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Review

Toward Climate Neutrality: A Comprehensive Overview of Sustainable Operations Management, Optimization, and Wastewater Treatment Methods

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Abstract: Various studies have been conducted in the fields of sustainable operations management (SOM), optimization, and wastewater treatment, yielding unsubstantiated recovery. In the context of Europe's climate neutrality vision, this paper reviews effective decarbonization strategies and proposes sustainable approaches to mitigate carbonization in various sectors such as buildings, energy, industry, and transportation and how these interlink with wastewater management. The study also explores the role of digitalization in decarbonization and reviews policies that can direct governments' actions towards a climate-neutral society. This paper presents a review of optimization approaches applied in the fields of science and technology, incorporating modern optimization techniques based on various peer-reviewed published research papers. It emphasizes non-conventional energy and distributed power-generating systems along with the deregulated and regulated environment. Additionally, this paper critically reviews the performance and capability of the micellar-enhanced ultrafiltration (MEUF) process in the treatment of dye wastewater. The review presents evidence of the simultaneous removal of co-existing pollutants and explores the feasibility and efficiency of biosurfactants instead of chemical surfactants. Lastly, the paper proposes a novel Firm–Regulator–Consumer-Technology Enablers/Facilitators interaction framework to study operations, decisions and interactive cooperation considering the relationships between the four agents through a comprehensive literature review of SOM. The proposed framework provides support for exploring future research opportunities and holistic sustainability initiatives.

Keywords: sustainable operations management; optimization; wastewater treatment; decarbonization strategies; carbonization; building; energy; industry; digitalization; decarbonization policies

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1. Introduction

The topic of study, known as sustainable operations management (SOM), centres around the incorporation of sustainability principles into the management of operations inside organizations. The primary objective of the SOM approach is to mitigate adverse environmental and social consequences associated with operational activities, while concurrently maximising economic advantages. In recent years, there has been a notable increase in interest towards this topic, mostly driven by the heightened recognition of the influence that corporate activities exert on both the environment and society. The concept of SOM encompasses the integration of sustainable practices across various domains, including supply chain management, product design, energy management, waste management, and transportation. The use of SOM practices has the potential to yield financial benefits through cost reduction, enhance the reputation of a business, and enhance its competitive advantage [1,2]. An integral part of SOM is waste management, which sets the foundation of a sustainable circular economy. The environmental impact of waste products, such as industrial and municipal garbage, is substantial because of their capacity to cause contamination and the inefficient use of resources. The scope of SOM should include the implementation of methods aimed at effectively managing and repurposing waste products to mitigate their impact on the environment. The recent literature on waste management includes the application of innovation technology. The authors of [3] explore a plethora of various applications of waste materials, such as their use in energy production, H_2 storage, catalysis, adsorption, and CO_2 capture. Integrating findings from this paper into the proposed SOM framework can help organizations identify sustainable ways to repurpose waste materials for energy generation, carbon capture, and more. Moreover, paper [4] examines how waste materials can also find applications in the pharmaceutical industry, such as drug delivery and detection. Incorporating insights from this paper allows firms to explore sustainable alternatives in drug manufacturing and delivery, potentially reducing the environmental impact of pharmaceutical operations, and finally, ref. [5] discusses the potential of waste material (orange peels) in cancer therapy. By leveraging waste materials for solar cell production, firms can contribute to renewable energy generation while reducing waste disposal burdens.

In the following paragraphs, emphasis is placed on innovative technologies, non-conventional energy, distributed power-generating systems, as well as deregulated and regulated environments. These systems and environments are pivotal in the transition towards more sustainable and resilient energy landscapes. The integration of renewable energy sources, such as solar, wind, and hydro, is emphasized, reducing the reliance on fossil fuels and mitigating the impacts of greenhouse gas emissions [6]. Furthermore, a critical appraisal of the MEUF process performance and capability in dye wastewater treatment is conducted. Evidence of the simultaneous removal of co-existing pollutants is presented, affirming the process's effectiveness. An investigation into the feasibility and efficiency of biosurfactants in lieu of chemical surfactants is explored. Furthermore, the use of biosurfactants not only enhances the MEUF process but also offers an eco-friendly alternative, reducing the chemical footprint and contributing to environmental preservation. The adaptability and efficiency of the MEUF process have instigated a broader application scope, addressing complex wastewater treatment challenges. Innovative modifications and optimizations are continually being researched to enhance its performance, reduce operational costs, and ensure compliance with environmental regulations. Finally, a novel firm–regulator–consumer interaction framework is proposed for studying operations decisions and interactive cooperation, considering interactions among four agents through an exhaustive literature review on SOM. This framework offers a foundation for delving into future research opportunities. It underscores the necessity for collaborative efforts, synergizing the capabilities and resources of firms, regulators, and consumers to achieve sustainability objectives. The inclusion of stakeholders' perspectives ensures comprehensive solutions, balancing economic viability, environmental preservation, and social responsibility. Future research, as guided by this framework, will likely focus on the development of integrated models and tools for decision making, enhancing the synergy between technological innovations, policy regulations, and consumer behaviours. The alignment of these elements is instrumental in fostering a sustainable transition, characterized by reduced emissions, resource optimization, and enhanced societal well-being. The evolution of SOM is predicated on continuous improvement, innovation, and adaptability (see Figure 1). The diagram provides an overall view of how SOM is linked to waste management. Decarbonization strategies vary from region to region and sector to sector based on local conditions, available resources, and policy priorities. They are a critical component of global efforts to limit global warming to well below 2 degrees Celsius above pre-industrial levels, as outlined in international agreements like the Paris Agreement. Achieving decarbonization goals requires a combination of government policies, private sector initiatives, technological advancements, and changes in individual behaviour to reduce emissions and transition to a low-carbon economy. This paper focuses on wastewater treatment strategies). As new challenges emerge, the integration of cutting-edge technologies, advanced methodologies, and collaborative strategies will be imperative, and the firm–regulator–consumer interaction framework serves as a catalyst, fostering multi-dimensional approaches to addressing the complexities of sustainability in a rapidly evolving global landscape.

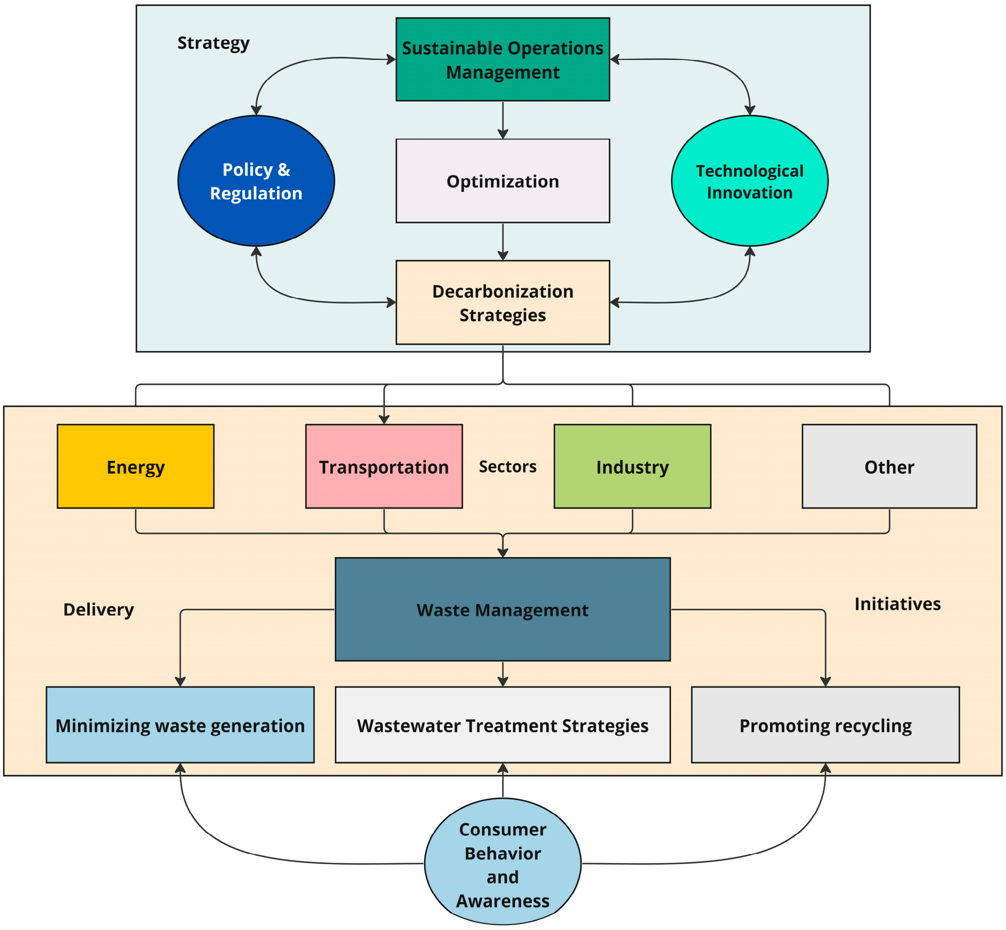

Figure 1. The diagram provides an overall view of how SOM links to waste management. Decarbonization strategies vary from region to region and sector to sector based on local conditions, available resources, and policy priorities. They are a critical component of global efforts to limit global warming to well below 2 degrees Celsius above pre-industrial levels, as outlined in international agreements like the Paris Agreement. Achieving decarbonization goals requires a combination of government policies, private sector initiatives, technological advancements, and changes in individual behaviour to reduce emissions and transition to a low-carbon economy. This paper focuses on wastewater treatment strategies. The strategy level refers to policy makers and long-term planning; both initiatives and delivery have shorter timespans.

1.1. Background and Motivation

Spanning back to the Minoan civilization around 3200 BC, Greece's wastewater management history is enriched with the initial development of drainage and sewerage systems, along with other sanitary infrastructures. Progressively, these technological advancements were adopted on the Greek mainland during subsequent eras of Greek civilization, encapsulating the Mycenaean, Classical, Hellenistic, and Roman periods [7]. During these periods, the ingenuity of engineering and architectural designs marked significant milestones in public health and sanitation. Aqueducts, for instance, became prominent, channelling clean water into urban centres, while intricate sewerage systems facilitated the efficient disposal of waste. These innovations were not only functional but also artistic, mirroring the aesthetic values intertwined with utility in ancient Greek culture. As civilization advanced, there was a noticeable enhancement in the complexity and efficiency of these systems. Urban planning incorporated sophisticated designs of wastewater management, reflecting an intricate understanding of hydraulics and environmental science. Fast forwarding to the contemporary era, the legacies of these ancient innovations continue to influence modern wastewater management and sanitation practices in Greece and beyond. The integration of technology and innovation, rooted in the foundational principles established thousands of years ago, underscores the enduring significance of ancient Greek contributions to this field. In the modern context, challenges such as population growth, urbanization, and industrialization have necessitated the evolution of wastewater management practices and SOM under the prism of sustainable development [8]. The principles and innovations instituted by ancient Greek civilizations provide foundational knowledge, offering insights for developing sustainable, efficient, and adaptable solutions to contemporary challenges. Nowadays, research in Greece has advanced and recommends the use of modern techniques focusing on coastal zones [9] aiming to develop an integrated approach for a sustainable blue economy in a coastal ecosystem using Sustainable Development Goals (SDGs) and ecosystem services frameworks. The study created a decision-making tool for this, classifying SDGs based on importance and helping stakeholders prioritize actions, taking the Elefsis Gulf as a case study, a coastal ecosystem near Athens, Greece. As humanity is mobilizing to preserve biodiversity and protect natural ecosystems through Protected Areas, the European Union directive requires national and local authorities and coastal communities to be involved in designing and managing Marine Protected Areas. A face-to-face questionnaire was conducted to improve the governance of the National Marine Park of Alonissos Northern Sporades, involving residents, hunters, and fishermen. Stakeholders have good knowledge of park issues and have neutral-to-negative opinions about the park's management [10]. Moreover, concerning reservoirs in mainland Greece like Lake Karla [11], which was recently affected by two major storms, aftermaths of the climate crisis, a study explored the provisional, regulating, and cultural ecosystem services, utilizing literature data and a dynamic GIS hydrologic and management model. Additional benefits included flood control, biodiversity maintenance, aesthetic improvement, and touristic opportunities. Finally, educating younger generations through small-scale initiatives like the Summer Academy for Environmental Educators in Greece, established by the Skyros Project in 2016, is an environmental communication service aimed at raising environmental awareness and transforming future generations into environmental stewards. The academy provides trainees with the necessary skills to effectively communicate environmental and public health concerns, aiming to enrich society with committed environmental stewards capable of championing sustainability issues. The academy's distinctive approach stems from its didactic approach and effective environmental communication [12].

1.2. Objectives and Scope of the Study

Research on achieving climate neutrality and greenhouse gas emission reduction incorporates investigation into governance, economic tools, technology, and dialogue to promote sustainable development and mitigate climate change. The potential of non-conventional vehicles like battery, compressed natural gas, and hydrogen fuel cell electric vehicles for greenhouse gas emissions reduction from land transportation are analysed [13,14]. The control of greenhouse gas emissions might be significantly influenced by economic instruments such as carbon pricing and carbon tax [15], with green finance and the circular economy providing support for the transition towards carbon neutrality. Gaining an understanding of climate change economics' principles and methodologies provide crucial insights. Lastly, advancements in wastewater infrastructure construction in Greece have been witnessed, yet challenges persist [16,17]. In this discourse, the role of interdisciplinary approaches is underscored [18], highlighting the integration of science, policy, and practice in addressing the multifaceted challenges of climate change and sustainability. The synergistic application of technological innovations and economic mechanisms is pivotal in driving transformative actions at both micro and macro levels. Public–private partnerships emerge as instrumental conduits, fostering collaborations that enhance resource mobilization, innovation, and the implementation of climate-resilient initiatives [19]. Adaptation and mitigation strategies are being refined to align with the dynamic landscape of climate change impacts. Emerging trends in research focus on the customization of solutions, tailoring interventions to the unique socio-economic and environmental contexts of different regions and communities. This nuanced approach facilitates the development of targeted strategies, optimizing the efficacy and impact of climate actions. Furthermore, the international community's concerted efforts are encapsulated in global frameworks and agreements aimed at galvanizing collective actions to combat climate change [20–22]. These include commitments to reduce greenhouse gas emissions, enhance adaptive capacities, foster resilience, and lower greenhouse gas emissions development in a manner that does not threaten food production. The integration of intelligent transportation systems, smart infrastructure, and policies promoting the use of clean and renewable energy sources is central to this transformation. Concerted efforts are aimed at not only reducing greenhouse gas emissions but also enhancing the efficiency, safety, and accessibility of transportation systems. In the context of Greece, investments in modernizing and expanding wastewater infrastructure are informed by the dual objectives of enhancing service delivery and environmental conservation [23]. The incorporation of innovative technologies and best practices is aimed at optimizing the treatment processes, resource recovery, and reuse, minimizing the environmental footprint and ensuring compliance with regulatory standards. The convergence of technological, economic, and policy interventions underscores the complexity of the climate change conundrum. It accentuates the need for a holistic and integrative approach, where diverse yet complementary strategies are mobilized to address the interconnected challenges of climate change, environmental degradation, and sustainable development.

1.3. Structure of the Paper

Initially, an introduction on SOM was provided, whereby context and background information were elucidated, and the objectives and scope of the study were outlined. Following this, the current regulatory framework in EU is briefly outlined. Subsequently, a chapter on achieving climate neutrality in Europe through decarbonization strategies is presented, wherein various approaches and technologies are thoroughly examined, and their effectiveness in reducing greenhouse gas emissions is assessed. A discussion follows, wherein findings are critically analysed, and potential limitations, implications, and areas for further research are identified [6] through the use case on a university campus and two use cases on wastewater management (Greece and Sweden) are elaborated. Lastly, a conclusion is drawn, synthesizing key insights gleaned from chapters and highlighting contributions made to the field of climate change mitigation.

2. Regulatory Framework

2.1. Council Directive 91/271/EEC of 21 May 1991 concerning Urban Wastewater Treatment Directive 91/271/EEC

The Urban Waste Water Treatment Directive (UWWTD), officially known as Council Directive 91/271/EEC [24], is a European Union legislation designed to safeguard the environment from the detrimental impacts of urban wastewater discharge. The directive especially pertains to the gathering, processing, and release of urban wastewater, as well as the processing and release of wastewater from designated industrial sectors. The UWWTD mandates that EU member states guarantee the following:

- The gathering and processing of sewage in all urban regions with a population exceeding 2000 individuals.
- The application of secondary treatment to all effluents originating from urban areas with a population exceeding 2000 individuals.
- Enhanced measures for metropolitan areas with a population over 10,000 residing in watershed areas with vulnerable water sources.

Urban wastewater entering collecting systems must be released into specific designated regions, which are categorized as follows:

- Sensitive areas refer to natural freshwater lakes, other freshwater bodies, estuaries, and coastal waters that are either already eutrophic or at risk of becoming eutrophic if no protective measures are implemented. They also include surface freshwater intended for drinking-water extraction and areas where additional treatment is required to meet the requirements of council directives.
- Less vulnerable regions include exposed bays, estuaries, and other coastal waterways with efficient water circulation and that are not prone to eutrophication or oxygen depletion, or those that are deemed unlikely to experience eutrophication or oxygen depletion because of urban wastewater discharge.

The UWWTD, which has been in effect for almost three decades, has led to a substantial enhancement in the condition of European rivers, lakes, and oceans since its implementation. Nevertheless, there remains pollution that necessitates attention and is not encompassed by the existing regulations. In response to this issue, the European Commission has put out a proposal to revise the directive.

2.2. Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 Establishing a Framework for the Setting of Ecodesign Requirements for Energy-Related Products

The Ecodesign Directive, sometimes referred to as Directive 2009/125/EC [25], was enacted by the European Parliament and Council on 21 October 2009. It provides a structure for establishing rules for eco-design of energy-related products. The directive seeks to attain a superior standard of environmental safeguarding by diminishing the probable ecological repercussions of energy-related items. The main aspects of the directive comprise:

- This regulation is applicable to all products related to energy, which contribute significantly to the consumption of natural resources and energy usage inside the European Union.
- The directive establishes a framework for the creation of community eco-design requirements for energy-related items. These requirements provide the essential environmental performance standards that items must satisfy prior to their availability for sale or use.
- Energy-related items that meet the eco-design requirements specified in the implementing measures of this directive must display the "CE" designation and relevant information. This labelling allows the products to be placed on the domestic market and circulate without restrictions.
- Enforcement: The strict implementation of measures is crucial to diminish the environmental consequences of regulated energy-related items and to guarantee equitable competition.

For more than ten years, the eco-design Directive has been in effect and has played a role in the advancement of energy-efficient and ecologically conscious products within the European Union. This is a component of a wider range of policies and measures implemented by the European Union with the purpose of fostering sustainability and tackling climate change.

2.3. Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on Sustainability-Related Disclosures in the Financial Services Sector

The European Parliament and the Council adopted Regulation (EU) 2019/2088 [26], commonly referred to as the Sustainable Finance Disclosure Regulation (SFDR), on 27 November 2019. The rule seeks to create a structure for disclosing sustainability-related information in the financial services industry, in order to encourage sustainable investment and guarantee that investors may obtain trustworthy and clear data. The main aspects of the regulation encompass:

- Regulations regarding the disclosure obligations of financial market players and financial advisers: The SFDR imposes further disclosure obligations regarding the environmental and social consequences of investment choices. Asset managers, insurance undertakings, and pension providers, among other financial market participants, are required to reveal how they include sustainability risks into their investment decision-making process. Financial advisers are required to furnish details regarding the incorporation of sustainability risks into their recommendations.
- Financial market participants who take into consideration the primary detrimental consequences on sustainability must provide an explanation of how their financial products include these implications. This entails the disclosure of the methodology employed and the outcomes of the assessment of the impacts.
- European supervisory authorities are mandated by the regulation to create technical standards and guidelines that guarantee uniform and comparable disclosures pertaining to sustainability.

The SFDR encompasses a broad spectrum of financial goods, encompassing investment funds, insurance-based investment products, and pension products. The regulation's objective is to ensure that end investors are provided with transparent, easily understandable, and readily available information, empowering them to make well-informed decisions. Financial market participants are obligated to verify the level of sustainability of their financial products through pre-contractual and periodic disclosures. The SFDR incorporates the principle of "do no significant harm", which mandates that financial market players declare the degree to which their financial products are in line with environmental goals and elucidate any adverse effects on these goals. The SFDR is a component of the European Union's comprehensive sustainable finance strategy, which seeks to activate private money for sustainable initiatives and facilitate the shift towards a more sustainable economy.

2.4. Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 Amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as Regards Corporate Sustainability Reporting

The European Parliament and Council adopted Directive (EU) 2022/2464 on 14 December 2022 [27]. This directive modifies many existing directives and rules in order to improve corporate sustainability reporting within the European Union (EU). The main aspects of the directive are:

- The directive broadens the range of non-financial reporting obligations to encompass sizable businesses and publicly traded small and medium-sized enterprises (SMEs) with a workforce exceeding 250 individuals. These entities must provide information regarding their environmental, social, and governance (ESG) performance, policies, and risks.
- The European Commission is responsible for implementing sustainability reporting standards that align with internationally recognised standards and frameworks, such as the Global Reporting Initiative (GRI) and the Task Force on Climate-related Financial Disclosures (TCFD). The implementation of these standards will establish a shared structure for reporting and guarantee the ability to compare and trust the reported information.
- The directive highlights the significance of materialism in sustainability reporting. Companies must provide disclosure of pertinent and essential information regarding their ESG performance and the ramifications of their activities on society and the environment.
- The guideline promotes the acquisition of external verification for organisations' sustainability reporting. Although not obligatory, independent verification can bolster the credibility and dependability of the revealed material. The directive advocates for the utilisation of digital tools and technologies for the purpose of reporting. Companies are advised to utilise structured data and the European Single Electronic For-

mat (ESEF) in order to enhance the accessibility, comparability, and analysis of their sustainability information.
- Member states must create penalties that are effective, proportionate, and deterrent in order to address non-compliance with the reporting requirements.

The directive also establishes a mechanism for the European Commission to evaluate the efficiency of the reporting system and suggest additional measures if deemed appropriate.

2.5. Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the Establishment of a Framework to Facilitate Sustainable Investment, and Amending Regulation (EU) 2019/2088

Regulation (EU) 2020/852 [28], commonly referred to as the Taxonomy Regulation, is a framework enacted by the European Parliament and the Council on 18 June 2020 with the aim of promoting sustainable investment. The regulation's objective is to establish a standardised terminology for businesses and investors to assess the extent to which economic activities can be classified as ecologically sustainable. The Taxonomy Regulation came into effect on 12 July 2020. The Taxonomy Regulation encompasses the following essential aspects:

- The regulation establishes a comprehensive EU-wide classification system or "framework" to identify economic activities that make a significant positive impact on at least one of six environmental objectives. It also ensures that these activities will not cause significant harm to any of the other five objectives and will meet minimum safeguards.
- The amendment to Regulation (EU) 2019/2088 stipulates that an investment can be deemed sustainable only if it does not cause substantial damage to any environmental or social purpose outlined in the regulation.
- Member states and the EU have a duty to enforce the Taxonomy Regulation when regulating the availability of environmentally friendly financial instruments or corporate bonds.

The Taxonomy Regulation establishes four fundamental criteria that an economic activity must fulfil in order to be considered environmentally sustainable; these conditions encompass the requirement of making a major contribution to at least one of the six environmental objectives, avoiding considerable harm to any of the other purposes, and complying with minimum safeguards. In conclusion, the European Commission is tasked with establishing technical screening criteria for each environmental objective through delegated and implementing acts.

3. Achieving Climate Neutrality in Europe through Decarbonization Strategies

Climate neutrality in Europe has been envisioned as a critical objective, with decarbonization strategies being extensively pursued to achieve this goal [29]. Simultaneously, innovative wastewater treatment methods, such as MEUF, have been employed to address environmental concerns. Through the amalgamation of Europe's climate neutrality vision, decarbonization efforts, and the implementation of cutting-edge technologies like MEUF, a sustainable future is being forged for the region with different strategies. By intertwining these essential topics, a comprehensive understanding of the multifaceted approach to environmental preservation and climate action can be gleaned. These strides towards sustainability are bolstered by policy frameworks and regulations that incentivize green innovation and penalize environmental degradation. In the energy sector, the transition to renewable energy sources is paramount. Solar, wind, and geothermal energy are being harnessed at an unprecedented scale, replacing fossil fuels and reducing greenhouse gas emissions significantly. The modernization of energy infrastructure, including smart grids and energy storage solutions, facilitates the integration of these renewable sources, ensuring energy reliability and security. Public awareness and engagement are also integral to this journey towards climate neutrality. Educational initiatives, public campaigns, and community involvement activities are vital in fostering a culture of environmental responsibility and sustainability. Citizens are empowered with knowledge and tools to contribute to climate action, enhancing the collective impact of individual efforts. In the context of wastewater management, advancements in technologies like MEUF signify a revolution in pollution control and resource recovery. As Europe marches towards achieving climate neutrality, the synergies between various sectors—from energy to waste management and from policymaking to public participation—are becoming increasingly evident. Each element is a piece of a complex puzzle, and their effective integration is indicative of the comprehensive strategy required to address the intricate challenges posed by climate change and environmental degradation, a summary of measures and strategies is presented at Table 1. The collective efforts, innovations, and policies are weaving a tapestry of resilience, sustainability, and climate neutrality that is expected to define Europe's future.

Table 1. The table outlines key strategies and measures for decarbonization across various sectors, including transitioning to renewable energy, promoting electric vehicles, enhancing building and operational efficiency, integrating circular economy principles, and utilizing technology and innovative methods to reduce emissions and waste. These comprehensive approaches span from sustainable agricultural practices and methane emission reduction to advanced wastewater treatment, emphasizing a multifaceted approach to mitigate climate change. Key Strategies and Measures per Sector.

Sectors	Key Decarbonization Strategies and Measures	Description
All	Sustainable Operations Management (SOM)	Strategies for eco-friendly operations.
All	Optimization	Maximizing efficiency and effectiveness.
Energy	Transition to Renewable Energy Sources	Shifting from fossil fuels to renewables.
Transportation	Electric Vehicles	Promoting the use of EVs for reduced emissions.
Buildings	Energy-Efficient Building Practices	Enhancing energy efficiency in construction.
Industrial	Circular Economy Integration	Prioritizing resource efficiency and waste reduction.
Policy and Regulation	Carbon Pricing and Carbon Taxes	Economic instruments to discourage carbon emissions.
All	Technological Innovation	Research and development of cleaner technologies.
Agriculture and Land Use	Sustainable Agricultural Practices	Implementing eco-friendly farming methods.
Waste Management	Methane Emission Reduction	Reducing methane emissions from landfills and waste sites.
All	Digitalization and IoT	Using technology for enhanced efficiency and sustainability.
Wastewater Treatment	Advanced Wastewater Treatment	Employing modern methods like MEUF for eco-friendly wastewater treatment.
Wastewater Treatment	Biosurfactant Use in Wastewater Treatment	Exploring the efficiency of biosurfactants as an alternative to chemical surfactants in wastewater treatment.

3.1. Advancing towards Europe's Climate Neutrality Ambitions

Progress towards Europe's climate neutrality ambitions has been steadily advanced through the implementation of comprehensive decarbonization strategies. The adoption of innovative technologies, such as MEUF, that is analysed at a later chapter has been promoted to ensure effective wastewater treatment and to address environmental concerns.

A sustainable future for the region has been facilitated by the harmonious integration of these efforts, thereby enabling a multi-faceted approach to environmental preservation and climate action. Consequently, a deeper understanding of the intricate interplay between climate neutrality, decarbonization, and cutting-edge technologies has been provided, highlighting the commitment of European nations to achieving a sustainable and environmentally responsible future for the geographical region [29,30].

3.2. Decarbonization Strategies in Key Sectors

Decarbonization strategies in key sectors have been increasingly prioritized as a crucial component of Europe's climate neutrality efforts. In the energy sector, a significant transition to renewable sources has been witnessed, while the reliance on fossil fuels has been gradually diminished. The transportation industry has been revolutionized by the widespread adoption of electric vehicles, and improvements in public transport systems have been made to reduce the carbon footprint. Industrial processes have been reevaluated and optimized to minimize greenhouse gas emissions, and sustainable practices have been integrated into agriculture and land use. Technological innovations and policy reforms are synergistically driving this transformation, enhancing efficiency and sustainability across sectors [31]. Collaboration among governments, businesses, and civil society is fostering a collective approach, amplifying the impact of individual contributions. As a result, the transition towards a low-carbon economy has been accelerated, and the ambition of achieving climate neutrality in Europe has been brought closer to realization.

3.2.1. Building Sector

Significant steps have been made in the building sector as part of the concerted efforts towards achieving climate neutrality in Europe. Energy-efficient practices and the use of eco-friendly materials have been increasingly prioritized, leading to the construction of greener, more sustainable buildings [32]; additionally, the construction sector is placing more emphasis on optimising energy processes in infrastructure construction using the concepts of embodied energy and lifecycle assessment. Embodied energy is the complete amount of energy needed to manufacture a product, whereas lifecycle assessment is a technique employed to examine the environmental consequences linked to every phase of a product's existence. Exploration is underway to utilise Building Information Modelling (BIM) software for the purpose of optimising energy processes. Furthermore, EU energy policy places a high level of importance on promoting energy efficiency. The civil sector, encompassing both residential and tertiary buildings, presents significant opportunities for enhancing energy efficiency. The implementation of policy instruments, such as tax deductions and economic incentives, has proven to be successful in generating significant opportunities for energy savings by addressing inefficiencies in the civil sector [33]. The adoption of passive house designs and the incorporation of renewable energy sources, such as solar panels and geothermal heating systems, have been embraced across the region. Retrofitting older buildings with improved insulation and energy-efficient technologies has been widely implemented to reduce overall energy consumption and greenhouse gas emissions attributable to the built environment [34].

In addition, building certifications promoting sustainability, like LEED and BREEAM, have gained prominence, setting stringent standards for environmental performance, and encouraging the adoption of green building practices. These certifications not only validate the sustainability credentials of a building but also enhance its value, fostering a market transformation towards sustainability [35]. The European Union (EU) has established a standardized set of fundamental sustainability indicators, called Level (s), for office and residential buildings. This framework aims to establish a consistent structure for certifying the sustainability of buildings throughout all EU member countries. This framework is utilized for the purpose of comparing the predominant Green Building Rating Systems (GBRSs) in the European Union, which encompass BREEAM, "Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB)", "Haute Qualité Environnementale (HQE)", and LEED [36].

The cumulative impact of these innovations and initiatives is profound. The building sector is transitioning from being a significant contributor to environmental degradation to becoming a catalyst for sustainability and climate action. The holistic approach, encompassing technology, policy, and societal engagement, is paving the way for a future where buildings are not only structures for habitation and work but also embodiments of ecological and social values.

3.2.2. Energy Sector

Identified as a crucial component for pursuing climate neutrality in Europe, the energy sector's significant greenhouse gas emissions are attributed to energy production and consumption. Nevertheless, there has been a gradual reduction in carbon emissions from energy systems in Europe, primarily due to the substitution of fuels and the growing adoption of renewable energy sources. This phenomenon has been notably apparent in the industry, buildings, and transport sectors [37]. The exploration and implementation of diverse low-carbon, renewable energy sources across Europe, for replacing fossil fuels, have resulted in a considerable carbon footprint reduction [38]. Intensified efforts for energy efficiency enhancement, prevention of losses [39] and conservation promotion have centred on energy consumption optimization in various sectors like electric vehicle charging [40]. Electric vehicle charging integration with the electricity grid is a crucial component of Europe's 2050 low-carbon plan. This approach promotes the use of sustainable energy sources and aids in mitigating the release of greenhouse gases. Innovative technologies for improved renewable energy integration into grids, investment encouragement in research and development, and the promotion of breakthrough energy technologies contribute to resilience, sustainability, economic growth, and job creation, underlining a green economy's potential [41]. The utilisation of renewable energy has a substantial influence on reshaping the global fuel and energy distribution. Promoting the advancement of renewable energy and a sustainable economy with reduced carbon emissions is a key objective of contemporary energy and international economic policies in numerous nations; for example, wind energy in Europe has been empirically proven to have a favourable influence [42]. The efforts to incorporate renewable energy sources (RES) into power networks, specifically transmission grids, are a primary area of emphasis. This encompasses the use of cutting-edge materials, novel electrical components, sophisticated electronic devices, automated control systems, intelligent technologies, and innovative management mechanisms. The formulation of comprehensive policies and regulatory frameworks has further accelerated this transition, ensuring that sustainable energy practices are not only technologically viable but also legislatively supported and economically incentivized.

3.2.3. Industrial Sector

The industrial sector has been recognized as a key contributor to greenhouse gas emissions, and as such, it is imperative that significant decarbonization efforts are focused on this domain. Various measures have been adopted to reduce the environmental impact of industrial processes, including optimizing energy consumption, using renewable energy sources, and implementing innovative waste management techniques. Additionally, the adoption of circular economy principles has been encouraged, in which resource efficiency and waste reduction are prioritized, thereby promoting sustainable industrial practices [43]. Developing economies such as Nigeria have examined the application of circular economy principles in the management of industrial solid waste. These concepts promote a regenerative approach to managing natural resources, which is in contrast to a linear strategy that is not sustainable because of the limited supply of raw resources for production and the resulting environmental degradation [44].

In recent years, the application of advanced technologies, such as MEUF, has been widely embraced in the industrial sector to address wastewater treatment challenges. By utilizing these cutting-edge methods, industries have been able to reduce their environmental footprint and support Europe's climate neutrality ambitions. Furthermore, the collaboration between the public and private sectors has been instrumental in driving research and development in environmentally friendly technologies, leading to the creation of innovative solutions that support a cleaner and more sustainable industrial sector. A relatively recent case study undertaken at Volvo CE, a multinational corporation, emphasized the significance of effective leadership, prompt implementation, and cultural change at the organizational level in attaining sustainable energy management [45]. Finally, another dynamic model, the multi-objective dynamic model developed for the industrial sector context is a tool designed to analyse all variables that impact the overall energy consumption in the sector. This model considers multiple factors that impact energy usage, beginning with the extraction of raw materials, their transportation to manufacturers, the grid network, and ultimately the delivery of the final product to consumers, as well as the disposal or recycling of used products. The model is created to comprehensively account for all relevant elements concurrently, with a particular emphasis on the insufficiency of solely implementing some ways, such as solar panels, while disregarding other crucial factors like end-user considerations and life cycle analysis [46]. As Europe moves towards achieving its climate goals, the continued commitment to decarbonization within the industrial sector remains a crucial component of the overall strategy.

3.3. Digitalization as a Catalyst for Decarbonization Efforts

Digitalization's role as a catalyst for decarbonization efforts across various sectors and businesses sizes in Europe is increasingly recognized [47]. Advanced technologies like artificial intelligence, big data, and IoT have resulted in substantial improvements in energy efficiency, resource management, and greenhouse gas emission reduction. Enhanced monitoring and control over energy consumption patterns have been facilitated, and processes have been optimized. A key enabler of Europe's low-carbon economy transition, digitalization accelerates the transition from fossil fuels to renewables, contributes to reducing Europe's carbon footprint, and encourages the adoption of electric vehicles through smart charging infrastructure. Industrial transformation through digitalization results in more sustainable practices, promotes the circular economy, minimizes energy consumption and waste, aligning with Europe's decarbonization and climate neutrality goals. Digitalization fosters sustainable development and accelerates Europe's transition towards a low-carbon future.

4. Discussion

Compliance with the UWWTD and the incorporation of water reuse into water resource management strategies are being pursued by Athens Water Supply & Sewerage Company (EYDAP S.A.) through several initiatives in Greece. EU Cohesion Fund co-financing has been authorized for two significant wastewater projects in East Attica, aimed at producing treated effluent wastewater suitable for limitless irrigation and urban reuse [48]. Additionally, another wastewater plan is being developed to produce reclaimed water for aquifer recharge, while public datasets related to water supply and wastewater management are being utilized for enhancing the efficiency of these initiatives. Greece is following the Swedish paradigm in wastewater management, learning from key success factors such as a holistic policy approach, the integration of recycling and energy recovery, and the use of economic instruments to incentivize positive practices, all while considering the country's specific needs and alignment with European Union policies and international technological trends. The implementation of these wastewater management initiatives is further enhanced by the adaptation of cutting-edge technologies, particularly in the field of digital transformation. Sensor technologies, automation, and advanced analytics are being increasingly deployed to monitor, control, and optimize wastewater treatment processes. Moreover, the role of stakeholders in the wastewater management ecosystem is paramount. Engaging various stakeholders, including governmental bodies, non-governmental organizations, the private sector, and local communities, fosters a collaborative approach to addressing challenges. In the context of environmental sustainability, the development and implementation of green technologies are gaining prominence. Bioremediation, phytoremediation, and other eco-friendly wastewater treatment techniques are being explored and adopted. Thus, the complexity and multifaceted nature of wastewater management require an integrated, holistic approach. The amalgamation of technology, policy, stakeholder engagement, environmental sustainability, infrastructure development, regulatory frameworks, education, R&D, climate adaptation, circular economy principles, quality assurance, and international collaboration is essential. Each component plays a crucial role, and their synergistic interaction amplifies the effectiveness of wastewater management initiatives. As Greece navigates its journey towards enhanced wastewater management, drawing insights from successful paradigms like Sweden's and integrating multifaceted strategies tailored to its unique context, a future characterized by sustainability, resilience, and environmental preservation is envisioned.

4.1. Wastewater Management in Greece

To comply with the UWWTD and include water reuse in its water resources management strategy, the Athens Water Supply & Sewerage Company (EYDAP S.A.) is working on several wastewater management initiatives. Two significant wastewater projects in East Attica (Rafina/Artemida and Marathon agglomerations) have been authorized for EU Cohesion Fund co-financing and implementation by EYDAP S.A. The goal of these programs is to create treated effluent wastewater that meets national criteria for limitless irrigation and urban reuse. Another wastewater plan is being developed incorporating the agglomerations of Koropi and Paiania, which will produce reclaimed water appropriate for aquifer recharge to restore the water quality of groundwater bodies. In addition, a plethora of public datasets related to water supply and wastewater management, such as the computer modelling of water supply and sewerage networks through the implementation of integrated supervisory control and data acquisition (SCADA) systems can prove valuable. The history of water supply and wastewater management in Paris and the historical data [49], could be used to further improve the efficiency of any recent initiatives. The integration of innovative technological solutions is pivotal in amplifying the effectiveness of these wastewater management projects. Machine learning and artificial intelligence are playing a crucial role in predictive maintenance, anomaly detection, and optimization of wastewater treatment processes. These technologies enable the processing of complex data, offering insights that facilitate informed decision making and strategic planning

Public–private partnerships are also emerging as a vital element in enhancing wastewater management. By leveraging the strengths of both sectors, these partnerships ensure that adequate resources, expertise, and technologies are mobilized to address the intricate challenges associated with wastewater treatment and water conservation. Furthermore, community engagement and education play an instrumental role in the successful realization of wastewater projects. Tailored awareness programs and interactive learning platforms can be instrumental in sensitizing the public about the importance of water conservation, recycling, and sustainable wastewater management practices. Informed communities are empowered to participate actively in initiatives that contribute to the preservation of water resources, fostering a collective approach to environmental sustainability.

4.2. Wastewater Management in Sweden

In 2013, the Swedish Environmental Agency recommended a national aim for increasing phosphorus recycling from wastewater sludge. Sweden has more than 80 years of experience protecting water quality, and the creation of phosphorus removal technology may be a Swedish contribution to advanced knowledge. Source separation systems have been found to be an efficient method of recovering nutrients and energy from wastewaters in both rural and urban settings, with research on the nutrient recovery potential and life cycle consequences of source separation systems undertaken in northern Finland and Sweden [50]. In Sweden, exploratory research looked at how local administration and municipally held enterprises influence the governance of industrial symbiosis in the water and sewage sectors. Finally, a special Issue was published on municipal wastewater management in 2021.

4.3. Greek Government following the Swedish Paradigm in Wastewater Management

Several key success factors from Sweden's waste management paradigm can be learned and applied by Greece to enhance its waste management practices. Sweden employs a holistic policy approach, addressing diverse public demands by integrating waste management with other environmental and economic policies. Recycling and energy recovery are seamlessly integrated; 99% of municipal solid waste is recycled and energy is harnessed, with less than 1% going to landfills. Sweden utilizes taxes and tariffs as economic instruments to discourage harmful practices and incentivize positive ones, such as recycling and energy recovery. Autonomy is given to Swedish municipalities, empowering them with the economic and operational capacity to manage waste collection and treatment systems effectively. By adopting these key success factors, improvements can be made to Greece's waste management practices, reductions in environmental pollution can be achieved, and sustainable development can be promoted. Careful consideration should be given to Greece's specific needs, such as interactions with the extensive tourism sector, and alignment of waste management strategies with the European Union's framework policies and international technological trends. In doing so, wastewater treatment plants can be transformed into sites where energy is efficiently used or produced, resources are recovered and reused, and environmental sustainability is practiced overall. Additionally, fostering partnerships between the government, private sector, and non-governmental organizations can further enhance waste management [51]. By pooling resources, expertise, and technology, innovative solutions can be developed and implemented to tackle waste management challenges effectively. Educational and awareness campaigns are also crucial in instilling a culture of recycling and environmental conservation among citizens. When people are informed and aware of the impacts of their actions, they are more likely to engage in behaviours that contribute to environmental preservation and sustainability. Implementing advanced technologies to automate waste sorting, recycling, and disposal processes can elevate the efficiency and effectiveness of waste management systems. Automation not only streamlines operations but also minimizes human errors, ensures consistency in waste treatment, and enhances the overall productivity of waste management ecosystems.

5. Future Research and Novel Framework

5.1. Micellar-Enhanced Ultrafiltration (MEUF)

MEUF is a separation technology that utilises surfactants to combine the effectiveness and simplicity of traditional methods with the operational adaptability of membrane-based separation. The process, see Figure 2 entails utilising micelles, which are spontaneously formed clusters of surfactant molecules, to dissolve and convey specific solutes across a membrane while excluding larger molecules and particles [52]. Surfactants are compounds that have both hydrophobic (water-hating) and hydrophilic (water-loving) properties. When surfactants are added to water, they self-assemble into spherical structures known as micelles once the concentration of surfactants exceeds the critical micelle concentration (CMC). MEUF has been employed for the elimination of diverse contaminants from wastewater [53], encompassing:

- Heavy metals;
- Dyes;
- Polyaromatic hydrocarbons (PAHs);
- Novel compounds;
- Chromium;
- Phosphorus;
- Phenolic compounds;
- Organic and inorganic materials;
- Aromatic hydrocarbons.

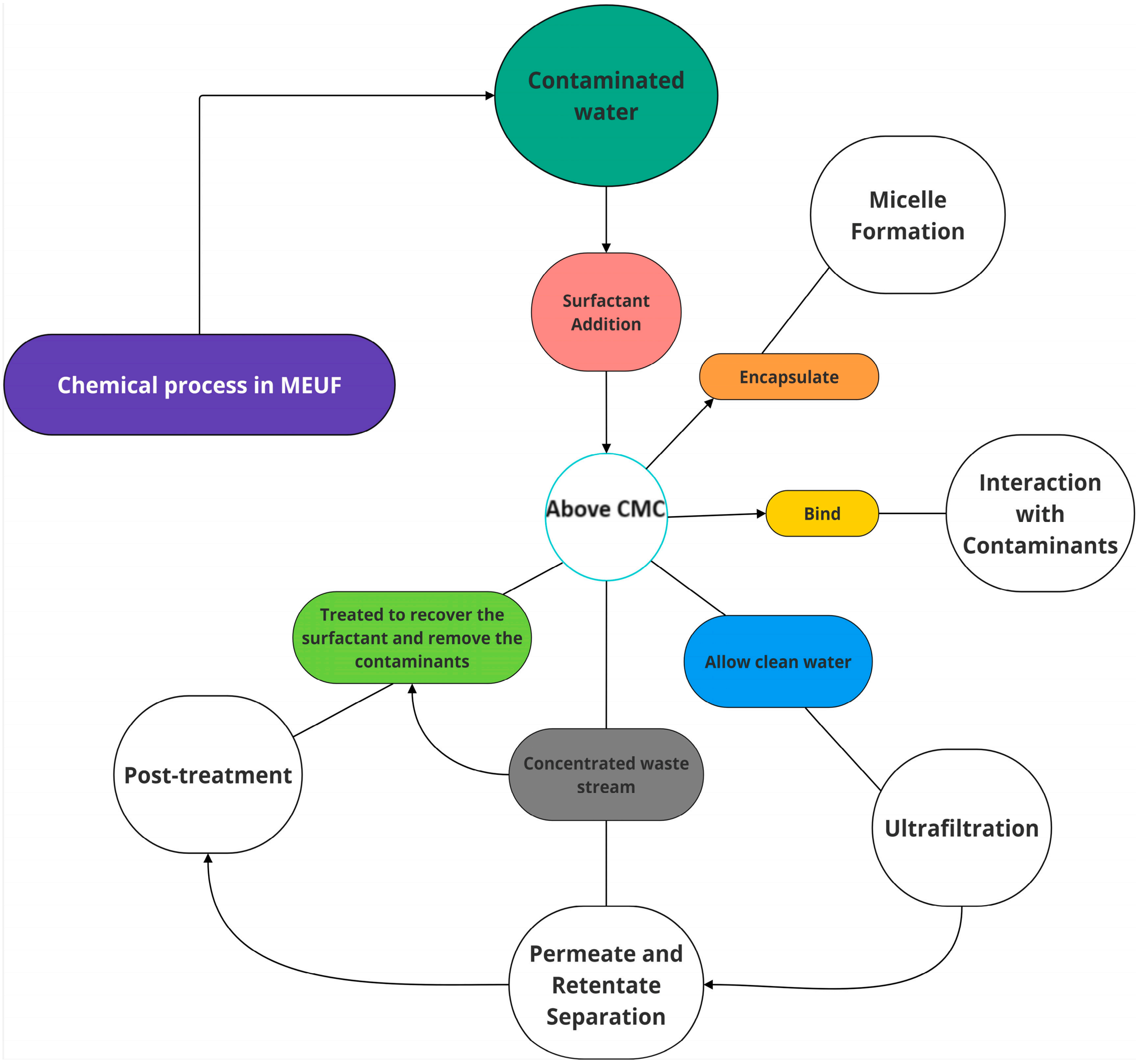

Figure 2. Conceptual Chemical Process in MEUF.

The examined literature [54–56] finds many advantages, such as the superior selectivity and efficacy in the elimination of pollutants, flexibility and adaptability in operations, and the fact that it can be integrated with additional treatment techniques, such as activated carbon fibre (ACF), to improve overall effectiveness. Last but not least, the reusability of surfactants is another advantage.

This solution has some drawbacks, the reagent and electricity costs are elevated in comparison to hybrid methods utilising MEUF. Additionally, it is limited to contaminants of a low molecular weight and performance is contingent upon multiple parameters, necessitating optimisation for particular applications. The chemical process in MEUF follows:

Surfactant addition in contaminated water: Surfactants are added to the contaminated water until the concentration is above the CMC. Above this concentration, surfactants form micelles.

Micelle formation: The hydrophobic tails of the surfactant molecules face inward, away from the water, forming the core of the micelle. The hydrophilic heads face outward, interacting with the water. These micelles can encapsulate hydrophobic contaminants within their core.

Interaction with contaminants: Charged micelles can also bind to oppositely charged contaminants through electrostatic interactions. For example, anionic surfactants can bind to positively charged heavy metal ions.

Ultrafiltration: The solution is then passed through an ultrafiltration membrane. The membrane has pore sizes that allow water and small, unbound molecules to pass through while retaining the larger micelle-bound contaminants.

Permeate and retentate separation: The water (permeate) that passes through the membrane is free of the micelles and the bound contaminants, which remain behind as a concentrated waste stream (retentate).

Post-treatment: the concentrated retentate containing the surfactant and bound contaminants can then be treated to recover the surfactant and remove the contaminants.

Overall, MEUF is a very adaptable approach with numerous diverse uses and real-world examples. Current research is dedicated to enhancing the efficiency of surfactant micelle generation and comprehending the interactions between micelles and desired solutes.

5.2. Biosurfactants Instead of Chemical Surfactants

Biosurfactants are surface-active molecules produced by a wide range of microbes, plants, animals, including bacteria, fungi, and yeast [57]. They are known for their diversity of structures and the possibility of production from a variety of substrates [58]. They have garnered attention as a potential substitute for chemical surfactants owing to their several benefits, including biodegradability, reduced toxicity, and enhanced efficacy at lower doses [59]. Nevertheless, there exist certain obstacles and restrictions linked to their utilisation. Biosurfactants has a broad spectrum of uses across many sectors, such as petroleum, food, pharmaceuticals, and environmental conservation. Biosurfactants have various applications, such as improving the extraction of oil, aiding in the removal of pollutants, facilitating food processing, and assisting in the delivery of drugs [60]. Biosurfactants offer environmental benefits like biodegradability, less toxicity, higher selectivity, and renewable resource production. However, they are often more expensive, complex, and influenced by environmental conditions. Despite these challenges, biosurfactants have a promising future as a sustainable alternative to chemical surfactants [61]. Biosurfactants are produced by microorganisms, with some yeasts presenting no risks of toxicity or pathogenicity, making them ideal for use in food formulations. The production of biosurfactants can be achieved using various substrates, including waste products. For example, cassava wastewater has been used as a cheap culture medium for the production of biosurfactants, contributing to a circular economy and an environmentally friendly production chain [62]. Similarly, oily wastewater has been used as a substrate for the production of rhamnolipid biosurfactants by Pseudomonas aeruginosa strains isolated from hospital wastewater [63]. The extraction and purification of biosurfactants are crucial steps in their production process. The most efficient downstream techniques for industries to achieve acceptable product quality in biosurfactant downstream processing focus on glycolipids and lipopeptides. For example, rhamnolipids, one of the most promising biosurfactants for commercialization, are typically identified and quantified using high-performance liquid chromatography with evaporative light scattering detection (HPLC-ELSD) [64]. In MEUF, biosurfactants overcome the drawback of relatively large pore size in traditional ultrafiltration [65]. MEUF processes can isolate and selectively separate valuable organics present in effluent streams, making them a potential broad-spectrum effluent treatment option. The use of biosurfactants in MEUF processes can enhance the cost-competitiveness of the process, making it a sustainable and efficient separation technique. In conclusion, biosurfactants are versatile compounds with a wide range of applications, from food formulations to wastewater treatment. Their production and extraction methods are continually being optimized to increase efficiency and reduce costs, contributing to a more sustainable and circular economy. Further research is needed to optimize production, develop new formulations, and evaluate their long-term environmental impact [66] that have area of application not only for waste water but sea water also [67].

5.3. Novel Firms–Regulators–Consumers–Technology Facilitators Interaction Framework

Based on the analysis of the literature review findings and the elaboration of the case studies, this paper proposes a novel four-agent framework to be researched further (see Figure 3), which builds upon the paradigm presented for SOM and entails the cooperative intersectoral engagement and interplay of four primary stakeholders: corporations, regulatory bodies, consumers, and Technology Facilitators/Enablers. The objective of this framework is to enhance the implementation of sustainable and environmentally conscious practices within organizations while simultaneously optimizing economic benefits. Presented below is an outline of the framework and an explanation of how these agents collaborate with one another; the proposed framework is currently a work in progress.

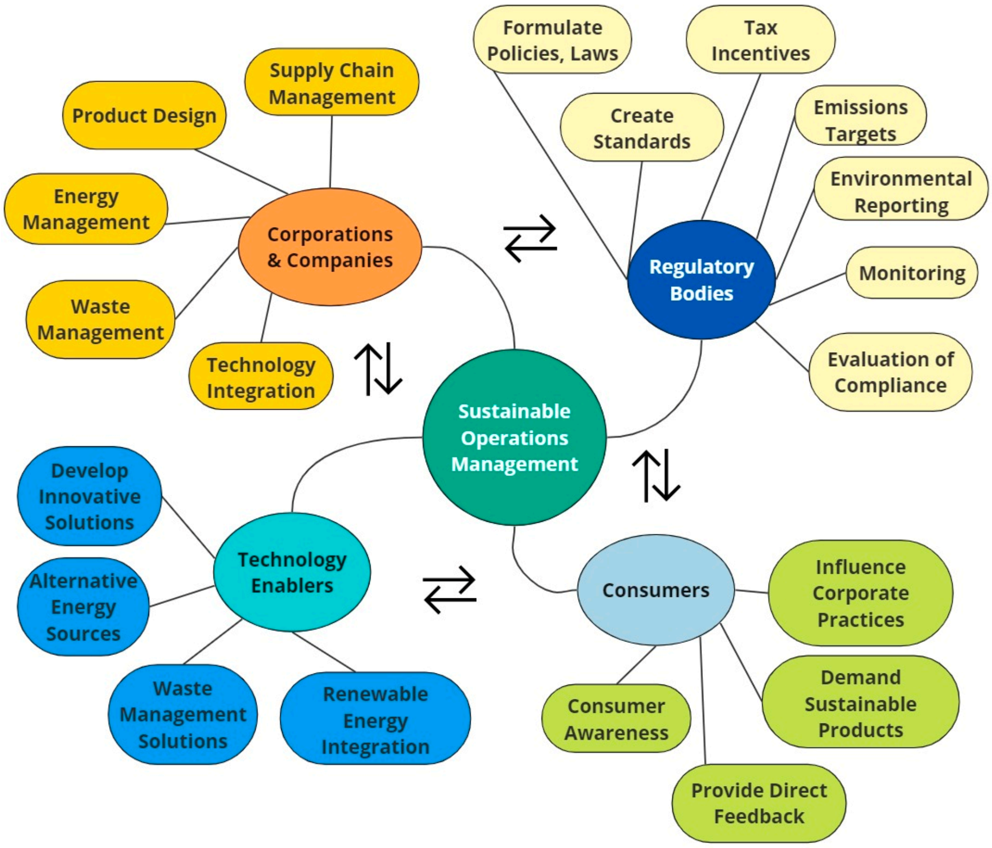

Figure 3. SOM framework.

Organizations and Companies (private and public) play a crucial role in the implementation of sustainable operations. The individuals in question bear the responsibility of incorporating sustainable practices into several areas, including but not limited to supply chain management, product design, energy management, waste management, and transportation. These bodies are incentivized to embrace sustainable operations management (SOM) practices to attain economic advantages, bolster their standing, and gain a competitive edge. Additionally, it is their responsibility to allocate resources towards the adoption and integration of cutting-edge technology and methodologies aimed at mitigating their impact on the environment.

Regulators serve as middlemen between corporations and governmental entities. The instruments in question bear the responsibility of formulating and implementing policies, laws, and standards pertaining to the promotion and maintenance of sustainable operations. Regulatory bodies employ a range of mechanisms, including tax incentives, emissions targets, and environmental reporting obligations, to encourage and enforce the adoption of sustainable practices by enterprises. The regulatory authorities engage in the monitoring and evaluation of firms' adherence to these regulations while also exercising oversight to assure the achievement of sustainability objectives.

Consumers assume a pivotal position in exerting influence over the actions and behaviours of organizations. Firms are compelled to implement SOM practices due to the influence of consumer preferences, purchasing patterns, and demands for sustainable products and services. The cultivation of consumer awareness and education on environmental and social issues has a crucial role in influencing the strategic decisions of firms. Furthermore, customers have the potential to offer direct criticism to companies regarding their sustainability initiatives and to enforce accountability for their actions.

Technology enablers encompass a diverse group of individuals and entities, including innovators, researchers, and technology suppliers. Their primary objective is to create and provide solutions that contribute to the improvement and optimization of sustainable operations. Their primary emphasis lies in the development of cutting-edge technology, alternative energy sources, decentralized power generation systems, and other breakthroughs in waste management, energy conservation, and the integration of renewable energy. Technology enablers assume a pivotal role in providing organizations with the necessary tools and methodologies to effectively accomplish their sustainability objectives.

The aforementioned paradigm establishes a collaborative ecosystem wherein enterprises, regulators, consumers, and technology enablers collectively collaborate to attain the goals of SOM. The framework has dynamic and adaptive characteristics, enabling a continual process of improvement, innovation, and adaption in response to emerging challenges and opportunities.

Significant attention must be put on waste management and its derivatives that possess intrinsic value as a resource. Firms, regulators, consumers, and technological enablers have the potential to engage in collaborative efforts aimed at optimizing the utilisation of waste materials to enhance the sustainability of their operations. Important elements to incorporate into the framework encompass the following:

Firms can investigate and implement novel technologies and methodologies that facilitate the conversion of waste materials into viable sources of energy. This approach is in line with the ongoing shift towards renewable energy sources. The utilisation of waste materials as catalysts or adsorbents in diverse industrial processes can provide environmentally sustainable and highly efficient operations. The utilisation of waste materials by organizations for the purpose of carbon capture and storage can effectively contribute to the mitigation of greenhouse gas emissions.

Pharmaceutical applications: Companies operating within the pharmaceutical business have the potential to embrace sustainable practices through the integration of waste materials into drug delivery systems and detection methodologies. The incorporation of waste materials into the manufacture of solar cells facilitates the transition towards sustainable energy alternatives.

Regulatory compliance is of utmost importance in waste management and recycling as regulators assume a crucial role in the establishment and enforcement of standards. One potential approach is to offer incentives to enterprises to promote the use of waste-to-product technologies. Additionally, establishing rules for the safe disposal of pharmaceutical waste can be an effective strategy. Furthermore, encouraging the implementation of sustainable practices that entail the utilisation of waste materials can contribute to the overall goal of waste management. Consequently, the advancement of technology should prioritize the development and enhancement of technologies that facilitate the utilisation of waste materials, while also maintaining compliance with environmental and safety regulations.

Additionally, consumer engagement plays a pivotal role in influencing enterprises to innovate with waste materials by catering to consumer demands for products and services that have a decreased environmental impact. The promotion of products crafted from recycled or repurposed materials can effectively cater to customer preferences for sustainability.

The efficacy of this framework relies on the establishment of efficient communication and collaboration among the involved agencies, ensuring that their objectives and tactics are harmonized to facilitate a sustainable transition. This paradigm assists organizations in contributing to a more sustainable and resilient global landscape by considering the environmental and social repercussions connected with their operational operations, while also maximising economic rewards. Additionally, it serves as a basis for forthcoming investigations, with a specific emphasis on the creation of comprehensive frameworks and resources for the purpose of decision making, policy formulation, and analysis of consumer actions. Consequently, this contributes to the progression of SOM as a discipline.

6. Conclusions

In compliance with the UWWTD, several wastewater management initiatives are being undertaken by the Athens Water Supply & Sewerage Company (EYDAP S.A.) to incorporate water reuse into Greece's water resources management strategy. Authorization for EU Cohesion Fund co-financing has been granted for two significant wastewater projects in East Attica (Rafina/Artemida and Marathon agglomerations), which are being implemented by EYDAP S.A [48]. National criteria for limitless irrigation and urban reuse are aimed to be met by the creation of treated effluent wastewater through these programs. Another wastewater plan is being developed, which will incorporate the agglomerations of Koropi and Paiania, with the production of reclaimed water appropriate for aquifer recharge to restore the water quality of groundwater bodies [48].

The utilization of advanced technologies like artificial intelligence and machine learning in analysing and processing vast datasets ensures the predictive maintenance, real-time monitoring, and efficient management of water and wastewater systems. These technologies enhance the decision-making process, facilitating timely interventions and optimal resource allocation to ensure the sustainability and resilience of these vital utilities. Furthermore, the efficiency of such initiatives can be improved by utilizing a plethora of public datasets related to water supply and wastewater management, such as the computer modelling of water supply and sewerage networks, the implementation of integrated SCADA systems, and the history of water supply in Paris and wastewater management evolution [49]. Public awareness and participation play a crucial role in the successful implementation of wastewater management projects. Community engagement initiatives, educational programs, and awareness campaigns are instrumental in fostering a sense of collective responsibility and participation in conserving water resources and promoting sustainable wastewater management practices. The integration of green infrastructure in wastewater management is another area receiving significant attention. Natural systems like wetlands, bioswales, and green belts are being incorporated into urban landscapes to enhance the treatment of wastewater, manage stormwater runoff, and contribute to urban biodiversity. These nature-based solutions offer cost-effective, sustainable, and aesthetically pleasing alternatives to traditional grey infrastructure. Legislative frameworks and policy guidelines are continually being refined to align with the evolving challenges and opportunities in wastewater management. Regulatory bodies are focused on establishing standards that promote innovation, ensure public health and safety, and safeguard the environment. Compliance with these regulations is enforced through monitoring, inspections, and penalties for violations, ensuring that wastewater management practices adhere to the highest standards of quality and safety. International cooperation and knowledge exchange are pivotal in enhancing the global response to wastewater management challenges. Collaborative projects, joint research initiatives, and technology transfer programs facilitate the sharing of knowledge, expertise, and technologies among countries and regions. These collaborations contribute to the development of innovative solutions, capacity building, and the formulation of policies and strategies that are tailored to diverse environmental, social, and economic contexts. In the context of climate change, the adaptation of wastewater management systems to cope with extreme weather events, fluctuating precipitation patterns, and rising temperatures is a priority. Strategies such as the diversification of water sources, the enhancement of storage capacities, and the integration of climate-resilient technologies are being implemented to ensure that wastewater management systems remain functional and efficient under changing climatic conditions. In conclusion, the multifaceted approach to wastewater management in Europe, exemplified by initiatives like those of EYDAP S.A., underscores the complex interplay of technology, policy, community engagement, and international cooperation in achieving sustainable water and wastewater management. As challenges and opportunities evolve, a dynamic, responsive, and integrative strategy is essential to ensure that water resources are managed sustainably, public health is safeguarded, and environmental integrity is preserved for current and future generations. Finally, the adoption of a complete framework for the implementation of best practices and promotion of intersectoral collaborations will benefit all agents and increase social welfare.

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