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Review

Mapping the interplay of technical, economic, social, and environmental dimensions in food-sector wastewater reclamation: A systematic literature review

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ABSTRACT

Water is an indispensable resource in the food sector, playing a critical role in production processes. However, wastewater generation presents significant challenges, including the opportunity to recover valuable resources. Wastewater reclamation within the food sector has emerged as a crucial practice, offering potential benefits such as economic efficiency, societal well-being, technological advancement, and environmental preservation. This study conducts a systematic literature review (SLR) to consolidate fragmented research and provide a comprehensive overview of the current state of wastewater reclamation in the food sector. This review analyses 51 articles published between 2013 and 2025, sourced from the Scopus and Web of Science database. The review synthesizes existing research and organizes it into two primary dimensions: (1) the factors influencing the implementation of wastewater reclamation in the food industry and (2) the benefits and barriers associated with these practices. The study classifies these factors into five key domains: water consumption, water generation, technological innovation, wastewater utilization, and reuse practices. It further highlights the crucial role of technical considerations in addressing barriers and maximizing the benefits of wastewater reclamation. The paper contributes to the scientific understanding of wastewater reclamation by proposing five key propositions that form a novel interconnected theoretical framework. This framework offers new insights into the complex dynamics of wastewater management in the food sector and identifies emerging trends. The study underscores the importance of aligning wastewater reclamation technologies with business objectives and encourages policymakers to implement robust environmental standards that facilitate sustainable practices.

1. Introduction

Water consumption and wastewater production in the food-sector are substantial, and they have drawn criticism for their link to adverse consequences on the environment, the economy, and public health and safety. Literature has argued that this sector has come under fire for its heavy water consumption, which has been linked to sharp increases in water use and depletion of water supplies (Neumann et al., 2024; Stachurski et al., 2024). One explanation might be that this sector works with a range of activities, including production, packing, preservation, sanitation, and sample preparation, all of which strongly imply that sustainable water management should be a key concern in accordance with the Sustainable Development Goals (SDGs)., Goal 6: clean water and sanitation (Shrivastava et al., 2022). Ineffective wastewater treatment is a significant cause of water pollution, emphasizing the need for technological progress to improve treatment processes and mitigate environmental degradation (Khan et al., 2022). A collective endeavour must embrace sustainable water management practices to address these consequences. Such an endeavour involves incorporating technologies such as wastewater reclamation to reduce the food-sector's

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environmental footprint and encourage the responsible use of resources. Effective management of natural resources is crucial for supporting sustainable development and addressing socio-economic inequalities (Ponce et al., 2023). Water reclamation is one of the main initiatives the United Nations Educational, Scientific and Cultural Organization (UNESCO) established to reduce 20% of the water used in industries by 2030 to ensure sustainable water management. Guidelines for water reuse in the food-sector are also available, and the sector needs to become more sustainable if it wants to endure. In this regard, the sector is forced to use wastewater reclamation techniques to maintain its competitiveness and rebuild its reputation for long-term benefit.

Several studies have systematically examined various topics related to wastewater reclamation, such as the drivers and barriers to urban water reuse (Lee and Jepson, 2020), the barriers to the implementation of wastewater reuse (Morris et al., 2021), on-site carwash wastewater treatment (Torkashvand et al., 2020) and life cycle cost analysis of wastewater treatment (Ilyas et al., 2021). While these studies have provided valuable insights into wastewater reclamation in various contexts, there is a notable gap in systematic reviews focusing specifically on wastewater reclamation within the food sector. A substantial body of research has explored multiple dimensions of wastewater reclamation in the food sector, addressing technical solutions, economic feasibility, and environmental sustainability (Arias et al., 2024; Kumari et al., 2024; Najar-Almanzor et al., 2024). However, these studies often concentrate on one or two dimensions of the issue, with limited exploration of the complex interconnections between the technical, economic, social, and environmental factors that influence the implementation and success of wastewater reclamation strategies in this sector.

Recent studies in other sectors, such as agriculture (Penserini et al., 2024), have explored barriers like the impacts of salinity and the economic feasibility of treatment plants. Additionally, technical barriers, such as variations in wastewater flow and effluent quality, and social barriers, particularly concerns about the safety of reclaimed water, have been identified as challenges hindering the widespread adoption of wastewater reuse technologies (Neumann et al., 2024). However, the specific interconnections between these challenges in the food sector remain underexplored, making it difficult to develop a comprehensive strategy for implementation. Given these gaps, there is a clear need for a systematic review investigating the specific benefits and barriers to wastewater reuse in the food industry—an area that remains under-researched. Furthermore, water consumption patterns in food production sectors exhibit substantial variation across countries due to differences in process automation levels, the availability and utilization of production factors, and equipment specifications. For example, water consumption for milk powder or cheese production demonstrates considerable variation: in Denmark, it ranges from 0.69 to 1.90 L water/L processed milk, while in Norway, it varies from 4.60 to 6.30 L water/L processed milk (Garnier et al., 2023). These variations contribute to significant differences in the quantity and quality of wastewater, which may contain a wide range of ingredients and products (He et al., 2023). The "water reuse guidelines for business in NSW considering reusing water" in Australia emphasize feasible recycling solutions and maintaining product quality by determining a reliable methodology to ensure that the solutions are not harmful (NSW-Food-Authority, 2008). According to Pulluru and Akkerman (2023), increased reuse and recycling of wastewater in food processing represent a proactive and responsible approach to addressing the significant water footprint of the food-sector.

In essence, the increased reuse and recycling of wastewater in food processing not only address the immediate water footprint but also contribute to broader environmental (Balbinoti et al., 2023; Bortolini et al., 2017; Shroti et al., 2023), economic (Kiran and Mohan, 2021; Meng et al., 2022; Usmani et al., 2022), and social (Josa and Garfí, 2023) benefits, thus characterizing wastewater reuse and recycling as a holistic and responsible paradigm. Recognizing the environmental impact of discharging such wastewater into water bodies, there is a growing need for investigations into two strategies: (i) the development of new water and (ii) the re-design of plants for water networks, including water reclamation initiatives, which have been explored due to the significant efforts to reduce water consumption. Reclaiming and treating wastewater mitigates environmental harm and offers the opportunity to conserve a valuable resource, address water scarcity concerns and enhance the food industry's sustainability (Lima et al., 2021; Shrivastava et al., 2022). However, Pulluru and Akkerman (2023) argue that the quality of regenerated water depends on several operational and technological factors and is frequently difficult to control, making it a danger to many businesses, including the food production sector. The complexity of food wastewater, with its various pollutants and fluctuating quality, presents challenges for treatment but also offers significant opportunities for resource recovery and reuse due to its valuable nutrients and relatively low levels of harmful substances (He et al., 2023). From this perspective, this situation has been attributed to increasing legislative pressure and sustainability concerns, which are currently fragmented and limited to the knowledge.

Several food industries have successfully implemented water reuse practices, realizing various benefits. For example, Coca-Cola has reused approximately 173 billion litres of water out of 804 billion litres of wastewater produced and has set a benchmark for other industrial giants, such as P&G and Heineken (Shrivastava et al., 2022). Food companies such as Coca-Cola, Nestlé and PepsiCo are major corporations actively engaged in practices related to water reuse as part of their water conservation efforts. Coca-Cola emphasizes sustainable water stewardship through its Water Stewardship and Replenish programmes, investing in community-based water projects and rainwater harvesting to offset water used in beverage production (The Coca-Cola Company, 2024). Nestlé integrates advanced water recycling systems in its production facilities to treat and reuse water, reducing its reliance on freshwater sources (Nestlé, 2024). PepsiCo adopts water-efficient manufacturing technologies, including water recovery systems, to capture and treat water from different stages of the manufacturing process, enabling significant water recycling and a reduction in overall water consumption (PepsiCo, 2024). Water recycling and reduced consumption can lead to positive interactive competition, encouraging other companies to follow suit and contribute to sustainable water management. However, integrating reclaimed water into manufacturing water systems faces several challenges and has not reached its full potential in many regions. The public's concern about health risks and the "yuck" factor associated with wastewater reuse, especially its proximity to human contact, can hinder its acceptance (Morris et al., 2021). In addition, concerns regarding biosecurity associated with water reuse (Pulluru and Akkerman, 2023), along with the main challenges for water reuse involving controlling ammonia and nitrate levels, with strict limits and protocols in place to ensure safe water recovery and avoid contamination (Stachurski et al., 2024) remain significant obstacles.

Unfortunately, there is a lack of transparency, fragmentation, and bias towards particular viewpoints in discussing these practices and strategies. Hence, the current study aims to overcome these limits by building on earlier wastewater reclamation and sustainability research. In this direction, this study aims to synthesize existing research on wastewater reclamation in the food sector, focusing on factors influencing its implementation and the associated benefits and barriers. Based on the findings, this review will identify key themes, benefits and barriers to and propose directions for future research and practice. Following this, the research questions are twofold: 1) What key factors influence the implementation of wastewater reclamation in the food sector based on the water reuse theme? and (2) How do the technical, economic, social, and environmental benefits and barriers interrelate in the context of wastewater reclamation within this sector? A structured literature review (SLR) method from Snyder (2019) is employed to systematically identify, assess, and analyse all relevant studies on research issues, subjects, or phenomena related to wastewater reclamation in the food sector. A total of 51 peer-reviewed journal articles published between 2013 and 2025 are included in the current study. The main reason such research questions are developed is that past literature on wastewater reclamation is fragmented, limiting the knowledge understanding, especially from the food-sector perspective; hence, the current insight could offer better solutions and strategies.

Following this, the factors of wastewater reclamation implementation are analysed based on the flow or chain in the food-sector. Meanwhile, the benefits and barriers are identified based on a multi-criteria methodology based on economic, social, technical and environmental aspects (Lizot et al., 2021). Finally, this holistic analysis yields five valuable propositions and contributes to the theoretical framework in the field of study. For each pair of aspects (technical-social, technical-economic, economic-environmental, etc.), the study explores how changes or considerations in one aspect affect each other and how these interconnections contribute to the overall dynamics of the system. The originality of this study lies in its conceptual framework, which illustrates the interconnections between technical, economic, social, and environmental benefits and barriers of wastewater reclamation in the food sector. This framework offers a foundation for future research. Additionally, the study identifies key factors, benefits, and barriers that make wastewater reclamation viable in the food sector, providing a more comprehensive understanding of previous mechanisms. The study also establishes the need to explore further the intricate relationships between sustainability practices and wastewater reclamation. The remainder of this study is organized as follows. Section 2 discussed the past literature on wastewater reclamation and food-sector. Next, Section 3 summarizes the research methodology adopted in this study. The results and discussion of descriptive and content analysis are provided in Section 4. In this section, the study also argues five factors influencing the implementation, their benefits and barriers, and the development of the conceptual framework through five propositions. Followed by the future research suggestion in Section 5. Finally, Section 6 presents the conclusion of the present study.

2. Literature review

2.1. Sustainability in wastewater reclamation

Wastewater reclamation, also known as water recycling, involves treating and purifying wastewater to make it suitable for reuse in various applications, such as agricultural irrigation, industrial processes, or even potable water. It is an effective strategy for conserving water resources, mitigating environmental impacts, and optimizing the costs and energy associated with water resource management (Takeuchi and Tanaka, 2020). The primary objective of the traditional wastewater treatment approach is to clean water before it is discharged into natural water streams. However, transitioning to a circular economy mindset entails rethinking this approach by incorporating water resource recovery technologies. This transition recognizes that wastewater is not merely a waste product to be disposed of but also a valuable resource and water reuse is a fundamental component of this approach (Shrivastava et al., 2022). By recovering valuable resources from wastewater, such as nutrients or energy, and by treating water so that it is of a quality suitable for reuse, this approach minimizes waste, reduces the need for virgin raw materials, and optimizes the utilization of water resources (He et al., 2023). In essence, it encapsulates the core tenets of the circular economy. It underscores the importance of water reuse, which serves as a transformative approach to resource management, offering a solution to the need for long-term sustainability for natural resources (Morris et al., 2021). The integration of wastewater reclamation into water resource management thus emerges as a comprehensive and transformative strategy that embodies sustainability principles and significantly contributes to achieving the broader global agenda for sustainable development.

Wastewater can be classified into various types based on its origin, such as domestic, industrial, agricultural, medical, or nuclear, each requiring different treatment approaches (Yadav et al., 2021). As wastewater reuse becomes increasingly crucial for addressing water scarcity, sustainability considerations are key in selecting appropriate treatment options. Torre et al. (2024) examined wastewater treatment methods from environmental, economic, social, and operational perspectives. The research underscores the importance of considering these factors to ensure effective wastewater reclamation. Integrating various treatment technologies can help mitigate environmental impacts, promote water resilience, and enable safe water reuse, which is crucial for sustainable water management.

Addressing systemic barriers and promoting integrated water management strategies is essential to achieve sustainability in wastewater reclamation. According to Morris et al. (2021), successful adoption of wastewater reclamation hinges on aligning economic, regulatory, and political factors within broader urban water systems. Evidence shows that external environmental shocks, like drought, maybe a catalyst, but a nexus of place-based factors combined with economic, regulatory, and political alignment is more likely to foster systemic change in water systems (Lee and Jepson, 2020). Challenges such as policy and regulatory fragmentation, stakeholder conflicts, and competition with other water sources like desalination can hinder progress (Morris et al., 2021). The integration of Life Cycle Costing (LCC), Life Cycle Assessment (LCA), and Societal Life Cycle Assessment (Societal LCA) provides a comprehensive framework for Life Cycle Sustainability Assessment (LCSA), which facilitates the evaluation of environmental, economic, and social impacts across the life cycle of a product or process (Ilyas et al., 2021). Environmental LCC focuses explicitly on integrating environmental impacts into the cost analysis, extending the scope of traditional LCC. This approach evaluates environmental impacts by incorporating environmental costs, assesses societal benefits such as health improvements from better water quality, and supports sustainable decision-making by combining financial, environmental, and societal analyses to ensure that wastewater treatment decisions align with sustainability goals (Ilyas et al., 2021).

2.2. Food sector wastewater for sustainable development

Industrial wastewater management is crucial to sustainable development, addressing environmental concerns and resource conservation. The growing interest in industrial wastewater treatment is driven by the need to prevent environmental issues and ensure safer wastewater disposal. Industrial processes often generate wastewater containing organic substances, suspended solids, and potentially harmful pollutants; thus, it is necessary to implement advanced treatments such as deammonification. The automatic dosing of coagulants serves as a control strategy to optimize the treatment process, ensuring stable water reclamation in food-sector plants by managing nitrogen levels and preventing flocculant interference in ultrafiltration units (Stachurski et al., 2024). Effective treatment strategies mitigate environmental impacts and contribute to sustainable water usage (Pulluru and Akkerman, 2023). Nevertheless, the strategies for water recycling are different at each level. For instance, treated water may be collected from water treatment plants to provide water to power stations and industrial users at the regional level. It is even used as supply storage for drinking water, launched by the Brisbane region (Australia) in 2009 through the Western Corridor Recycled Water Project (Apostolidis et al., 2011). This differs from the factory level, where the collected effluent is mixed before global treatment and possible recycling for non-food uses and agricultural irrigation (Apostolidis et al., 2011).

In addition, reclaimed water is a viable alternative to conventional tap water, particularly for the food-sector, where water is utilized for various purposes, such as cooling, boiling, and cleaning (Takeuchi and Tanaka, 2020). conducted survey research on the acceptance of reclaimed water among industrial and tap water users based on cost considerations. According to the survey, 69% of industrial water users find reclaimed water acceptable if its cost is lower than that of industrial water (priced at 35 yen/m^3). In comparison, 45% of tap water users accept reclaimed water if its cost is below that of tap water (priced at 200 yen/m^3). These results imply that tap water users are more open to reclaimed water than industrial water users. The investigation also investigated the water consumption patterns of tap water users who expressed a willingness to use reclaimed water at a lower cost. Among the companies investigated, 7 food companies indicated they consumed a significant portion (68%) of tap water. In conclusion, the study suggested that reclaimed water should be supplied to food companies because they currently use substantial amounts of tap water. Offering reclaimed water to these companies provides an opportunity to reduce their environmental impact and promote responsible water consumption in food production.

In recent studies, the sustainable treatment of wastewater in the food sector has gained increasing attention due to its potential for environmental and economic benefits. Najar-Almanzor et al. (2024) highlight the challenges of implementing microalgae biorefineries for wastewater treatment, focusing on issues such as the high costs of wastewater dilution, environmental concerns associated with conventional extraction methods, and the limited adaptability of microalgae to concentrated effluents. To improve efficiency and scalability, the study calls for the development of sustainable technologies, including green extraction techniques and synergistic mixed cultures. Arias et al. (2024) exemplify a shift from traditional "end-of-pipe" solutions to integrated waste valorization strategies, positioning wastewater as a resource rather than a waste that addresses environmental and economic sustainability concerns by creating value-added products. Kumari et al. (2024) investigate using coconut coir dust (CCD) as a biosorbent for removing Sunset Yellow dye from wastewater, demonstrating high dye uptake and confirming chemisorption as the primary adsorption mechanism. The techno-economic feasibility of CCD demonstrates its cost-effectiveness and commercial viability, offering a promising solution for wastewater treatment in the food industry. Thus, this systematic literature review (SLR) will explore various aspects of the benefits and barriers in wastewater reclamation's technical, economic, social, and environmental dimensions, shedding light on the multifaceted challenges and opportunities for sustainable development in the food sector.

3. Methodology

The SLR framework proposed by Snyder (2019) has been adopted, incorporating four phases: design, conduct, analysis, and structure. The current study began with phase 1: design, which involves research questions development, search terms, inclusion/exclusion criteria, additional limitations and choosing appropriate databases. This study also employed a guided protocol by collecting past published articles, as Mohamed Shaffril et al. (2021) suggested, to identify search terms used in the database. In line with this design, the research questions of this study are as follows.

1. What key factors influence the implementation of wastewater reclamation in the food sector based on the water reuse theme?
2. How do the technical, economic, social, and environmental benefits and barriers interrelate in the context of wastewater reclamation within this sector? and

To answer these research questions, four sets of related keyword searches from the previous literature were used as guidelines (see Table 1).

In conducting this review, it is vital to establish clear rules for including and excluding studies. Following the advice of (Kitchenham and Charters, 2007), researchers should select criteria that directly address their research questions. For this review, the set of criteria was carefully determined based on the research questions, ensuring that the chosen studies aligned with the main focus and contributed relevant information. A comprehensive set of inclusion and exclusion criteria was established to refine the literature search and identify the most pertinent articles, as presented in Table 2, providing transparency in the selection process. Following the guidelines of Snyder (2019), criteria such as publication year, article language, publication type, and journal quality were prioritized. The review considered articles published in English from 2013 to 2025 in reputable, peer-reviewed journals. Conference proceedings, editorials, and book chapters were excluded to ensure methodological rigour. Aligned with (Ghobakhloo et al., 2021), only peer-reviewed publications were selected as these represent the highest standard of quality in academic research. Articles must be published in journals indexed in Clarivate Analytics' Social Sciences Citation Index®, ensuring consistency with recognized scholarly benchmarks.

The selection of an appropriate database was another critical step in the literature review process, as it directly impacts the quality and comprehensiveness of the results. While several databases such as Scopus, Web of Science, Google Scholar, and EBSCO have been highlighted in prior research (e.g., Jia et al., 2020; Kamble et al., 2018), this study exclusively utilized the Web of Science and Scopus database. The exclusive use of the Web of Science and Scopus databases for systematic literature reviews is based on their comprehensive coverage and high sensitivity, which ensures a broad and relevant selection of scholarly articles (Kumpulainen and Seppänen, 2022). These databases are widely recognized for their extensive citation indexes, improving the quality and relevance of retrieved articles (Alfandari and Taylor, 2021). In particular, Scopus has been noted for its high sensitivity in retrieving articles that may not be found in other databases, while Web of Science demonstrates a slight edge in retrieval quality (Singh et al., 2023). Thus, the choice was based on its extensive coverage of peer-reviewed journals across disciplines—science, technology, economic, and social sciences—along with publications from leading publishers like Elsevier, Springer, Emerald, Taylor & Francis, and IEEE, ensuring a thorough review while minimizing sampling bias (Abdul-Hamid et al., 2022).

Then, in phase two, conduct involves the practical plan, search process, article selection and quality of processes and articles. The data

Table 1
Keywords for the search string.

No	Keywords	Search string	Sources
1	Food industry	"food compan*" OR "food industry" OR "food business*" OR "food manufact*"	Adams et al. (2021)
2	Wastewater	"wastewater" OR "effluent" OR "sewage" OR "sewerage" OR "sullage" OR "water"	Torkashvand et al. (2020)
3	Reclamation	"treatment" OR "reclamation" OR "recycling"	Quispe et al. (2022)
4	Sustainability	"sustainability" OR "sustainable" OR "green" OR "environmental performance" OR "social performance"	(Abdul-Hamid et al., 2022; Seuring and Müller, 2008)

Table 2
Inclusion and exclusion criteria used for screening.

Criteria	Inclusion	Justification
Language	English	To enhance the efficiency and effectiveness of the literature review process
Year published	2013–2025	To capture a decade of key advancements in wastewater reclamation while incorporating the latest insights to reflect current trends and innovations
Publication	Peer-review journal articles	To focus on high-quality articles
Theme	The article focuses on the food industry and wastewater	To enhance the review's precision, efficiency, and coherence

was collected on January 15th, 2025, through the Scopus and Web of Science (WoS) databases in this phase. Initially, the searches resulted in 530 from WoS and 911 from Scopus. 422 articles remained after the studies were qualitatively evaluated based on the inclusion and exclusion criteria, and duplicates were removed. Then, during the screening process, 422 articles were based on the title, keywords, and abstract, and only 199 articles remained that were eligible for full-text assessment. Finally, 51 articles were included that fit well within the scope of this study for final analysis (as shown in Appendix 1). In detail, Fig. 1 summarizes the selection steps in this study.

4. Results and discussion

In the third phase, the analysis is employed to scrutinize the related information and the primary outcomes of this SLR are discussed through descriptive and content analysis.

4.1. Descriptive analysis

This research detected the trends in the number of papers on wastewater reclamation in the food sector included in this SLR gradually increasing from year to year, as shown in Table 3. In addition, it also identifies the top contributing journals, with the Journal of Environmental Management leading at 7 articles, and provides an overview of research methodologies, with experimental research being the most common at 32 articles.

In addition, Table 4 provides a comprehensive overview of various sectors within the food-sector, from beverage manufacturing to dairy processing, cheese manufacturing, and agricultural sectors like grape, maize, and vegetable production. These sectors represent diverse facets of the food-sector, from primary agricultural production to secondary processing and manufacturing, each contributing uniquely to the global food supply chain. Notably, wastewater reclamation studies within the brewery industry are the highest among those analysed.

Table 3
Descriptive statistic.

5 recent years of publication	Number of articles
2020	3
2021	5
2022	5
2023	6
2024	10
Top 5 journal publisher	**Number of articles**
Journal of Environmental Management	7
Environmental Science and Pollution	4
Bioresource Technology	4
Sustainability	4
Water Science and Technology	3
Research Methodology	**Number of articles**
Experimental research	32
Review	10
Survey	2
Case study	4
Life cycle assessment	3

4.2. Factors influencing the implementation of wastewater reclamation

This section discusses the answer to the first research question in detail. Wastewater reclamation is closely linked to broader wastewater management practices, and its identification is based on the water reuse theme outlined by Cisneros (2014). Based on this framework, five key factors influencing wastewater reclamation were identified: (i) economizing on water consumption, (ii) combating wastewater generation, (iii) embracing wastewater reclamation, (iv) optimizing wastewater utilization, and (v) practising wastewater reuse as shown in Fig. 2. For further details, please refer to Appendix 2.

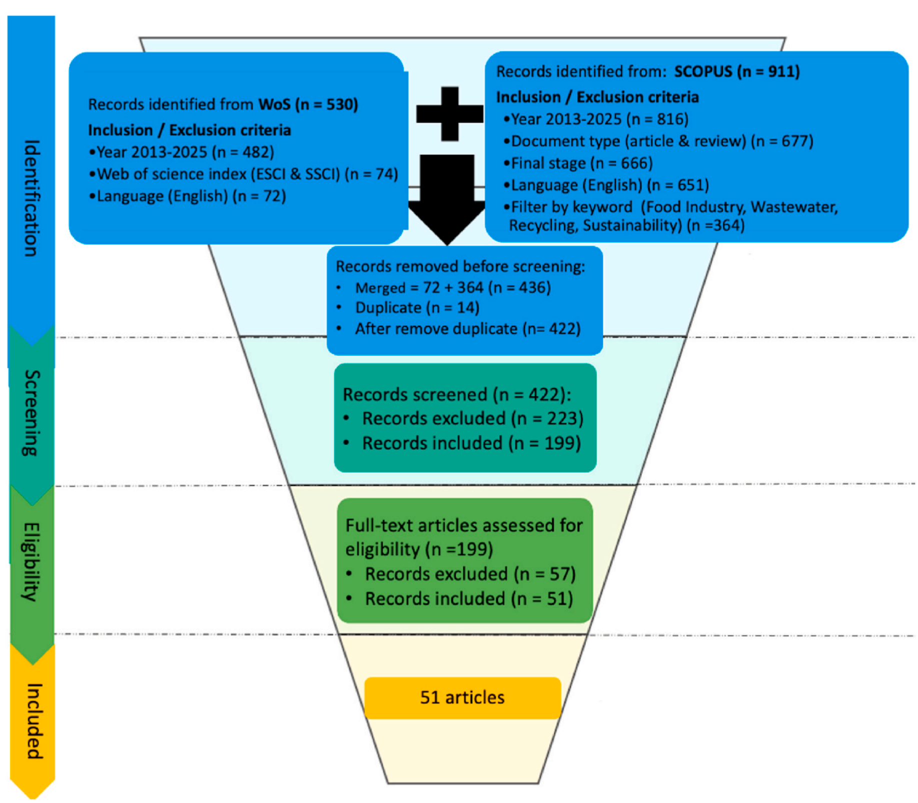

Fig. 1. Selection process.

Table 4
Types of food-sectors.

Type of food sector	Source
Beer	Valili et al. (2013)
Beverage industry	Shroti et al., (2023); Alkaya and Demirer (2015)
Brewery	Wang et al., (2022); Lu et al., (2017); O'Rourke et al. (2016); Sant'Ana et al. (2024); Anagnostopoulou et al. (2024)
Cheese manufacturing	Guerreiro et al. (2020); Anagnostopoulou et al. (2024)
Chilled chicken meat processing	Menussi et al. (2023)
Corn	España-Gamboa et al. (2017); Najar-Almanzor et al. (2024); Arias et al. (2024)
Dairy	Kiran and Mohan (2021); Usmani et al. (2022); Karadag et al. (2014)
Distillery	Kumari et al. (2019)
Fish canning	Monteiro et al. (2018)
Food and Beverage	Bortolini et al. (2017)
Food processing	Meng et al. (2022); Amit et al. (2021)
Grape	Nayak et al. (2018)
Guava	Mateus et al. (2021)
Maize	Paz-Samaniego et al. (2016)
Olive	Ochando-Pulido and Martinez-Ferez (2018); Ahmed et al. (2024)
Palm oil	Hasanudin et al. (2015)
Potato Food processing	Lima et al. (2021)
Rice mill	Mukherjee et al. (2015)
Seafood processing industry	Jain et al. (2019)
Snack food	Boguniewicz-Zablocka et al. (2020)
Sugarcane	Fito et al. (2019)
Tomato	Vidyarthi and Simmons (2020)
Vegetable	Wang et al. (2021)
Winery	Welz et al. (2014)

4.2.1. *Economizing on water consumption*

Water scarcity has catalysed a shift in the food-sector towards sustainable water management practices, with wastewater reclamation and reuse being a viable and responsible solution for mitigating the impact of water scarcity (Lima et al., 2021; Shrivastava et al., 2022). The food-sector is known for its substantial water consumption, which is used throughout various production stages. Most water is raw from natural sources or municipal supplies to meet these demands. Menussi et al. (2023) highlighted the significance of water consumption in the food-sector, with 55.8% of water being utilized and not returned to the same water body from which it originated. This finding highlights the pressing need for the sector to adopt sustainable water management practices, with a primary focus on reducing raw water consumption. As water becomes increasingly scarce, the food industry must focus on efficient water management. Wastewater reclamation is essential to mitigate water scarcity while maintaining production efficiency (López-Cabarcos et al., 2024). Implementing wastewater reclamation and reuse has emerged as a critical strategy for achieving this goal. By treating and reusing water that would otherwise be discharged, the food-sector can effectively reduce its reliance on raw water sources (Bortolini et al., 2017; Lima et al., 2021; Menussi et al., 2023). Doing so addresses the environmental concerns associated with non-returnable water and is pivotal in overall water conservation efforts.

In addition, Lima et al. (2021) conducted a water pinch analysis to address the problems of reducing raw water consumption and allowing wastewater reuse in the food processing industry. They reported a 55% reduction in raw water consumption and a 45% reduction in the volume of treated wastewater discharged. These findings indicate enhanced environmental sustainability and the potential for significant cost savings in resource management. However, a study by Meng et al. (2022) showed that the managerial perception of water costs is low (which may hinder the adaptation of water treatment practices) and that managers are less likely to adopt water treatment practices in the food processing industry. Hence, the inconsistency between these findings highlights the need for further research or investigation.

4.2.2. *Combating wastewater generation*

Wastewater generated from the food-sector is acknowledged to be complex, containing various constituents. There is concern about the environmental impact of discharging food processing wastewater, which carries heavy loads of salinity, nutrients, organic matter, solids, oils and fats (Guerreiro et al., 2020). Effluent from food-sector discharges must meet increasingly stringent quality requirements to minimize their impact on the environment. Compliance with regulatory standards and requirements is a crucial factor influencing wastewater reuse in the food-sector. Adhering to established regulations ensures that treated wastewater meets quality and safety standards, making it suitable for reuse or disposal in the environment (Guerreiro et al., 2020; Mukherjee et al., 2015; Ochando-Pulido and Martinez-Ferez, 2018; Shrivastava et al., 2022). The average concentrations and specific loads of wastewater have been determined by European food industries based on global parameters such as BOD, COD, TSS, total organic carbon (TOC),

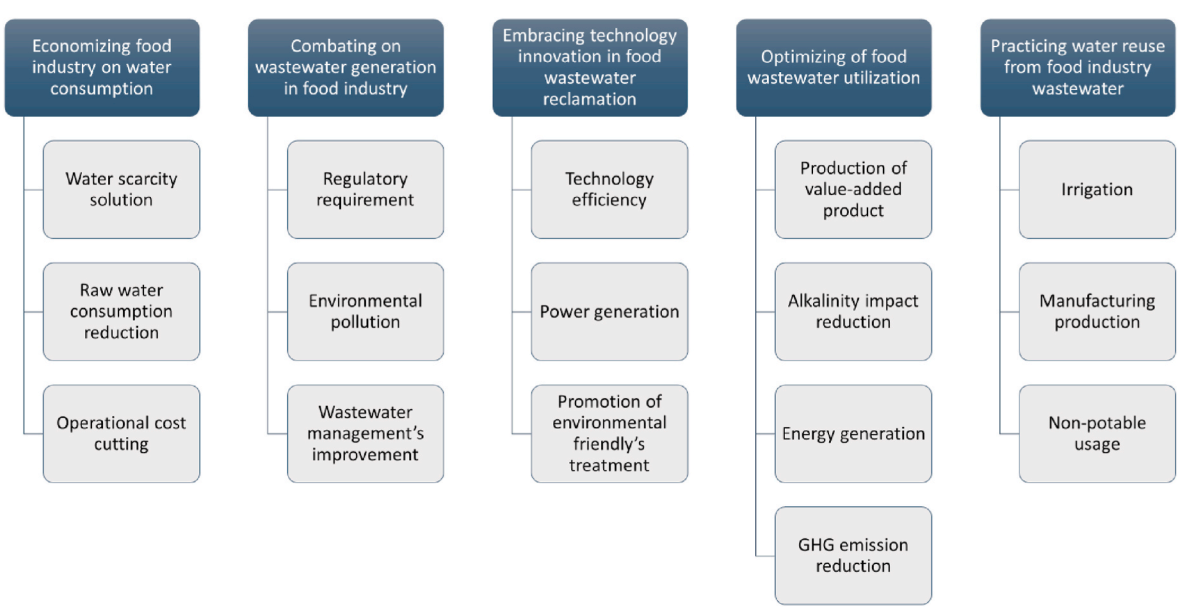

Fig. 2. Factors of wastewater system implementation in the food-sector.

total nitrogen (TN), and total phosphorus (TP) (European Commission, 2019).

In addition, the discharge of wastewater without proper processing can pose a threat to the environment. For instance, wastewater produced from dyes in the snack-food-sector can harm treatment facilities and the environment, especially for aquatic life (Boguniewicz-Zablocka et al., 2020). Vegetables frequently utilized in the food-sector have the potential to contaminate both underground and surface water via the leachate generated from vegetable waste, thereby posing an indirect threat to the health of both cattle and humans due to the presence of microorganisms and mycotoxins (Wang et al., 2021). In addition, the organic acids that contaminate the wastewater of the fruit and vegetable industries or the ethanol in the wastewater from the production of breweries and wineries (Garnier et al., 2023) are even more challenging to treat using membrane technology due to the low molecular weight. There is also the case of the insignificant contribution of organic micro-pollutant and their degradation outputs to global parameters; however, these pollutants are still present in effluent (Garnier et al., 2023). This reality underscores the importance of implementing a wastewater reuse system in food industries. By doing so, factories can effectively mitigate pollution from specific components such as dyes and mycotoxins, thereby preventing environmental contamination and promoting more efficient and strategic wastewater management.

Vidyarthi and Simmons (2020) argue that the characteristics of by-product or discharge streams (solid streams and process water streams) generated at different stages of tomato processing in California's tomato processing plants highlighted the need for wastewater reclamation. The findings underscore the necessity of improving wastewater management strategies in the tomato processing industry. The current management strategies, relevant policies, and recommendations for sustainable management strategies emphasized in the study point to the importance of implementing wastewater reclamation practices to enhance overall wastewater management in the food-sector. Welz et al. (2014) highlighted the critical need to reduce the environmental impact of the wine industry by developing more effective treatment methods for winery effluent. Doing so can help decrease the industry's contribution to the global environmental wastewater burden. Understanding the composition and variability of winery effluent can lead to more efficient treatment processes, ensuring that organic compounds are effectively degraded and reducing the potential for water pollution. Ahmed et al. (2024) offer a sustainable alternative to conventional wastewater treatment methods, reducing the harmful effects of food industry waste on human health, aquatic life, and the environment.

4.2.3. Embracing technological innovation in wastewater reclamation

Advancements in treatment technologies have contributed to increased efficiency in removing contaminants from wastewater. In addition, the estimation of the amount and type of composition in the wastewater to be treated, as well as the requirements that need to be fulfilled for treated water, is another consideration that should be taken into account when choosing reliable treatments and optimizing the water network (Garnier et al., 2023). Instead of analysing global parameters such as colour, conductivity, odour, oxidability, and turbidity, additional specific analyses, especially of organic micro-pollutants (pesticides, disinfectants, oils and polychlorinated biphenyls) and heavy metals, should be considered for the evaluation of treated water quality (Garnier et al., 2023). Most of the studied papers on wastewater reclamation have focused on increasing the technology efficiency of wastewater treatment. Continuous research and development in this area have led to more effective and reliable treatment methods, ensuring a higher quality of reclaimed water in the study period of this SLR (from 2013 to the present). Some examples of specific studies on enhancing treatment efficiency include the following (Valili et al., 2013). explored the use of malt spent rootlets (MSRs), by-products of the beer industry, as sorbents for removing organic hydrophobic pollutants such as phenanthrene. Sant'Ana et al. (2024) evaluated the potential of biosurfactants produced from brewery wastewater to treat effluents from the beer processing industry and showed significant improvements in effluent quality, with reductions of 55.9% in BOD, 23.8% in COD, and 50.6% in TS at an optimal biosurfactant concentration (0.5 CMD). Patange et al. (2018) demonstrated that atmospheric cold plasma (ACP) treatment effectively reduces microbial populations in food-sector effluents and mitigates their eco-toxicological impact. Guerreiro et al. (2020) identified potential treatment options for effluents from cheese manufacturing. Finally (Mateus et al., 2021), worked on a combination of magnetic bentonite treatment techniques to treat wastewater from the food-sector, especially in guava wastewater.

The dairy industry is one of the most extensively investigated sectors in terms of water recycling and application at the industrial scale (Kiran and Mohan, 2021; Usmani et al., 2022; Karadag et al., 2014). For example, in the production of concentrated milk, a condensate produced during the evaporation process could be recycled as high-quality water steam after RO filtration (Mavrov and Bélières, 2000). A simulation and experimental results were reported for the largest plant in India (Tiwari et al., 2016). Water can be recycled in ghee production for its pre-washing step after coagulation and the adsorption process from CIP vessels for butter clarification (Tiwari et al., 2016). In other food sectors, such as the fruit and vegetable industry, a substantial amount of water can be reused after the blanching process for the preliminary cleaning of equipment (European Commission, 2019; Klemes et al., 2008). Research has shown that this food sector can reduce its water use by approximately 90% if all the wastewater produced from the cleaning and rinsing process is recycled for device cleaning (Lehto et al., 2014; Manzocco et al., 2015). Nevertheless, in some instances, disinfection is required before recycling processes, such as ozone/ultraviolet (UV) treatments for the fresh-cut vegetable industry and neutral electrolyzed oxidizing water (NEOW) for salad disinfection (European Commission, 2019).

The energy crisis poses a significant challenge, particularly in emerging economies, where energy demand is rising with economic development, serving as a compelling factor for studying wastewater reclamation (Selvasembian et al., 2022). To treat wastewater, some studies have aimed to harness the microbial processes involved in treatment to generate bioelectricity. For instance, researchers such as (Selvasembian et al., 2022) found that the integration of microbial fuel cells (MFCs) enhanced treatment efficiency and the production of electrical energy, demonstrating the potential for dual benefits in bioelectricity production. This method is one of the technological approaches that efficiently reduces wastewater and recovers energy (Ramanaiah et al., 2023). In addition, emphasizing environmentally friendly treatment approaches (Balbinoti et al., 2023), reported on plant-based coagulants to treat food-sector wastewater. Similarly, Ahmed et al. (2024) investigated using bio-based cationic flocculants derived from crude olive pomace oil (COPO) for treating food industry wastewater, offering a sustainable and cost-effective alternative to conventional methods. This approach enhances removal efficiency with lower chemical dosages and reduced treatment time, addressing the challenges of wastewater generation and pollution. By identifying eco-friendly treatment options, these studies contribute to sustainable effluent treatment, which is essential for reducing the environmental impact of industrial activities.

4.2.4. Optimizing food-sector wastewater utilization

Wastewater utilization is crucial in implementing wastewater reclamation efforts in the food-sector. The effective and responsible use of reclaimed wastewater adds value to the reclamation process. Treating and reusing wastewater can offer several benefits over simply disposing of wastewater. For example, Shroti et al. (2023) leveraged the capacity of alkaliphilic organisms to reduce the pH of wastewater and utilized residual sugars from beverage industrial wastewater to produce commercially applicable biodegradable polymers. Previous studies have illuminated the potential of utilizing wastewater to mitigate alkalinity-related environmental impacts effectively (España-Gamboa et al., 2017; Fito et al., 2019; Paz-Samaniego et al., 2016). Hence, applying wastewater reclamation is imperative for sustainable and responsible environmental management.

Research on wastewater utilization is driven by a diverse range of opportunities to repurpose food-sector wastewater, leading to the production of valuable products. Numerous studies have highlighted the potential to transform wastewater into various beneficial resources, including biodiesel (Amit et al., 2021; Jain et al., 2019), bio-H_2 (Wang et al., 2022), hydrogen (Karadag et al., 2014), phosphate (Kumari et al., 2019), biomass (Wang et al., 2024; Kiran and Mohan, 2021; Lu et al., 2017), liquid fertilizer (Hasanudin et al., 2015), biodegradable polymers (Shroti et al., 2023), ω-lipids (Monteiro et al., 2018), bioactive material (Arias et al., 2024) and probiotics (Paz-Samaniego et al., 2016). Most of the value-added products from wastewater are for energy generation. The gases produced, such as methane, are captured and utilized as renewable energy sources through some processes. This process can reduce greenhouse gas emissions and replace traditional energy (Amit et al., 2021; España-Gamboa et al., 2017). For instance, in a study by Wang et al. (2022), the energy revolution has emerged, with wastewater from the brewery industry being utilized to recover energy from the production of bio-H_2 as green and clean energy.

4.2.5. Practising water reuse from food-sector wastewater

Practising water reuse from food sector wastewater is a key factor influencing the implementation of wastewater reclamation because it directly contributes to the goal of treating and repurposing wastewater for sustainable applications (Chen et al., 2024). Wastewater reclamation is a comprehensive process that aims to treat and purify wastewater from the food-sector to a quality that makes it suitable for reuse. Reclaimed water serves several vital purposes, including irrigation for agricultural activities (Fito et al., 2019; Guerreiro et al., 2020; Mateus et al., 2021; Ochando-Pulido and Martinez-Ferez, 2018). Utilizing treated wastewater for irrigation reduces the demand for freshwater resources and enhances plant growth (Shroti et al., 2023). Furthermore, reclaimed water is purposefully being reused for industrial production (Alkaya and Demirer, 2015; Hernández et al., 2016; Lima et al., 2021). Wastewater reclamation supports industrial output by providing a reliable and cost-effective alternative water source. Such reuse contributes to the conservation of freshwater reserves and minimizes the environmental impact of industrial water consumption. Finally, wastewater reclamation aims to produce treated water suitable for indirect human contact applications. A study by Hernández et al. (2016) revealed that an electrocoagulation (EC)-electro-oxidation (EO) coupled system efficiently treats soft drink wastewater, meeting Mexican standards by reducing nitrogenous matter by 84% and total phosphorus by 89% and achieving 100% colour removal, thus enabling the sustainable reuse of treated wastewater for indirect human contact and directly contributing to the sustainable reuse of industrial effluent. Furthermore, Kanarek et al. (2024) evaluate the effectiveness of a modular water treatment system for purifying wash water from fruit and vegetable processing plants. The system improves the microbiological and physicochemical properties of the rinse water, making it suitable for recycling and reuse in production instead of being discarded as wastewater.

4.3. Benefits of and barriers to wastewater reclamation in the food-sector

Next, this study also tries to address the benefits of and barriers to implementing wastewater reclamation in the food-sector based on four aspects (technical, environmental, economic and social), with propositions on how all these aspects are interrelated, resulting in a conceptual model. Wastewater reclamation in the food-sector offers a multitude of benefits and presents various challenges across environmental, economic, technical, and social dimensions. The interconnectedness of these aspects underscores the significance of understanding their relationships. Fig. 3 shows the proposed interrelationships among environmental, economic, technical and social aspects (for more details, please refer to Appendix 3).

4.3.1. Environmental and economic integration

The symbiosis between environmental and economic considerations in wastewater reclamation within the food-sector yields several advantages. Resource recovery, energy recovery, and enhanced resource efficiency are key benefits. In the food-sector, wastewater components and their characteristics can be transformed into valuable resources, as shown in previous studies (Anagnostopoulou et al., 2024; Arias et al., 2024; Shroti et al., 2023). This transformative process not only results in resource recovery but also contributes to generating green energy (Amit et al., 2021; Kiran and Mohan, 2021; Wang et al., 2022). Additionally, it promotes resource efficiency by facilitating more efficient water resource use and reducing dependence on external inputs (Shrivastava et al., 2022; Hasanudin et al., 2015). In the study by Bortolini et al. (2017), an economic assessment revealed that the system has a relatively short payback time of approximately two years to reduce the water footprint of the food and beverage industry. The recovery and reuse of wastewater help to minimize the reliance on freshwater sources, which is particularly critical in regions facing water scarcity and advantageous in terms of cost savings in the long term by reducing water consumption and related expenses. In addition, microalgae can serve as a renewable feedstock for clean fuel or biofuel production, reducing the dependence on fossil fuels and promoting sustainability (Anagnostopoulou et al., 2024; Kiran and Mohan, 2021; Zkeri et al., 2024) which in turn contributes to cost savings and increased economic efficiency. In addition to ensuring waste management and sustainable development, using microalgae promotes the concept of a circular economy.

Summary of findings – Most of the studies in this paper address the environmental benefits to the economy brought by the recovery of resources and the efficient use of resources. However, the barriers should be considered. According to Yadav et al. (2021), large-scale wastewater reclamation should be a win-win situation in terms of environmental and economic aspects, making it a good strategy for beginning wastewater reclamation implementation. They also stated that the major barrier to commercializing resource recovery is technology due to its excessive operating and capital costs, which impact the profitability of the overall process. High resource consumption and substantial investment and operational costs present significant hurdles to technology adoption (Torre et al., 2024). Studies have identified major contributors to operational costs, encompassing energy, chemicals, sludge disposal, and maintenance (Ilyas et al., 2021). Strategically integrating environmental stewardship with economic prosperity in the food-sector, especially through wastewater reclamation systems, is pivotal for businesses to contribute to sustainable water management and secure long-lasting financial success, emphasizing the critical role of return on investment (ROI) analysis in assessing economic returns and ensuring long-term financial sustainability. Wastewater reclamation initiatives can yield positive ROI by enabling significant cost savings through proper capacitation of treatment equipment and reduction in freshwater intake and wastewater discharge (Pulluru and Akkerman, 2023). The emphasis on ROI analysis as a pivotal factor in wastewater reclamation systems underscores the critical role of economic considerations in promoting sustainable water management, demonstrating that a positive ROI catalyzes businesses to invest in environmentally friendly practices, such as resource recovery and the efficient use of resources.

Proposition 1. *Environmental considerations positively contribute to economic benefits in the food-sector.*

4.3.2. Technical and environmental integration

In the realm of wastewater reclamation in the food-sector, integrating environmental considerations with technological advancements in wastewater treatment not only offers significant benefits but also

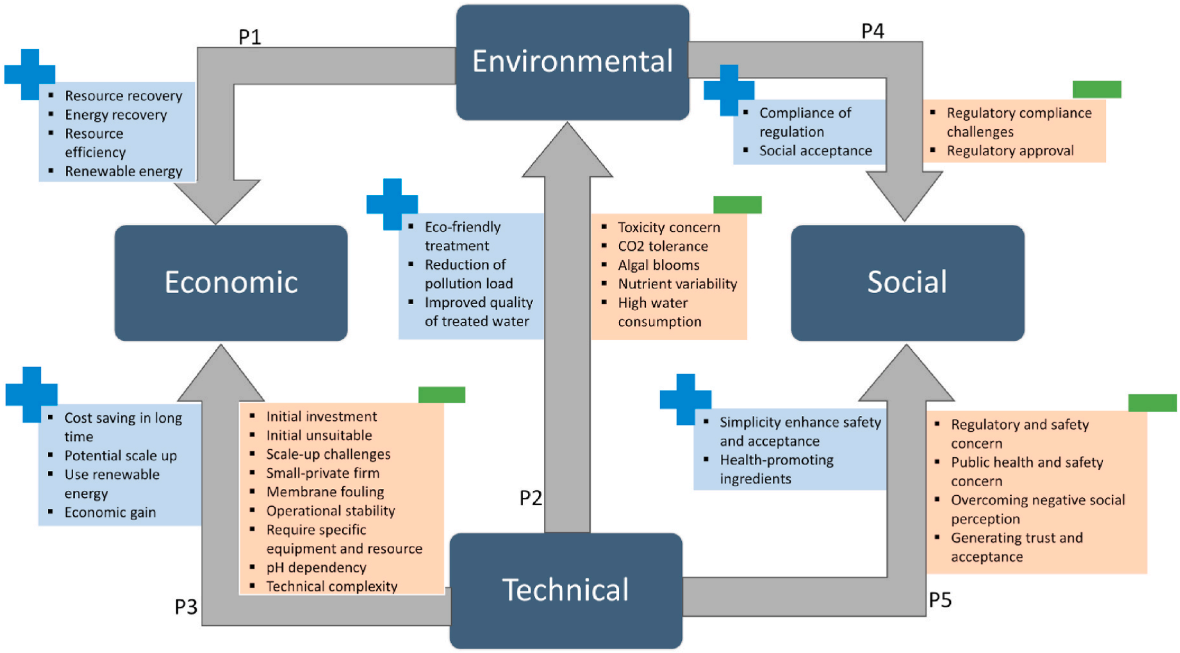

Fig. 3. Integration of the interrelationship framework.

presents challenges that require careful management and innovative solutions to ensure both environmental protection and economic viability. Wastewater reclamation involving biodegradable and non-toxic plant-based coagulants offers an environmentally friendly alternative to synthetic coagulants in wastewater treatment, reducing ecosystem harm and promoting sustainable practices (Balbinoti et al., 2023). Sant'Ana et al. (2024) explored using Corynebacterium aquaticum and 10% brewery wastewater as a carbon source for effluent treatment, offering a cost-effective, sustainable solution that reduces pollution and improves wastewater treatment efficiency. Wastewater generation in the food sector has certain characteristics that can harm the environment; thus, technological advancement can decrease the pollution load. Pervez et al. (2021) reported that electrospun nanofiber membranes can eliminate organic pollutants such as methylene blue dyes from food wastewater. Ochando-Pulido and Martinez-Ferez (2018) revealed that selecting the appropriate membrane technology can be beneficial by reducing COD by 60% and lowering electrical conductivity, thus making effluent suitable for irrigation reuse. Their study also demonstrated that purified effluent meets the salinity standards recommended by the Food and Agriculture Organization (FAO) for irrigation purposes. Shroti et al. (2023) demonstrated that utilizing industrial beverage wastewater for polyhydroxyalkanoate (PHA) production reduces the burden on wastewater management because of the high sugar content and alkalinity of wastewater, which can harm the environment. Prazeres et al. (2016) showed that traditional wastewater treatment methods, which can negatively impact the soil structure, are being implemented through technological advancements. Conventional treatments aim to reduce organic contamination, leading to improved soil health.

Nevertheless, studies have identified challenges in wastewater reclamation in the food sector from technical and environmental perspectives. These challenges pose significant barriers that need careful consideration and management. Patange et al. (2018) noted that prolonged contact (up to 48 h) with ACP-treated effluents can be toxic to certain aquatic species, such as Daphnia, raising concerns about potential ecological impacts. Regarding treatment used in microalgae cultivation, O'Rourke et al. (2016) reported that the quality and nutrient content of brewery wastewater can vary, which may lead to inconsistent microalgal growth and biomass production. In addition, the bioremediation (the process of using biological microorganisms) approach not only helps mitigate environmental hazards associated with insufficient treatment but also supports nutrient recovery and biomass generation, aligning with the principles of a circular economy (Wang et al., 2024; Zkeri et al., 2024). Recognizing and managing nutrient variability is paramount for ensuring the effectiveness of the cultivation process. Jain et al. (2019) emphasized the potential risk of algal blooms if the cultivation process is not carefully managed. Uncontrolled algae growth can have detrimental effects on the ecosystem, underscoring the imperative for careful nutrient control and monitoring in microalgal cultivation. Furthermore, Paz-Samaniego et al. (2016) noted a significant water consumption issue during the nixtamalization process, particularly problematic in regions experiencing water scarcity or water resource mismanagement. Efficient water use and management have emerged as imperative components for ensuring the sustainability of wastewater reclamation efforts in the food-sector.

Summary of findings – In wastewater reclamation in the food sector, integrating environmental considerations with technological advancements poses both benefits and challenges from technical and environmental perspectives. The adoption of biodegradable plant-based coagulants stands out as a technically innovative and environmentally friendly solution for mitigating harm to ecosystems. Advancements such as electrospun nanofiber membranes and specialized membrane technologies have contributed to efficient wastewater treatment, reducing COD and making effluent suitable for irrigation reuse. However, the challenges identified in studies, such as the potential toxicity to aquatic species, the effect of nutrient variability on microalgal cultivation, and water consumption issues, emphasize the importance of addressing both technical and environmental aspects in wastewater reclamation efforts. Thus, LCA is needed to aid in improving the technical efficiency of a system and to ensure that improvements contribute to environmental sustainability by minimizing negative impacts across the entire life cycle. Monteiro et al. (2018) exemplified the crucial role of LCA in identifying the most sustainable and cost-effective methods for valorizing process wastewater, ensuring that environmental benefits are maximized throughout the process.

Proposition 2. *The technical efficiency of food-sector wastewater reclamation contributes to environmental sustainability.*

4.3.3. Technical and economic integration

This integration has numerous advantages. For example, Patange et al. (2018) reported that assessing the performance of ACP in controlling microbial indicators in food-sector effluent has the potential for scale-up to larger industrial installations, indicating its suitability for practical applications in the food-sector. In terms of the economy, the ability to scale up ACP indicates the potential for increased production capacity in the food-sector. Similarly, scaling up nutrient recovery from wastewater demonstrates significant potential, with effluent and biosolids providing up to 5 kg N and 0.76 kg P per person per year, sufficient to meet 6.7–29.2% of urban vegetable needs in cities like Seattle and Tacoma, while supporting sustainable, cost-effective nutrient supply chains and advancing circular economy goals (Brown et al., 2023). This expanded capacity can lead to higher output and potentially contribute to economic growth within the sector. Microalgae cultivation is an economically favourable strategy because it does not require additional nutrients and uses wastewater from the seafood processing industry as a resource (Jain et al., 2019). This can reduce the costs associated with both wastewater treatment and biofuel production. In addition, a study by Monteiro et al. (2018) on liquid by-products from fish canning conducted an LCA and revealed that extraction with hydrostatic pressure offers economic advantages by providing a cost-effective extraction method. The adoption of such a method can result in cost savings for the fish canning industry, making the industry's operations more economically viable. Moreover, Arias et al. (2024) explored the valorizing ferulic acid from wastewater from a corn tortilla plant and using it to create a functional bioactive material. Thus, it leads to economic benefits through cost reduction in waste management and the potential for generating revenue from bioactive material applications. Technological innovations in the food industry, i.e., reducing water withdrawal and waste production, can lead to significant cost efficiencies and long-term savings, enhancing the sector's economic viability (López-Cabarcos et al., 2024). Similarly, Ahmed et al. (2024) introduced a new bio-based flocculant that is more affordable than existing commercial flocculants, which could further reduce operational costs for food industry wastewater treatment, supporting cost-effective and sustainable wastewater management in the sector.

Despite the evident benefits, challenges persist in this integration. Technically, some treatment plants need a high initial investment, where implanting membrane technology and integrated membrane processes (IMPs) can be associated with high upfront costs, particularly in acquiring the necessary membrane equipment (Castro-Muñoz et al., 2017). Additionally, the economic costs and technical challenges of adopting sustainable practices in the food sector are considerable, given its heavy reliance on natural resources such as water, energy, and raw materials (López-Cabarcos et al., 2024). Although research indicates a relatively short payback time for small food and beverage companies, their barriers are the significant initial capital costs associated with system implementation (Bortolini et al., 2017). Small private firms with part-time employees are less likely to treat water before discharge due to limited resources and financial constraints (Meng et al., 2022). The setup and equipment require an initial investment for treatments that use EC and EO, especially when using advanced materials such as boron-doped diamond (BDD) electrodes (Hernández et al., 2016). Bioelectrochemical systems (BESs) may face technical challenges, such as membrane fouling, electrode stability, and microbial management, affecting long-term performance (Ramanaiah et al., 2023). Transitioning from a research setting to industrial-scale production can be challenging, especially in the scalability, cost-effectiveness, and consistent quality control (Ahmed et al., 2024; Brown et al., 2023; Paz-Samaniego et al., 2016). Implementing reuse strategies involves technical complexity and financial costs (Shrivastava et al., 2022). For instance, implementing microbial processing for dairy wastewater can be technically complex and requires expertise in microbiology, biotechnology, and engineering (Usmani et al., 2022). For wastewater treatment, pH dependency can be a barrier when dealing with variations in the pH of real wastewater, as it may require adjustments or pH control for effective treatment (Nayak et al., 2018). The effectiveness of membrane processes can be limited by concentration polarization, cake layer growth, and fouling, which can reduce the efficiency of such processes over time (Castro-Muñoz et al., 2017; Pervez et al., 2021). The membranes' cost can be a limiting factor, especially when membranes need replacement or maintenance.

Summary of finding – Exploring wastewater treatment strategies' integrated technical and economic aspects reveals notable advantages, such as the potential for scale-up, economic gains and economic benefits. However, challenges persist, such as the initial investment cost, technical complexity, maintenance costs and scale-up challenges. Hence, a thorough LCC assessment is needed to address the economic viability of wastewater treatment strategies.

Proposition 3. *The technical aspects of wastewater reclamation substantially influence the economic benefits.*

4.3.4. Environmental and social integration

The environmental aspect of wastewater reclamation can significantly influence social factors, particularly the public's acceptance of wastewater reclamation and the regulatory compliance of companies involved in wastewater management. A study by Josa and Garfí (2023) found that water reclamation in the food sector commonly uses a standard growth medium (an essential nutrient solution widely used to grow microalgae) to meet the stakeholders' expectations. This result is due to the medium's simplicity, reduced health and safety risks, and greater acceptability, making it more socially acceptable. In addition, well-established frameworks provide a clear set of guidelines and standards for various practices, ensuring consistency and accountability. The presence of well-established legislation and regulatory frameworks for standard growth medium scenarios benefits value chain actors and society (Josa and Garfí, 2023). The system's ability to produce water that meets or exceeds the standards for advanced industrial use helps food and beverage companies comply with regulatory requirements for water quality (Bortolini et al., 2017). Companies need to adhere to regulatory requirements related to wastewater quality and treatment. Simultaneously, the public's willingness to accept and adopt wastewater reclamation practices can be influenced by how well these practices align with environmental standards and regulations.

Regulatory approval and validation are necessary to ensure the safety and effectiveness of wastewater reclamation systems. However, the process may pose challenges in terms of lengthy, time-consuming and bureaucratic processes (Valili et al., 2013). Compliance with regulations and sustainability standards is not always straightforward. It may demand extra effort and resources, possibly due to the complexity of the regulations, changing standards, or the need for ongoing monitoring and reporting (Hasanudin et al., 2015). Depending on local laws and permitting requirements, implementing a wastewater recovery and purification system may face legal and regulatory hurdles, which could impede system adoption (Bortolini et al., 2017).

Summary of finding – The environmental dimension of wastewater reclamation significantly influences social aspects, impacting public acceptance and regulatory compliance. Compliance with standards is crucial for companies and contributes to public trust. However, obtaining regulatory approval may face challenges, and compliance efforts demand resources. Legal hurdles may impede wastewater system adoption. Thus, it is suggested that companies engaging in corporate social responsibility (CSR) initiatives related to wastewater management demonstrate commitment to environmental stewardship and enhance public trust, showing a strong motivation to reuse wastewater. Reusing wastewater is gaining momentum among commercial enterprises, as it facilitates regulatory compliance and enhances their CSR standing (Shrivastava et al., 2022). Comprehensive education and awareness campaigns about the environmental benefits of wastewater reclamation are essential, as they emphasize the positive impacts on water conservation and ecological sustainability. A responsible approach to wastewater reclamation contributes to fostering positive social attitudes.

Proposition 4. *Environmental responsibility in food-sector wastewater reclamation has the potential to impact social attitudes positively.*

4.3.5. Technical and social integration

Technical-social integration represents a holistic approach that combines technological advancements with social considerations, intending to optimize technical processes and community well-being. For example, simpler microalgal-based systems that have fewer contaminants improve health and safety for workers, consumers, and the local community (Josa and Garfí, 2023). Ensuring the safety and well-being of stakeholders is a crucial component of sustainability. Therefore, the implementation of wastewater treatment not only contributes to environmental sustainability but also yields valuable health-promoting ingredients. Utilizing arabinoxylans (AXs) extracted through this process as a probiotic encapsulation material has significant potential to revolutionize the food-sector. The resulting food products can enhance public health by improving gut health, providing antioxidant properties, and supporting the immune system (Paz-Samaniego et al., 2016). This breakthrough not only addresses environmental concerns through wastewater treatment but also introduces innovative approaches to creating functional foods that can positively impact the well-being of society.

However, wastewater treatment can still pose microbiological contamination risks if not properly managed. This may lead to health threats, especially if the untreated water is reused in food processing, particularly in minimally processed products (Kanarek et al., 2024). This risk can undermine public confidence in water reuse practices, affecting the acceptance of such systems. In addition, some countries limit wastewater reuse due to legal constraints and restrictions due to public health and safety concerns, which suggests that ensuring water quality is a significant challenge (Shrivastava et al., 2022). The use of microalgae in wastewater treatment and food production may be subject to regulatory and safety considerations that need to be addressed (Kiran and Mohan, 2021). Overcoming the negative social perception and generating trust and acceptance of products recovered from wastewater treatment processes can be challenging and a barrier to widespread adoption (Josa and Garfí, 2023).

Summary of finding – Regarding the holistic integration of technical and social aspects in wastewater reclamation, the simplicity of treatment improves the health and safety of employees and presents an innovative opportunity for health-promoting benefits. In terms of safety, acceptance among the public may be challenging. For instance, He et al. (2023) stated that the public's acceptance and support are crucial to ensure that wastewater reuse projects are implemented safely and effectively. Strict regulations and public feedback help prevent companies from prioritizing profits over safety standards (J. He et al., 2023). Addressing concerns related to health, safety, and environmental impact is essential for fostering positive social attitudes. Therefore, successful wastewater reclamation projects require cutting-edge technical solutions and effective communication, education, and engagement strategies to garner support and acceptance from the community.

Proposition 5. *The technical success of wastewater reclamation initiatives in the food-sector directly shapes public perceptions and acceptance.*

5. Future research directions

The SLR reveals a research taxonomy, discusses findings and identifies propositions. In this light, the current study suggests six limitations that must be highlighted to guide future research on wastewater reclamation in the food sector, as shown in Table 5. First, most of the methodologies in this SLR are experimental research designs that have provided insights into the characteristics and recovery of compounds

Table 5
Future research directions.

Literature gaps	Possible future directions	Possible research questions
Most studies involve experimental research designs	Analysing the transition from laboratory-scale experiments to larger-scale applications in wastewater management	● How can wastewater management techniques be effectively integrated into existing industrial processes within the food-sector at a larger scale? What modifications or adaptations are required for seamless integration? ● What are the key parameters that need to be optimized when scaling up wastewater management techniques from laboratory settings to larger industrial scales, and how do these parameters impact the overall effectiveness of the process?
Lack of an economic-social interrelationship	Developing thorough frameworks to systematically study and understand the simultaneous economic and social impacts of wastewater reclamation practices in the food sector	● What are the interdependencies between economic and social indicators, and how can they be integrated into a unified impact assessment model for wastewater reclamation initiatives?
Lack of examination of consumer perceptions	Analysing the factors influencing consumers' acceptance of food products derived from wastewater reclamation practices in the food-sector	● How do consumers perceive and evaluate the adoption of food products derived from wastewater reclamation practices in the food-sector, and what factors influence their willingness to incorporate these products into their consumption patterns?
Lack of research on managerial perceptions	Exploring the multifaceted aspects influencing food companies' willingness to adopt wastewater reclamation practices	● What are the primary determinants influencing the willingness of food companies to adopt wastewater reclamation practices, considering factors such as economic considerations, regulatory compliance, and sustainability goals? ● What is the level of acceptance or willingness of food companies to adopt wastewater reclamation practices?
Lack of examinations of different company scales	Investigating and comparing the experiences, challenges, and strategies of small-, medium-, and large-scale food companies in implementing wastewater reclamation	● How does adopting wastewater reclamation practices contribute to the overall CSR initiatives of small-, medium-, and large-scale food companies, and are there variations in CSR priorities across different scales? ● How does the scale of food companies (small, medium, large) influence their adoption and implementation of wastewater reclamation practices, and what are the unique challenges companies face at each scale?

(*continued on next page*)

Table 5 (*continued*)

Literature gaps	Possible future directions	Possible research questions
Lack of research studying political and legal perspectives and the regulatory scale	Investigating how political and legal factors at different levels of governance influence the implementation and regulation of wastewater reclamation in the food-sector	● How effective are existing legal frameworks in addressing the challenges and promoting the adoption of sustainable wastewater management practices in the food-sector? ● What is the role of intergovernmental relations in influencing the development and implementation of regulations related to wastewater reclamation in the food-sector?

from wastewater, revealing significant benefits and the potential for reuse. These findings emphasize the need for future research to transition from laboratory experiments to pilot studies and larger-scale demonstrations. This transition will address the disparity between controlled experiments and practical implementation by substantiating the feasibility and effectiveness of wastewater management techniques in real-world industrial contexts. This shift should aim to advance insights into scalability, operational challenges, and integration within existing processes in the food-sector, fostering the evolution of sustainable practices that harmonize scientific knowledge with actionable solutions for environmental management.

No economic-social interrelationships were found in this SLR. This absence underscores a critical gap in the current understanding of how economic considerations, such as cost-benefit analyses or market dynamics, may influence or interact with social elements, including community perceptions, employment dynamics, and overall societal well-being within the context of wastewater reclamation in the food-sector. Thus, it is necessary to develop comprehensive frameworks for assessing the simultaneous economic and social impacts of wastewater reclamation practices in the food-sector. Furthermore, the papers in the SLR lacked a specific focus on social aspects, particularly concerning consumers' perceptions of purchasing or accepting food products derived from wastewater reclamation practices in the food-sector. Therefore, a critical direction for future research involves conducting a thorough analysis of how various social factors, such as public awareness, trust, and attitudes, influence consumers' willingness to purchase and embrace food products resulting from wastewater reclamation initiatives in the context of food production.

Furthermore, there is a notable gap in the literature regarding case studies on the willingness of food companies to adopt wastewater reclamation practices. To address this deficiency and advance our understanding of industry practices, it is strongly recommended that future research focus on conducting in-depth case studies within the context of food companies. This research should explore the specific factors influencing companies' decisions to adopt or reject wastewater reclamation initiatives, taking into account aspects such as economic considerations, regulatory compliance, corporate sustainability goals, and the potential impact on consumer perceptions. Moreover, there is a lack of research examining how companies of varying sizes within the food-sector engage in or are affected by wastewater reclamation practices. Future research can perform a comparative analysis to systematically investigate the distinct experiences, challenges, and outcomes associated with wastewater reclamation practices among small-, medium-, and large-scale companies in the food-sector, providing valuable insights for tailored and scalable sustainable solutions. Finally, there is a lack of research on regulations' political and legal aspects at different levels. How politics and laws influence the rules for reusing wastewater in the food-sector is insufficiently understood. Future research should focus on how government policies and laws impact these practices. Such research should examine how different levels of government work together and how well existing laws work.

6. Conclusion

The food-sector is under fire for using a lot of water as a result of its unsustainable practices. This is why it is suggested that wastewater reclamation be executed to align with the SDGs and prioritize sanitation and clean water. However, the literature on this is fragmented, which limits the knowledge. Therefore, the present study explores the relationship between wastewater reclamation and sustainability by structuring the existing literature. In total, 40 peer-reviewed articles were used to answer the three aforementioned research questions by employing Snyder (2019) four-phase methodology (design, conduct, analysis and structure). Exploring wastewater reclamation in the food-sector through this SLR has provided several crucial findings.

- The answer to the first research questions:

The present study has identified five factors that influence the implementation of wastewater reclamation: economizing water consumption, combating wastewater generation, embracing wastewater reclamation, optimizing wastewater utilization, and practising wastewater reuse.

- The answer to the second research question:

An in-depth exploration of the benefits of and barriers to, covering the technical, environmental, economic, and social dimensions, has been undertaken where, in total, 15 benefits and 19 barriers have been identified. The benefits of wastewater reclamation led to its implementation. Most studies cover technology use in wastewater reclamation, and the findings reveal that technical aspects are the most significant players in terms of benefits and barriers. Technical aspects are independent factors that influence social, economic, and environmental aspects (dependent factors).

Additionally, this research significantly advances the understanding of wastewater reclamation in the food sector, particularly in its theoretical and conceptual frameworks. The paper fills existing gaps in the literature by synthesizing diverse findings and providing a more holistic view of wastewater reclamation's role in sustainability. It also contributes to the growing field of sustainable water management by offering a more precise, evidence-based conceptual framework specific to the food industry. The insights provided here are essential for scholars aiming to expand on the theoretical foundations of wastewater reclamation. Moreover, the study identifies key areas where future research is needed, contributing to the academic discourse by proposing future research directions focused on untapped gaps within the field. This study is a reference point for future studies and theoretical advancements in sustainable water management practices.

Moreover, from a practical standpoint, this paper holds significant value for industry practitioners and policymakers. It emphasizes the economic advantages of wastewater reclamation and recommends strategies for investment in reclamation technologies that align with business objectives. The study calls for increased research and development to address the technical barriers identified, encouraging collaboration with technology providers to enhance feasibility. Furthermore, industry players are urged to integrate environmental responsibilities into their corporate social responsibility (CSR) goals and educate and engage local communities to ensure a positive social impact. For policymakers, the research recommends implementing and enforcing stringent environmental standards to ensure that wastewater reclamation practices comply with regulatory requirements while being easy to monitor, regulate and safe to reuse.

Finally, this study acknowledges certain limitations, which offers opportunities for future research on the topic. First, while the Scopus and WoS databases are comprehensive, there is a possibility that some relevant publications on wastewater reclamation in the food-sector were not captured. One might be the reason for the restriction on getting free articles from the websites. Second, the exclusion of book chapters and conference papers might have led to the omission of valuable insights which might be left out unintentionally. Lastly, this study might not have captured all relevant articles due to the use of different search-related keywords, even though these keywords were based on previous research. This limitation highlights the importance of a thorough and careful literature review process. To this end, future studies should improve the keyword search string and broaden the situation of the food-sector.

CRediT authorship contribution statement

Nabiilah Mat Yusoff: Writing – original draft, Investigation, Conceptualization. **Norhidayah Suleiman:** Writing – review & editing, Visualization, Validation, Investigation. **Asma-Qamaliah Abdul-Hamid:** Writing – review & editing, Supervision, Project administration, Methodology, Formal analysis. **Mohd Helmi Ali:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

There is no conflict of interest between the authors.

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Appendix 1. Summary of the reviewed studies

No	Authors	Research Methodology	Objective
1	Ahmed et al. (2024)	Experimental research	To find an affordable and effective method for managing this waste using a new flocculant made from sustainable sources, specifically crude olive pomace oil, and combining it with alum for better coagulation and flocculation.
2	Alkaya and Demirer (2015)	Case study	To investigate water conservation and reuse opportunities in a soft drink/beverage manufacturing company.
3	Amit et al. (2021)	Review	To discover the information of the use of different food processing wastewater for microalgae biomass cultivation
4	Anagnostopoulou et al. (2024)	Experimental research	To optimize bioremediation using microalgae (Chlorella vulgaris, Nannochloropsis oculata, and Scenedesmus sp.) for treating food industry wastewater, enhancing growth and removing phosphate, nitrogen, COD, and TOC to support wastewater management and circular bioeconomy.
5	Arias et al. (2024).	Life Cycle Assessment	To design and assess an enzymatic process to valorize ferulic acid from corn tortilla plant effluent, immobilizing it on chitosan to create a bioactive film with enhanced antioxidant properties, while evaluating the process's environmental and economic performance through Techno-Economic Analysis (TEA) and Life Cycle Assessment (LCA) for potential biotech applications.
6	Balbinoti et al. (2023)	Review	To explore the benefits and feasibility of replacing synthetic coagulants with plant-based coagulants for effluent treatment.
7	Boguniewicz-Zablocka et al. (2020)	Experimental research	To assess the impact of adding new ingredients, annatto and yeast extract, in snack production on the nature of process wastewater and to explore solutions for efficient wastewater treatment
8	Bortolini et al. (2017)	Life-cycle assessment	To address the issue of high-water consumption in the EU F&B industry; 2) to develop and assess a wastewater closed-loop recovery and purification system tailored for a standard mid-size F&B company, with the goal of reducing water consumption, environmental impact, and costs.
9	Brown and Butman (2023)	Experimental research	To quantify nutrient recovery from urban residuals, like food scraps and wastewater, and assess their potential to enhance urban agriculture and sustainability through a circular nutrient economy.
10	Castro-Muñoz et al. (2017)	Review	To address waste disposal challenges in agro-food industries.
11	España-Gamboa et al. (2017)	Experimental research	To explore the potential for methane production from nejayote, 2) to optimize its treatment using a two-phase anaerobic digestion system for the methanogenic phase.
12	Fito et al. (2019)	Experimental research	1) To assess the physicochemical properties of sugar industry and ethanol distillery wastewater 2) to treat the combined wastewater from both industries.
13	Guerreiro et al. (2020)	Experimental research	To design a cost-effective treatment method for cheese manufacturing effluents, utilizing various precipitation processes.
14	Hasanudin et al. (2015)	Survey	To assess the current treatment and utilization of palm oil mill effluent (POME) in Indonesia and propose alternative scenarios to improve the sustainability of the palm oil industry
15	Hernández et al. (2016)	Experimental research	To implement a coupled system involving monopolar Electrocoagulation (EC) and Electrooxidation (EO) processes for treating soft drink wastewater.
16	Jain et al. (2019)	Experimental research	To assess the efficiency of CO2 utilization by the microalgae Chlorella vulgaris NIOCCV when cultivated in seafood processing industry wastewater.
17	Josa and Garfí (2023)	Life-cycle assessment	To evaluate how the use of microalgae in treating wastewater and producing bioproducts affects various social aspects and stakeholders involved in these systems.
18	Kanarek et al. (2024)	Experimental research	To assess the properties of rinse water from a post-harvest processing plant before and after treatment with an innovative modular system, evaluating its effectiveness for reuse in agri-food production
19	Karadag et al. (2014)	Review	To investigate the potential for sustainable hydrogen production from dairy wastewater, focusing on dark fermentation as a biological method.
20	Kiran and Mohan (2021)	Experimental research	To investigate how different light intensities affect the photosynthetic performance and behavior of Chlorella sorokiniana SVMBIOEN2 during the treatment of dairy wastewater.
21	Kumari et al. (2019)	Experimental research	To find out if it's possible to recover phosphorus from distillery spent wash by using a process called struvite precipitation.
21	Kumari et al. (2024)	Experimental research	To explore coconut coir dust (CCD) as a biosorbent for removing Sunset Yellow dye from wastewater, assessing its effectiveness in batch and column modes, adsorption characteristics, and economic feasibility.
22	Lima et al. (2021)	Case study	Exploring the possibilities of reusing treated water in the production cycle, contributing to the sustainable use of water resources and presenting solution.

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No	Authors	Research Methodology	Objective
23	López-Cabarcos et al. (2024)	Case study	To identify water and waste management practices that drive overvaluation of food companies (Tobin's Q > 1) and explore how sustainable practices enhance financial performance.
24	Lu et al. (2017)	Experimental research	To investigate factors limiting algae growth in brewery effluent, with specific objectives focused on cultivating Spirulina sp. in raw brewery effluent.
25	Mateus et al. (2021)	Experimental research	To assess the treatment and potential reuse of wastewater produced during guava paste production in agricultural irrigation.
26	Meng et al. (2022)	Survey	This paper examines pre- and post-production water treatment practices among food processors and investigates factors, especially managerial perceptions of environmental pressure that encourage or preclude either process
27	Paz-Samaniego et al. (2016)	Experimental research	To evaluate the ability of maize wastewater arabinoxylans (MWAX) to encapsulate probiotics.
28	Menussi et al. (2023)	Case study	To determine the water footprint of chilled chicken meat processing, analyse the allocation of water use (blue, green, and grey) in the production process, and assess how the water footprint aligns with and contributes to specific Sustainable Development Goals.
29	Monteiro et al. (2018)	Experimental research	To develop a sustainable and economically viable method for extracting valuable ω3 lipids from fish canning liquid waste by-products.
30	Mukherjee et al. (2015)	Experimental research	To investigate the potential of utilizing the free-floating aquatic plant water lettuce (*Pistia stratiotes*) for phytoremediation of parboiled rice mill wastewater.
31	Najar-Almanzor et al. (2024)	Experimental research	To assess the potential of Chlorella vulgaris in bioremediating complex wastewater effluents from the food and beverage industries while producing valuable compounds such as pigments, proteins, and phenolic compounds.
32	Nayak et al. (2018)	Experimental research	To develop a sustainable and eco-efficient process for removing total polyphenols from wine wastewater as a pretreatment step for anaerobic digestion.
33	O'Rourke et al. (2016)	Experimental research	To assess the effectiveness of Parachlorella kessleri, a type of microorganism, in utilizing brewery wastewater (Br WW) for growth and metabolite production.
34	Ochando-Pulido and Martinez-Ferez (2018)	Experimental research	To assess the concentration and recovery of high-added value compounds, specifically the polyphenolic fraction, from two-phase olive mill wastewater (OMW).
35	Patange et al. (2018)	Experimental research	To assess the effectiveness of using dielectric barrier discharge atmospheric cold plasma (ACP) for controlling microbial indicators in food industry effluent.
36	Paz-Samaniego et al. (2016)	Experimental research	To evaluate the ability of maize wastewater arabinoxylans (MWAX) to encapsulate probiotics.
37	Pervez et al. (2021)	Review	To summarizes the role of available membrane technologies that have been employed for food wastewater treatment and analyse their performance.
38	Prazeres et al. (2016)	Experimental research	To investigate the treatment of raw cheese whey wastewater (CWW) using a multi-step process
39	Ramanaiah et al. (2023)	Review	To tackle challenges in food production related to the environmental and climate impacts of organic waste and wastewater generation.
40	Sant'Ana et al. (2024)	Experimental research	To evaluate the potential of treating beer industry effluents with biosurfactants from brewery wastewater, assessing their effectiveness in reducing BOD, COD, and TS.
41	Selvasembian et al. (2022)	Review	To discusses the recent implementation and advancement of MFCs to treat various wastewater for power generation with a special focus on industrial effluents.
42	Shrivastava et al. (2022)	Review	To address key issues pertaining to water consumption, wastewater generation, treatment, and successful implementation cases of water reuse in the food and beverage industry.
43	Shroti et al. (2023)	Experimental research	To address the environmental issues caused by the beverage industry's wastewater by using a specific bacterium.
44	Usmani et al. (2022)	Review	To investigate how aerobic and anaerobic microbial treatments can be employed to convert dairy waste into valuable products.
45	Valili et al. (2013)	Experimental research	To discover a sustainable solution for handling malt spent rootlets (MSR), abundant by-products of the beer industry.
46	Vidyarthi and Simmons (2020)	Review	To reviews the characteristics of byproduct/discharge streams (solid stream and process water stream) generated at different stages of tomato processing from the California tomato processing plants.
47	Wang et al. (2021)	Experimental research	To evaluate the feasibility of reducing energy consumption by using forward osmotic membrane technology to concentrate vegetable liquor.
48	Wang et al. (2022)	Experimental research	To examine the potential and performance of bio-H_2 production from brewery wastewater using Clostridium butyricum NH-02.
49	Wang et al. (2024)	Experimental research	To explore bioremediation using an indigenous microbial community, including Halamphora coffeaeformis monoculture and synthetic bacteria, to recover nutrients and generate biomass from FIPW, aiming for high nutrient recovery and biomass use in biochemicals and fertilizer production.
50	Welz et al. (2014)	Experimental research	To compare the biodegradation of two distinct formulations of winery effluent in sand bioreactors.
51	Zkeri et al. (2024)	Experimental research	To investigate Chlorella sorokiniana for treating winery wastewater, examining the effects of biomass acclimatization, wastewater dilution, and ammonium nitrogen on microalgae growth and pollutant removal, while exploring the potential for producing valuable products like proteins, lipids, and pigments.

Appendix 2. Factors influencing implementation of wastewater reclamation in food-sector

1) Economizing food industry on water consumption	2) Combating on wastewater generation in food industry	3) Embracing technology innovation in food wastewater reclamation	4) Optimization of food wastewater utilization	5) Practicing water reuse from food industry wastewater
i) Solve water scarcity Shrivastava et al. (2022); Lima et al. (2021) López-Cabarcos et al. (2024)	i) Regulatory requirement Patange et al. (2018); Shrivastava et al. (2022); Guerreiro et al. (2020); Ochando-Pulido and	i) Improve of technology of treatment efficiency Valili et al. (2013); Castro-Muñoz et al. (2017); Patange et al. (2018);	i) Production of Value-Added Product Castro-Muñoz et al. (2017); Hasanudin et al. (2015); Jain et al. (2019);	i) Irrigation Ochando-Pulido and Martinez-Ferez (2018); Mateus et al. (2021); Guerreiro et al. (2020);

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1) Economizing food industry on water consumption	2) Combating on wastewater generation in food industry	3) Embracing technology innovation in food wastewater reclamation	4) Optimization of food wastewater utilization	5) Practicing water reuse from food industry wastewater
	Martinez-Ferez (2018); Mukherjee et al. (2015)	Hernández et al. (2016); Welz et al. (2014); Mateus et al. (2021); Guerreiro et al. (2020); Pervez et al. (2021); Wang et al. (2021); Mukherjee et al. (2015); Prazeres et al. (2016); Nayak et al. (2018); Welz et al. (2014) Sant'Ana et al. (2024)	Karadag et al. (2014); Kumari et al. (2019); Amit et al. (2021); Paz-Samaniego et al. (2016); Fito et al. (2019); Kiran and Mohan (2021); Shroti et al. (2023); Wang et al. (2022); Monteiro et al. (2018); España-Gamboa et al. (2017); Lu et al. (2017); O'Rourke et al. (2016) Wang et al. (2024)	Fito et al. (2019) Kanarek et al. (2024)
ii) Reduce raw water consumption Bortolini et al. (2017); Lima et al. (2021); Alkaya and Demirer (2015); Ochando-Pulido and Martinez-Ferez (2018); Menussi et al. (2023); Usmani et al. (2022)	ii) Reduce of impact toward environment Shrivastava et al. (2022); Boguniewicz-Zablocka et al. (2020); Wang et al. (2021); Prazeres et al. (2016); Usmani et al. (2022) Ahmed et al. (2024)	ii) Power generation Selvasembian et al. (2022); Ramanaiah et al. (2023)	ii) Reduce impact of alkalinity towards environment Paz-Samaniego et al. (2016); Fito et al. (2019); Shroti et al. (2023); España-Gamboa et al. (2017); Ramanaiah et al. (2023)	ii) Production Castro-Muñoz et al. (2017); Shrivastava et al. (2022); Alkaya and Demirer (2015); Lima et al. (2021); Hernández et al. (2016)
iii) Reduce cost production Meng et al. (2022)	iii) Improve of wastewater management strategies Boguniewicz-Zablocka et al. (2020); Vidyarthi and Simmons (2020); Welz et al. (2014); Wang et al. (2021)	iii) Promotion of environmentally friendly treatment Balbinoti et al. (2023) Ahmed et al. (2024)	iii) Energy generation Selvasembian et al. (2022); Ramanaiah et al. (2023); Lu et al. (2017); O'Rourke et al. (2016); Wang et al. (2022) iv) Reduce GHG emission Amit et al. (2021); España-Gamboa et al. (2017)	iii) Non-potable usage Hernández et al. (2016)

Appendix 3. Benefits and barriers of wastewater reclamation in food industry (environmental-economic integration and environmental-social integration)

	Economic	Social	
	Benefits	Benefits	Barriers
Environmental	1) Resource recovery Amit et al. (2021); Ochando-Pulido and Martinez-Ferez (2018); Kiran and Mohan (2021); Shroti et al. (2023); Wang et al. (2022); Josa and Garfí (2023); Valili et al. (2013) Arias et al. (2024) Anagnostopoulou et al. (2024) 2) Energy recovery Amit et al. (2021); Kiran and Mohan (2021); Wang et al. (2022) Zkeri et al. (2024) Anagnostopoulou et al. (2024) 3) Resource efficiency Shrivastava et al. (2022); Hasanudin et al. (2015) 4) Renewable energy Jain et al. (2019); Kiran and Mohan (2021)	5) Compliance of regulation Bortolini et al. (2017) 6) Social acceptance Josa and Garfí (2023)	1) Regulatory compliance challenges Hasanudin et al. (2015) 2) Regulatory approval Valili et al. (2013)

6.1 Table 3B. Benefits and barriers of wastewater reclamation in food industry (technical-environmental integration, technical-economic integration and technical-social integration)

	Environmental		Economic		Social	
	Benefits	Barriers	Benefits	Barriers	Benefits	Barriers
Technical	7) Eco-friendly treatment Balbinoti et al. (2023)	3) Toxicity concern Patange et al. (2018)	10) Cost saving in long time Meng et al. (2022) López-Cabarcos et al. (2024) Ahmed et al. (2024)	8) Initial unsuitable Lu et al. (2017); Castro-Munoz et al. (2017)	14) Simplicity enhance safety and acceptance Josa and Garfí (2023)	16) Regulatory and safety concern Kiran and Mohan (2021)
	8) Reduction of pollution load Pervez et al. (2021); Ochando-Pulido and Martinez-Ferez (2018); Shroti et al. (2023); Balbinoti et al. (2023); Prazeres et al. (2016) Sant'Ana et al. (2024)	4) CO_2 tolerance Jain et al. (2019)	11) Potential scale up Patange et al. (2018) Brown et al. (2023)	9) Scale-up challenges Bortolini et al. (2017); Hernández et al. (2016) López-Cabarcos et al. (2024)	15) Health-promoting ingredients Paz-Samaniego et al. (2016)	17) Public health and safety concern Shrivastava et al. (2022) Kanarek et al. (2024)
		5) Algal blooms Jain et al. (2019)	12) Use renewable energy Kiran and Mohan (2021); Jain et al. (2019)	10) Small-private firm Meng et al. (2022) Balbinoti et al. (2023)		18) Overcoming negative social perception Josa and Garfí (2023)
		6) Nutrient variability O'Rourke et al. (2016)		11) Membrane fouling Castro-Muñoz et al. (2017) Pervez et al. (2021)		19) Generating trust and acceptance Josa and Garfí (2023)
	9) Improved quality of treated water Bortolini et al. (2017)	7) High consumption water Paz-Samaniego et al. (2016)	13) Economic gain Shroti et al. (2023); Monteiro et al. (2018) Arias et al. (2024)	12) Operational stability Ramanaiah et al. (2023) Ahmed et al. (2024) Brown et al. (2023) 13) Require specific equipment and resource Usmani et al. (2022) 14) pH dependency Nayak et al. (2018) 15) Technical complexity Paz-Samaniego et al. (2016); Castro-Munoz et al. (2017); Pervez et al. (2021)		

Data availability

No data was used for the research described in the article.

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