. Consequently, seafood restaurants remain a policy blind spot in many coastal tourism economies. Reducing seafood restaurant waste is closely linked to sustainable development agendas. Halving seafood waste directly supports Sustainable Development Goal (SDGs) 12.3, which targets a 50% reduction in food waste by 2030. Moreover, reducing seafood waste contributes to SDG 14, which focuses on conserving marine life by alleviating pressure on overfished stocks. Indirectly, waste reduction also lowers greenhouse gas emissions, aligning with SDG 13 on climate action. The high potential of seafood waste also presents opportunities for circular economy approaches: unused portions can be processed into value-added products such as chitosan, gelatin, biodiesel, and even bio-nanocomposites for biodegradable packaging (Zhao et al., 2022; Boronat et al., 2023; Shalma et al., 2023). Seafood restaurants can transform from mere waste generators into key nodes in an environmentally friendly bio-circular economy.

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This study aims to understand seafood restaurant waste through five focal areas comprehensively. First, it measures and analyzes the scale of seafood restaurant waste globally and regionally. Second, it explores the causes and behavioral patterns specific to seafood restaurant contexts. Third, it summarizes tested mitigation strategies at the operational level, consumer behavioral interventions, and public policy measures. Fourth, it discusses promising valorization pathways for seafood waste, ranging from biodiesel production and chitosan extraction to collagen and gelatin recovery. It examines circular economy models relevant to seafood restaurants and how their implementation can reduce waste while creating added value. By integrating findings from more than fifty studies, this paper seeks to provide evidence-based practical guidance for restaurant operators, policymakers, and researchers working in sustainable food supply chain management.

SCALE AND IMPACT OF FOOD WASTE IN SEAFOOD RESTAURANTS

Global Scale

Restaurant food waste is a widespread problem across the globe. It is often linked to consumer behavior and oversized portion sizes in developed countries. In the United States, restaurants discard 33 pounds of food for every USD 1,000 in revenue (Blum, 2020). In the United Kingdom, the restaurant and catering industry generates 1.6 million tons of waste annually (Christ & Burritt, 2017).

In Asia, the scale of the problem is equally alarming. In China, restaurant food waste reaches 40 million tons per year. In contrast, Thailand's hotel and restaurant sector faces waste management challenges due to high operational costs, consumer habits, and inadequate staff training (Kattiyapornpong et al., 2023). Food waste from Indonesia's restaurant and catering sector has become a significant concern. Recent analyses reveal that Bali has the highest per capita food waste from consumption (201 kg/year), followed by Central Java (164 kg/year) and West Java (137 kg/year) (PAGE, 2024).

Environmental, Economic, and Social Impacts

The impacts of restaurant food waste encompass three interconnected dimensions:

1. Environmental Impact: The decomposition of food waste produces methane gas, a potent greenhouse gas that significantly contributes to climate change.

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2. Economic Impact: Restaurants incur costs for purchasing, preparing, and disposing of food that generates no revenue. For example, in the United States, this equates to USD 162 billion annually (Blum, 2020).
3. Social Impact: There is a stark contradiction between the large quantities of food wasted and the persistent problem of hunger and malnutrition.

Table 1. The Scale of Food Waste in Restaurants Based on Literature.

Title/Scientific Scope	Key Findings	References
Global Operational Assessment of Restaurant Food Waste Generation	*45% waste during prep, 34% from plate leftovers, 21% storage errors; 40M tons in China, €682M management cost in UK*	*Mendoza & Felicen (2024)*
Food Waste Management Practices in Five-Star Hotels in Thailand	*Hierarchy of prevention, reuse, recycling; barriers include cost, consumer habits, lack of staff training*	*Kattiyapornpong et al., (2023)*
Consumer Behavior and Food Waste in Indonesian Restaurants	*20.9M tons/year restaurant & catering food waste; 4–5% GDP lost; behavior prevention strongly affects waste reduction*	*Maswadi et al., (2024)*
Economic Impact of Food Waste in U.S. Restaurant Operations	*33 lbs of food waste/US$1,000 revenue; USD 162B annual loss*	*Blum (2020)*
Waste Streams in UK Catering and Restaurant Industries	*1.6M tons waste/year, including 600K tons food waste*	*Christ & Burritt (2017)*
Regional Analysis Indonesia	*Bali has the highest consumption of waste (201 kg/year), Central Java 164 kg, West Java 137 kg*	*PAGE (2024)*
Green Cities Case (Multiple)	*25–75K lb/restaurant/year; only 14.3% recycled; 84.3% landfill*	*Tehrani et al., (2020)*

CAUSES OF FOOD WASTE IN SEAFOOD RESTAURANTS

Food waste in seafood restaurants arises from various factors widely discussed in the literature. A recent study by Mendoza and Felicen (2024) indicates that, in restaurants

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in general—including seafood establishments—approximately 45% of waste occurs during the preparation stage, 34% originates from consumer plate waste, and storage errors cause 21%. These figures are particularly relevant for seafood restaurants, where raw materials require more complex processing than in typical restaurants. Research by Zhan et al. (2024) confirms that seafood has a disproportionately high proportion of waste, accounting for 30–35% of total production. When analyzed by product type, crustacean shells contribute 30–40% of the discarded fresh weight, while fish heads, bones, and scales represent 25–60% of the raw material weight. This demonstrates that seafood restaurant filleting, trimming, and aesthetic plating processes directly generate large volumes of preparation waste.

Additionally, Boronat et al. (2023) found that during fish processing, up to 70% of the fish's total weight is not utilized as the primary restaurant menu item, while bones and scales alone contribute an additional 14–20% of waste. This problem is exacerbated by premium seafood restaurant consumers who demand only the finest cuts of meat—such as for sashimi or fillet menus—leading to the immediate disposal of other parts that retain nutritional value. Consumer behavior is also a key driver. Huang & Tseng (2020) found that over-ordering, especially in the context of large banquets, is one of the main reasons for plate waste. This behavior is reinforced in seafood restaurants by the visual appeal of seafood buffets and all-you-can-eat menus, encouraging guests to take portions beyond their actual consumption capacity. Similar findings were confirmed by Kattiyapornpong et al. (2023) in five-star hotels in Thailand, where over 50% of seafood restaurant waste originated from untouched buffet food.

Internal restaurant factors also play a significant role. Theogene & Ernest (2023) showed that a lack of staff training, surplus food donation protocols, and weak monitoring systems caused restaurants to lose up to 42.4% of revenue in one seafood hotel and 54.5% in another seafood lounge. Kattiyapornpong et al. (2023) further noted that the most significant challenges for luxury hotel seafood restaurants were the high costs of waste management, deeply ingrained consumer habits, and insufficient employee training in effectively managing and valorizing seafood waste. From a storage perspective, Maswadi et al. (2024) reported that in Indonesia, limited cold-chain facilities and suboptimal stock rotation led to 25% of seafood ingredients spoiling before processing. These findings align with global patterns described by Mendoza & Felicen (2024), who noted that cold-chain failures are one of the most significant contributors to seafood waste.

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When compared across regions, the literature reveals similar patterns with varying intensities. In Thailand and Indonesia, the main drivers are storage failures and overproduction for buffets (Kattiyapornpong et al., 2023; Maswadi et al., 2024). The dominant factor in Europe and North America is plate waste due to oversized portions and consumer preferences for specific seafood parts only (Christ & Burritt, 2017; Blum, 2020). However, one consistent pattern across all contexts is that seafood buffet services generate more waste than à la carte services. Therefore, based on the analyzed literature, the primary causes of seafood restaurant waste can be mapped as follows:

1. High preparation waste results from seafood's intrinsic characteristics and aesthetic demands (Zhan et al., 2024; Boronat et al., 2023).
2. Consumer plate waste is driven by over-ordering behaviors and banquet culture (Huang & Tseng, 2020; Kattiyapornpong et al., 2023).
3. Storage-related waste is influenced by infrastructure limitations and stock management (Maswadi et al., 2024; Mendoza & Felicen, 2024).
4. Internal operational factors, such as insufficient staff training and the absence of surplus food donation policies, exacerbate the situation (Theogene & Ernest, 2023).

Mitigation Strategies For Food Waste In Seafood Restaurants

The literature indicates that reducing food waste in seafood restaurants requires a multi-level approach, encompassing kitchen operational improvements, consumer behavior interventions, staff training, food donation policies, and waste valorization practices. According to Mendoza & Felicen (2024), implementing appropriate strategies can reduce restaurant waste by 20–40%. At the operational level, menu redesign and portion control have effectively reduced consumer plate waste. Blum (2020) reported that seafood restaurants in the United States offering smaller portion options achieved a 20% reduction in plate waste. Similarly, Christ & Burritt (2017) noted that inventory optimization and stricter storage management in UK restaurants and catering services decreased preparation and storage waste by 25%.

For seafood restaurants employing a buffet model, the adoption of innovative buffet replenishment technology has also shown significant results. Kattiyapornpong et al. (2023) demonstrated that five-star hotels in Thailand using real-time monitoring systems for seafood buffets reduced untouched buffet food from 40% to 22%. In addition, staff training played a critical role; the same study revealed that after specialized training for kitchen staff, seafood preparation waste was reduced by up to 15%. Consumer behavior interventions through nudging campaigns also emerged as effective strategies.

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Renfors & Wendt (2024) demonstrated that buffet-style European seafood restaurants' "Eat What You Take" campaign reduced plate waste by 12–18% within three months. Moreover, adopting pay-as-you-eat pricing models in Scandinavian seafood buffets reduced buffet waste by up to 30% (Tehrani et al., 2020).

Surplus food donation programs have also been introduced in some regions. In France, national regulations mandate restaurants to donate surplus food, and this policy reduced total seafood restaurant waste by 20% over two years (PAGE, 2024). However, food donation practices in Southeast Asia remain limited due to logistical constraints and concerns about legal liabilities. Beyond upstream reduction, some seafood restaurants have adopted upcycling strategies to repurpose preparation waste into value-added products. Yusoff et al. (2024) showed that unused fish parts, such as heads and bones, can be processed into gelatin and collagen with high economic value. Similarly, Zhao et al. (2022) emphasized the potential use of crustacean shells for producing chitosan and biodegradable packaging, which can replace conventional plastics.

These strategies demonstrate that there is no universal solution to reducing seafood restaurant waste. Instead, operational improvements, consumer interventions, staff training, and donation policies are necessary to achieve optimal results. Theogene & Ernest (2023) stressed that seafood restaurants failing to integrate multiple mitigation strategies continue to suffer significant revenue losses, reaching 42.4% to 54.5%. The reviewed literature shows that operational strategies, such as inventory optimization, storage management, and menu redesign, are highly effective in reducing storage and preparation waste. Meanwhile, consumer-oriented interventions, including nudging campaigns and flexible pricing models, effectively lower plate waste. Staff training yields additional measurable benefits, while donation and upcycling practices help redirect unavoidable waste into more sustainable value chains.

However, the literature also highlights key barriers to implementation. According to Kattiyapornpong et al. (2023), the high cost of implementing technologies such as intelligent buffet replenishment remains a challenge for many seafood restaurants, especially in Southeast Asia. Additionally, Theogene & Ernest (2023) emphasize that seafood restaurants are reluctant to invest in staff training or waste monitoring systems without economic incentives and policy support. When integrated, all mitigation strategies documented in the literature show that seafood restaurant waste reduction potential can reach 30–50%, particularly when strategies are adapted to local contexts and cultural consumption patterns.

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Valorization Technologies For Seafood Waste

Beyond waste prevention efforts, the literature highlights that seafood restaurants hold substantial potential to convert their waste into value-added products through valorization technologies. The waste generated by seafood restaurants—such as fish heads, bones, scales, skins, and crustacean shells—is rich in bioactive compounds like chitosan, collagen, gelatin, and fish oil, which can be utilized in the food, pharmaceutical, and renewable energy industries. Zhan et al. (2024) emphasized that approximately 30–35% of seafood remains unused globally, including seven to nine million tons of crustacean shells discarded annually. However, these shells are a rich source of chitin and chitosan, which are essential raw materials for producing biodegradable packaging. Zhao et al. (2022) further noted that seafood waste—particularly shrimp, crab, and lobster shells, which account for 30–40% of the wet weight—can be extracted into chitosan, gelatin, and alginate to replace conventional plastics.

Boronat et al. (2023) focused on utilizing fish parts that are typically discarded. Their study revealed that up to 70% of a fish's total weight, including bones and scales that contribute 14–20% of additional waste, can be processed into fish bone meal or gelatin, which exhibits a creamy texture at 23°C. This product can partially substitute wheat flour in specific applications without significant textural differences. Such findings open opportunities for seafood restaurants to process fish bones and scales into secondary food ingredients, such as soup bases, sauces, or raw materials for the broader food industry. More advanced technologies were explored by Shalma et al. (2023), who utilized fish waste to produce bio-nanocomposites. By combining corn starch, zinc oxide (ZnO) nanoparticles, and curcumin, they developed bioactive films that enhanced mechanical and antimicrobial properties but also extended the shelf life of food packaging. This demonstrates that seafood restaurant waste can be an innovative feedstock for environmentally friendly packaging materials.

Beyond food and packaging products, seafood waste can also be utilized for renewable energy production. Smaisim et al. (2022) showed that biodiesel can be produced from fish processing by-product oil with a yield of up to 95% at 55°C using nano-magnetic catalysts, producing biodiesel that meets ASTM D6751 quality standards. This allows seafood restaurants to redirect residual fish oil into the bioenergy sector. Furthermore, Yusoff et al. (2024) conducted a life cycle assessment (LCA) of seafood waste biorefineries. They found that up to 50% of fish waste and 80% of shellfish waste can be converted into high-value products, significantly reducing the environmental

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footprint of the sector. However, the high energy consumption during processing remains a major challenge for large-scale implementation.

A relevant circular economy approach for seafood restaurants involves integrating waste prevention, surplus food donation, and valorization of unavoidable waste (Renfors & Wendt, 2024). A circular-economy-based restaurant design can reduce greenhouse gas emissions by 25–30%, especially when seafood waste is diverted into bioplastics, bioenergy, and nutraceutical products. These valorization strategies highlight that seafood restaurant waste is not merely an unusable residue but a secondary resource with significant economic potential. Crustacean shells previously discarded as waste can become chitosan feedstock for packaging and pharmaceutical industries. Disregarded fish bones and scales can be processed into gelatin for food and nutraceutical applications. Residual fish oil can be transformed into biodiesel for renewable energy, while combined fish waste can create antimicrobial bio-nanocomposite packaging materials.

However, the literature also notes implementation challenges at the restaurant level. Yusoff et al. (2024) highlighted that while seafood waste biorefineries can significantly reduce environmental impacts, energy consumption during processing remains high. Kattiyapornpong et al. (2023) also pointed to high upfront costs, lack of staff training, and logistical limitations in efficiently collecting seafood restaurant waste for further processing. Renfors & Wendt (2024) stressed that adopting circular economy practices in seafood restaurants will only be effective if combined with upstream waste prevention measures, such as menu optimization and consumer education, as well as partnerships with third-party processing facilities. In other words, seafood restaurants cannot be isolated within the circular economy; they must collaborate with processing industries, local governments, and communities to create a closed-loop system.

Circular Economy Concept For Seafood Restaurants

Based on the available literature, the circular economy approach for seafood restaurants can be summarized in three main stages:

1. Prevention
   a. Reducing overproduction, optimizing storage, and redesigning menus to minimize potential waste generation.
   b. Supported by findings from Mendoza & Felicen (2024), which indicate that waste prevention can reduce food waste by 20–40%.
2. Redistribution

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a. Donating surplus edible food is mandated in countries such as France, where national regulations require restaurants to redistribute surplus meals (PAGE, 2024).

3. Valorization
   a. Processing unavoidable waste (e.g., fish heads, bones, shells) into chitosan, gelatin, biodiesel, and bio-nanocomposites for various industrial applications (Zhao et al., 2022; Boronat et al., 2023; Smaisim et al., 2022; Shalma et al., 2023; Yusoff et al., 2024).

By integrating these three stages, seafood restaurants can reduce environmental burdens while simultaneously creating additional economic value. By preventing upstream waste, redistributing surplus, and valorizing unavoidable residues, seafood restaurants can transition from linear waste generation models to sustainable, closed-loop systems that align with the principles of the circular economy.

Future Research Directions

The existing literature indicates that there is still significant room for advancing research on seafood restaurant waste management. First, more detailed studies on life cycle assessment (LCA) of the seafood restaurant supply chain are needed, similar to the work conducted by Yusoff et al. (2024), to better understand the environmental impacts at each stage. Future research could further explore energy efficiency improvements in seafood waste biorefinery processes to achieve more resource-efficient valorization.

Second, there is a need for more field experiments on the effectiveness of mitigation strategies across different cultural contexts. Nudging campaigns have proven successful in Europe (Renfors & Wendt, 2024), but their effectiveness in countries with banquet-oriented dining cultures, such as Indonesia or China, remains underexplored. Comparative regional studies could provide valuable insights for designing context-sensitive interventions. Third, research on integrating digital technologies to monitor seafood restaurant waste remains limited. While innovative buffet replenishment systems studied by Kattiyapornpong et al. (2023) have shown positive outcomes, further research could investigate the application of artificial intelligence (AI) for demand prediction and precise seafood stock management, potentially reducing overproduction and storage-related waste. Fourth, the circular economy potential of seafood restaurants is still largely untapped. Studies by Zhao et al. (2022), Boronat et al. (2023), and Shalma et al. (2023) have demonstrated the possibility of converting seafood waste into bioplastics, gelatin, and bio-nanocomposites, but further research is needed to examine sustainable business

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models and partnerships between restaurants, processing industries, and local communities to enable effective large-scale implementation.

CONCLUSION

Seafood restaurants are a critical point in the global food supply chain. However, they are also a major contributor to food waste due to the perishable nature of seafood, strict quality standards, and consumer demand for premium cuts. Waste is mainly generated during preparation, leftovers on plates, and storage failures, resulting in significant environmental, economic, and social impacts. The reviewed literature highlights that integrated mitigation strategies—such as optimized inventory management, menu redesign, portion control, innovative technology, consumer behavior interventions, and food redistribution—can significantly reduce waste. Beyond prevention, seafood waste holds high economic and ecological value through valorization pathways that transform by-products into biodegradable packaging, collagen, gelatin, bio-nanocomposites, and biodiesel. These solutions enable seafood restaurants to transition from a linear waste model to circular economy practices. However, implementation is still limited by high initial costs, lgistical constraints, staff training shortages, and energy demands from processing technologies. Achieving sustainable seafood restaurant operations requires a multidimensional approach that combines waste reduction, surplus redistribution, and resource valorization, supported by policies, economic incentives, and cross-sector collaboration. When effectively integrated, seafood restaurants can transform from waste hotspots into strategic actors driving innovation, sustainability, and measurable environmental, economic, and social benefits within the circular economy framework.

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