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Environmental Footprint of Inland Fisheries: Integrating LCA Analysis to Assess the Potential of Wastewater-Based Microalga Cultivation as a Promising Solution for Animal Feed Production

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Abstract: This study evaluated the environmental impacts of producing 1 kg of biomass for animal feed grown in inland fisheries effluents as a culture medium using the ReCiPe method. Four scenarios with two downstream alternatives were modeled using the life cycle assessment method: Algal Life Feed (ALF), Algal Life Feed with Recycled nutrients (ALF+Rn), Pelletized Biomass (PB), and Pelletized Biomass with Recycled nutrients (PB+Rn). The findings reveal a substantial reduction in environmental impacts when wastewater is employed as a water source and nutrient reservoir. However, the eutrophication and toxicity-related categories reported the highest normalized impacts. ALF+Rn emerges as the most promising scenario due to its reduced energy consumption, highlighting the potential for further improvement through alternative energy sources in upstream and downstream processes. Therefore, liquid waste from fish production is a unique opportunity to implement strategies to reduce the emission of nutrients and pollutants by producing microalgae rich in various high-value-added metabolites.

Keywords: microalga; sustainable development; feed sustainability; fish production

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1. Introduction

Due to the increasing demand, sustainable animal food production has become a challenge for modern agriculture. Usually, conventional production methods are characterized by a considerable environmental footprint, significantly contributing to water pollution and greenhouse gas emissions [1]. In this case, aquaculture is the leading industry in the production of food and feed-based protein for the consumption of millions of people worldwide [2–4]. In the face of growing global challenges, the aquaculture industry must establish and adopt practices that satisfy the growing appetite for animal-based products and comply with local environmental regulations.

The new trends of sustainable production require new and novel forms of production, which have processes with less impact on the environment [5]. Under this idea, life cycle assessment (LCA) is considered one of the most effective tools for designing, redesigning, and implementing new products or services under an environmental sustainability approach [6–8]. This analysis allows for quantifying the different environmental impacts of the product life cycle (material extraction, transformation, use, and final disposal of the product). This type of analysis makes it possible to identify the bottlenecks in a production chain [9].

Evaluating the sustainability of a product within a novel production system necessitates a standardized methodology underpinned by thoroughly validated assessments. This encompasses the comprehensive computation of all inbound factors, containing energy and resources, as well as the quantification of outbound elements, specifically emissions, for every stage of production [10]. Following the LCA guidelines delineated in ISO 14040:2006 and ISO 14044:2006 [11,12], these data streams serve as the foundation for constructing a virtual process model, which is subsequently transformed into a set of environmental impacts through mathematical modeling. LCA primarily emphasizes the processes within the Technosphere, which encompasses our economies and societies and their interactions with the surrounding environment. When considering the latter aspect, the impact of natural resource utilization is primarily measured by assessing the equilibrium between the affected and unaffected environmental components [13].

The environmental impacts of traditional fish production include the depletion of local fish populations, the destruction of aquatic habitats, and waterway contamination [14]. Furthermore, initial fish production, often reliant on wild-caught fish, exacerbates the impact on freshwater ecosystems [1]. These impacts are compounded using conventional animal food production methods, heavily dependent on fish meal and fish oil. Such production demands significant energy and water resources, contributing to problems like overfishing and bycatch. Additionally, fish meal and fish oil production generate substantial greenhouse gas emissions, further exacerbating climate change [15]. One potential solution to reduce the environmental impact of such industries is the cultivation of algae on wastewater from fish production [16]. This approach is emerging as a promising sustainable animal food production solution, offering numerous advantages over traditional fish production methods [17]. Firstly, using wastewater as a source of nutrients and water for microalgae cultivation can help conserve freshwater resources and reduce the environmental impact of wastewater discharge [18]. Secondly, some algae (including diatoms) are extensively cultured as a sustainable source of protein and fatty acids to produce fry. Moreover, microalgae can be cultivated using various wastewater, including municipal, industrial, and agricultural wastewater [19]. Thus, the implementation of this system not only reduces the environmental impact of traditional fish production and provides a sustainable solution for wastewater treatment [18].

The industrial production of microalgae and cyanobacteria has taken off worldwide recently [20–24]. This is due to a greater acceptance by different industries and end consumers for high-value-added products derived from renewable sources [25,26]. According to Araujo et al. [27], in the European Union alone, at the end of 2019, there were over 200 companies producing biomass from both microalgae and cyanobacteria for different industries such as cosmetics, pharmaceutics, human food, feed and nutraceutics. Large-scale production is separated into processes with associated input requirements (energy consumption, nutrients, fresh or sea water, and others). The most common processes are cultivation, dehydration, harvesting, drying, and further processing (extraction, stabilization, and packaging), which has an environmental footprint [28–32].

While cultivating microalgae from wastewater offers many environmental benefits, several challenges are associated with scaling up this technology for commercial use [19,33]. A significant challenge is the environmental impact of microalgae cultivation systems, particularly in terms of energy consumption and climate change [18]. Additionally, the technic and economic viability of this method compared to traditional animal food production methods is a critical consideration, since not all algal species can be produced under intensive conditions. Conducting an LCA investigation facilitates the identification of critical areas of concern within an algae production chain, pinpointing where issues may arise [34,35]. Adopting life cycle assessment (LCA) methodology within the algae industry has witnessed a growing prevalence, particularly in assessing products and services within the food and energy sector [14,36–42]. The LCA tool enables precise quantification of environmental emissions, pinpointing vital aspects, contrasting processes, and appraising the potential for adopting innovative production methods in contrast to current alternatives [10].

According to an analysis of bibliographic production in the SCOPUS database (made in November 2023) using the following search query (TITLE-ABS-KEY (microalgae OR microalga AND life AND cycle AND assessment OR LCA), between 2001 and 2023, 585 papers were published (Figure 1). Of these, only 18 papers address the issue of LCA in microalgae production to partially replace feed in fish farming and aquaculture processes.

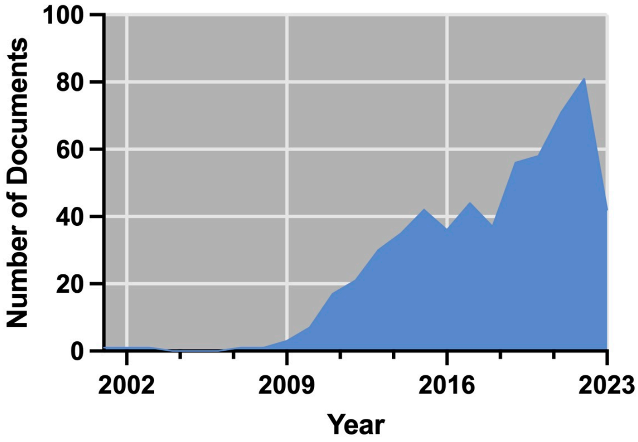


Figure 1. The number of papers published on LCA-based microalgal production.

According to the literature, most LCA studies applied to producing different microalgae products employ data obtained on a small scale [43–45]. Some of these papers focus on the production chain, evaluating the relationship between the raw material, its refining into high-value-added metabolites, and the energy required to achieve the above [18,46,47]. In contrast, others have focused on determining the impact of emissions of certain chemicals of environmental concern (such as NH_4 and N_2O) that are common during the upstream [48,49]. Although specific LCA investigations express optimism regarding the future potential and attractiveness of microalgae cultivation for primary uses, such as energy production [50,51], and as feedstock for other industrial services [52], others are more cautious in defining and constraining the role algal production may have in the future [35,49,53–55]. The main countries where LCA has been applied as an exciting tool to identify the sustainability of microalgal biotechnology are the United States, followed by China, Brazil, Italy, Germany, and others (Figure 2).

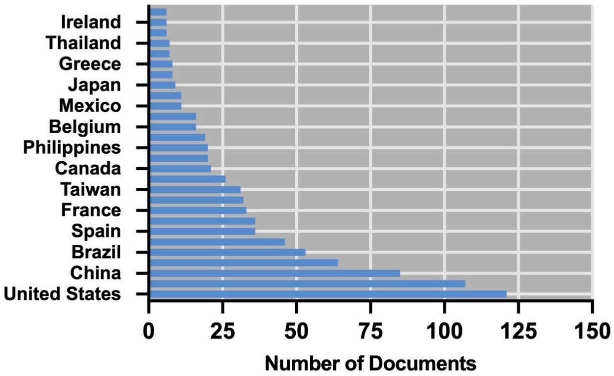


Figure 2. Number of papers by country.

So far, only eight papers can be found for the specific case of LCA applied to microalgae production as a sustainable alternative for partially substituting fish feed in fish farming and aquaculture. Table 1 summarizes these papers, including their goal, functional unit, strain used, and country of origin.

Table 1. Summary of LCA studies related to algal production.

Goal	Functional Unit	Strain	Country	Reference
Assessment of the environmental impacts of algae-based bio-stimulants and aquaculture feed.	1 kg of dried biomass	n/a	Spain	[10]
Quantifying the environmental footprint of ω-3 oil from algae.	1 kg of ω-3 oil	*Schizochytrium* sp.	The Netherlands	[36]
Comparison of life cycle impacts between fish and algal oil for aquafeed.	1 kg of oil		United States	[37]
Assessment of the impact of fish oil substitute produced by algae.	1 ton of DHA oil	*Crypthecodinium cohnii*	Germany	[14]
Environmental impact assessment of the algae at the industrial scale for food production.	1 kg of dried biomass	*Nannochloropsis* sp.		[38]
Using LCA, compare a set of protein sources (including algae) as substitutes for fishmeal.	1 ton of crude protein	*Tisochrysis lutea*	Italy	[39]
Large-scale production of algae.	1 kg of dried biomass	*Tetraselmis suecica*	France	[40]
Analyze the feasibility of linking an FMFO facility and an algae production plant.	Algae-based flour (ton/h)	*Scenedesmus almeriensis*	Argentina	[41]

Considering the above, this work evaluates the environmental impacts of producing 1 kg of biomass for animal feed in fish farming, cultivated in fish farming effluents as a culture medium, for which four scenarios with two downstream alternatives were modeled using the LCA methodology.

2. Materials and Methods

2.1. Goal and Scope Definition

This work aims to model the environmental impact of 1 kg of microalgal biomass production using post-culture wastewater from inland fish farming as a sustainable alternative for feed generation for fish farming.

2.2. Functional Unit

The functional unit (FU) used is 1 kg of processed biomass under four scenarios in Figure 3, Pelletized Biomass (PB) (Figure 3a), Algal Life Feed (ALF) (Figure 3b), Pelletized Biomass with Recycled nutrients (PB+Rn) (Figure 3c), and Algal Life Feed with Recycled nutrients (ALF+Rn) (Figure 3d). The system boundaries included “gate to gate”, starting from the inoculation and bioaugmentation of the algae, followed by their production in raceway reactors and their harvesting and packing (Figure 3).

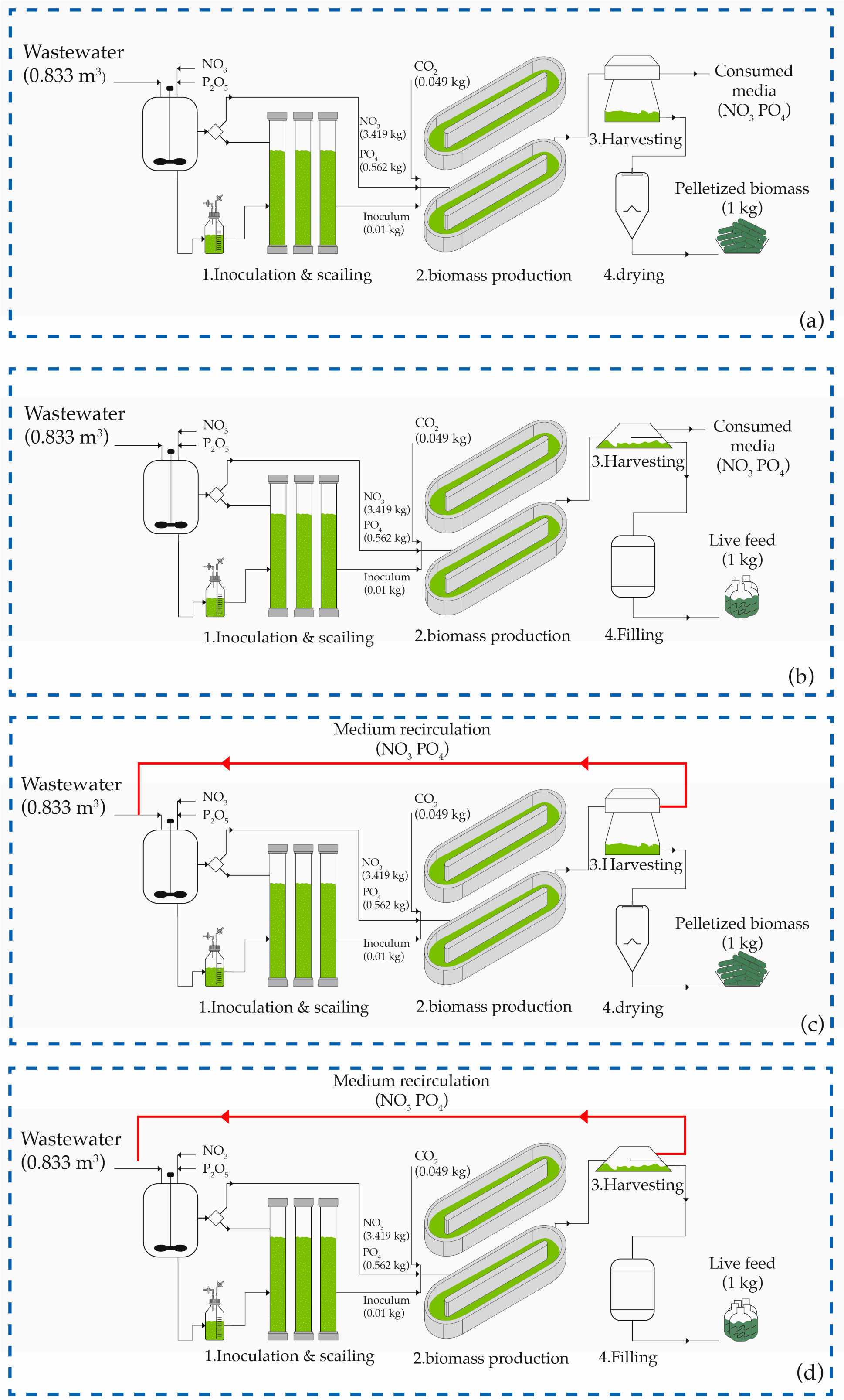


Figure 3. Scenarios evaluated in LCA, Pelletized Biomass (**a**), Algal Life Feed (**b**), Pelletized Biomass with Recycled nutrients (**c**), and Algal Life Feed with Recycled nutrients (**d**).

2.3. Production Process

The alga used in this study is a strain of *Chlorella* sp. (CHLO_UFPS010), previously isolated in another study [32]. The biomass production kinetics, $NO_3{}^-$ and $PO_4{}^-$ consumption kinetics were obtained from García-Martínez et al. [32] and the data on CO_2 removal, energy consumption, mass transfer, and wastewater were obtained from García-Martínez et al. [31].

2.4. Life Cycle Impact Assessment

The Life Cycle Inventory Assessment (LCIA) developed considers all foreground system processes. The primary data (inputs and outputs) were experimentally obtained from pilot-scale scenarios. The secondary data were obtained from the Ecoinvent database [56]. The LCIA analysis considered one year of plant operation. The LCIA data and the assessment model were compiled using SimaPro® software (version 9.4). The ReCiPe 2016 midpoint technique (hierarchic approach) [57], which focuses on environmental concerns, was used to quantify potential environmental consequences and is the best method for this study. The categories evaluated were freshwater eutrophication, global warming, stratospheric ozone depletion, terrestrial ecotoxicity, human carcinogenic toxicity, marine eutrophication, marine ecotoxicity, shortage of fossil resources, water consumption, and freshwater ecotoxicity. These classifications are suitable for the study and have been used in other microalgae biomass studies [18,58]. Additionally, neither scenario considered long-term emissions.

2.5. Data Normalization

The normalization involves dividing the characterized results by an estimate of the total emissions or per capita equivalent emissions associated with a specific geographical region. In LCIA (Life Cycle Impact Assessment) methods, there are provisions to normalize midpoint characterized results using external references. In this case, the ReCiPe midpoint H method offers European and World normalization references. These references enable the comparison of results based on estimates of annual per capita emissions in either the European or global context.

$$NI_{a,i} = \frac{CI_{a,i}}{NR_i} \tag{1}$$

where:

$NI_{a,i}$ represents the yearly normalized impact of alternative a within impact category i.

$CI_{a,i}$ denotes the characterized impact of alternative a within impact category i.

NR_i serves as the normalization reference for a particular geographical region concerning impact category i, expressed in physical units (per year), aligning with the characterized impact $CI_{a,i}$.

2.6. ReCiPe Endpoint

The ReCiPe Endpoint (H) assessed three categories: human health, ecosystems, and resources. These categories are derived from midpoint indicators. This assessment provides a more straightforward understanding and a complete picture of the environmental impacts of the process [59–62].

3. Results

3.1. Life-Cycle Inventory

The four scenarios analyzed for the life cycle inventory are presented in Figure 3. The first part summarizes the processes for the inoculation, production, and harvesting of Algal Life Feed (ALF) (Figure 3a) and Pelletized Biomass (PB) (Figure 3b). The second part of the figure summarizes the proposed scenarios: Algal Life Feed with Recycled nutrients (ALF+Rn) (Figure 3c) and Pelletized Biomass with Recycled nutrients (PB+Rn) (Figure 3d). At the end of biomass production, two main output streams will be produced: microalgal biomass (solid) and a post-culture medium (or wastewater); each of these streams can be considered as co-product, which considers them responsible for the environmental impacts produced. To avoid assigning these impacts, the system boundary was expanded [63,64] by ISO 14040. By expanding the boundary, the multifunctional system is treated as monofunctional [53]; therefore, as the microalgal biomass is the main target of the process, the utilization of wastewater from the whole system is considered as a way to reduce the impact of producing the algal biomass. In the case were wastewater is not used as a source of nutrients, the culture media must be enriched with industrial-grade fertilizers, which will add the required N and P to allow a proper algal growth. Therefore, N and P assimilated by microalgae and transformed into biomass and metabolites of interest were considered avoided products [63–65].

3.2. Impact Evaluation

The analysis of the different environmental impacts assessed for the four proposed scenarios is presented in Figure 4. The ten categories considered were freshwater ecotoxicity (kg 1,4-DCB), terrestrial ecotoxicity (kg 1,4-DCB), freshwater eutrophication (kg P eq), global warming (kg CO_2 eq), fossil resource scarcity (kg oil eq), marine ecotoxicity (kg 1,4-DCB), stratospheric ozone depletion (kg CFC11 eq), marine eutrophication (kg N eq), water consumption (m^3), and human carcinogenic toxicity (kg 1,4-DCB). These categories have been widely used to analyze the impact of both algae and fish production systems [18,38,55,58]. The results obtained show the contribution of sodium nitrate ($NaNO_3$) in freshwater ecotoxicity (0.009 kg 11,4-DCB), marine eutrophication (0.01271 kg N eq), ozone depletion (0.0001309 kg CFC11 eq), global warming (15.29 kg CO_2), terrestrial ecotoxicity (55.334 kg 1,4-DCB), marine ecotoxicity (0.0396 kg 11, 4-DCB), scarcity of fossil resources (2.7054 kg oil eq), and carcinogenic toxicity in humans (0.1448 kg 11,4-DCB) for both Life Feed and Pelletized Biomass systems. In these systems, $NaNO_3$ is supplied as a nutrient required for the correct growth of algal biomass to enrich the fish farming wastewater used as a culture medium. However, NO_3^- enhances the proliferation of hazardous microorganisms, which increases the risk of eutrophication in water bodies [66]. This shows the adverse effect of this component on the environment and the need to look for alternatives, such as using nitrate-rich waste components from the same fish farming system or other waste sources.

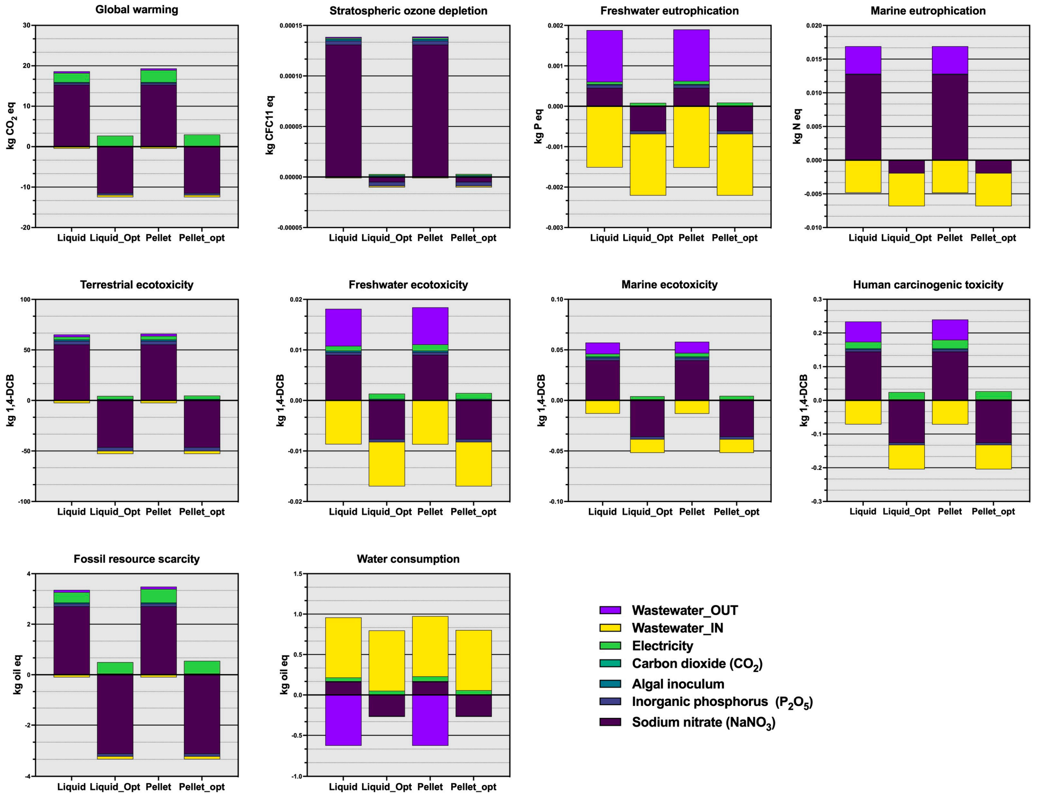


Figure 4. Assessment of environmental impacts.

3.3. Normalization

The normalization of the ten categories is shown in Figure 5, as these categories were expressed in different reference units. Normalization is an essential component of life cycle assessment (LCA), a methodology commonly employed in environmental and sustainability analysis. This step serves to enhance the interpretability and comparability of LCA results. Normalization aims to provide a reference point for the results obtained in LCA. It helps stakeholders understand the significance of impact category indicators by placing them in a common, easily interpretable context. This methodology establishes a reference, often a unit or a benchmark, against which the impact category indicator results are measured. By using normalization, impact category indicators with differing units, scales, and magnitudes become comparable. This facilitates straightforward comparisons between different environmental impacts [67]. ISO 14040 and ISO 14044 are international standards that provide guidelines for conducting LCA studies. They are widely used to ensure consistency and quality in LCA methodologies. Normalization in LCA help make the results more understandable and relevant to decision-makers. Normalization enables comparability by providing a common reference.

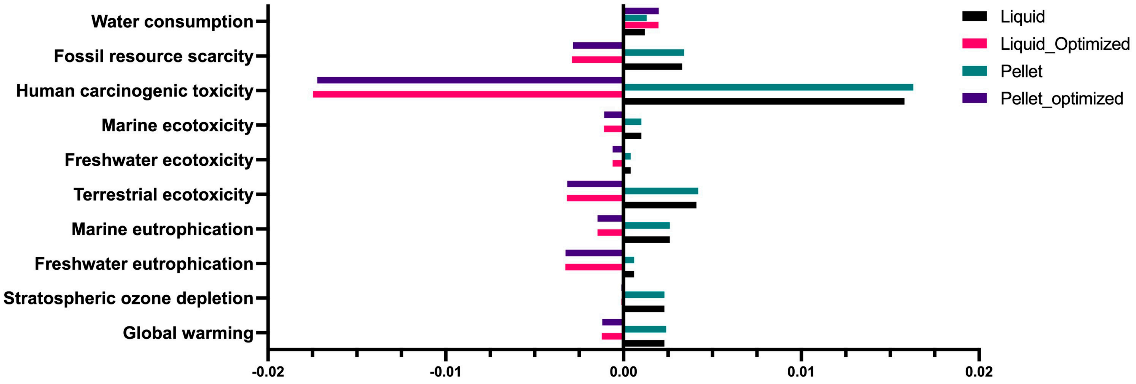
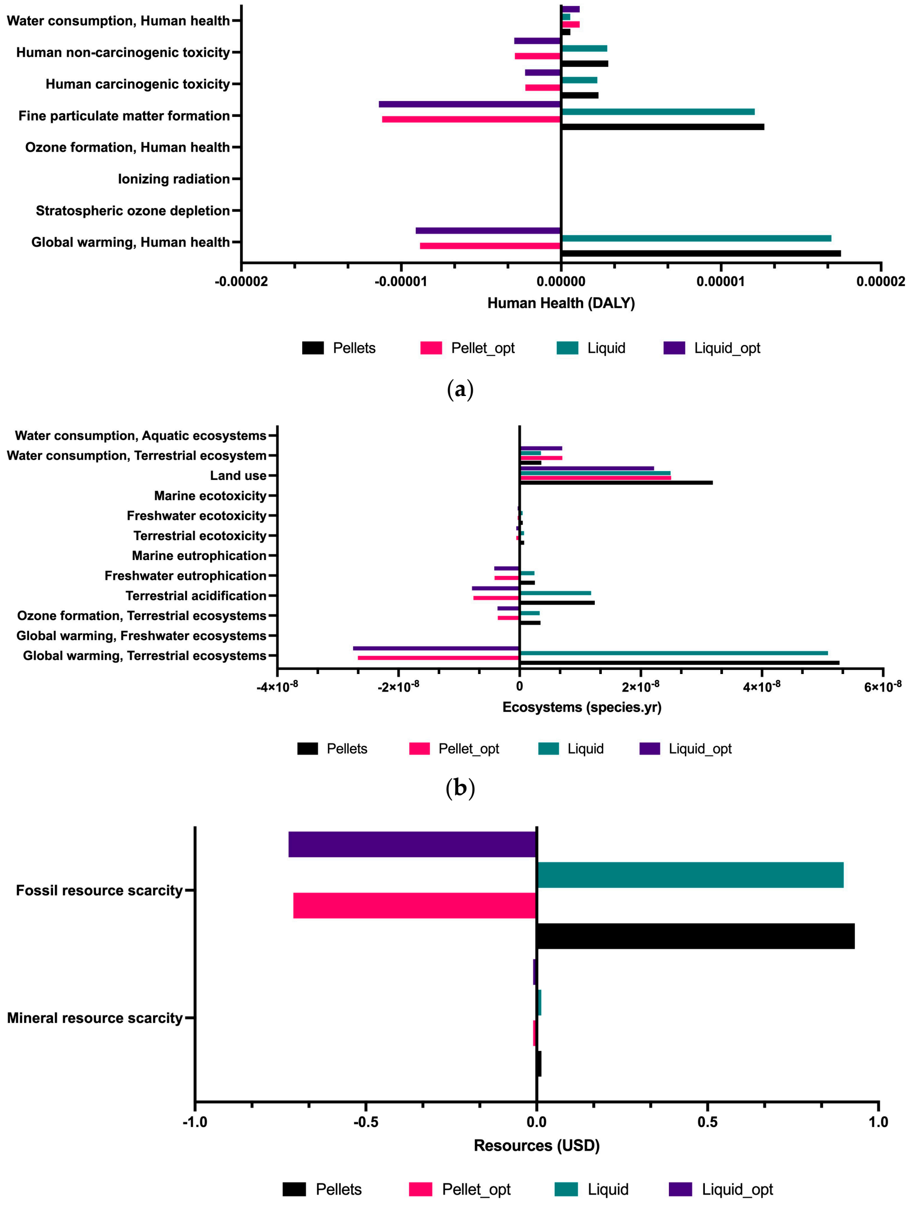


Figure 5. Normalization of environmental impacts.

Each of the scenarios studied has significantly high contributions in the different categories. Both scenarios have significant contributions in various categories, and it is essential to know which of them causes the most pressure on the environment; it should be noted that a negative value indicates little or no environmental impact. For the optimized scenarios, all impact categories report a negative value except for water consumption, which suggests that most of the categories in the optimized scenarios have little or no environmental impact. The latter occurs even though wastewater is used in the process; this also implies water resource use and, therefore, this impact is reported to the system.

3.4. ReCiPe Endpoint

Figure 6 presents the results for the ReCiPe endpoint method, in which it is possible to describe the influence by impact category of each of the midpoint indicators that end up impacting the endpoint categories. Both "Global Warming" and the formation of fine particles have a contribution that exceeds 80% towards Human Health in the non-optimized scenarios. In contrast, these impacts are presented in negative values in the optimized processes, indicating a lower impact assessment. This supports the sound decision of the optimization process. Another relevant impact category in human health measurement focuses on water consumption. Although the cultivation system is oriented to the use of fish wastewater, it is identified that water consumption still generates a weight in the evaluated impact, influenced by the service and availability of this resource. One metric worth mentioning the Disability-Adjusted Life Years (DALYs), which include the effects of mortality and morbidity and are an essential public health indicator used to measure disease burden. It thoroughly assesses the state of health within a population by measuring the total disease burden by considering the years of life lost to early death and the years lived with disability. DALYs provide a standard method for comparing the effects of different illnesses or ailments since they consider death and non-fatal consequences. In this case, the higher impacts can be found under the processes without wastewater recirculation (Pellet and Liquid).



(**a**)

(**b**)

(**c**)

Figure 6. ReCiPe endpoint for human health (**a**), ecosystem (**b**), and resources (**c**).

Regarding the "Ecosystem" endpoint category, it is crucial to highlight the impacts derived from global warming, with approximately 50% contribution in the non-optimized scenarios, and land use, with a contribution between 25% and 30% for the Pellet and liquid scenarios, respectively. These phenomena have significant consequences on the health and stability of ecosystems, underscoring the importance of addressing these problems comprehensively. In the case of the land use category, evaluated in the resource indicator, a considerable impact is observed in all the scenarios analyzed, mainly associated with the land extension needed for the implementation of microalgae crops required for the cultivation of the algae in question. This aspect is of utmost relevance since the allocation of extensive areas for such crops can directly affect the availability of land for other purposes and the preservation of natural ecosystems. In addition, resources were also affected, following the same trend, primarily due to the energy needs of the cultivation phase and the use of nutrients, specifically sodium nitrate. Notably, the Colombian energetic matrix mainly comprises electricity generated by hydroelectric plants, a source of energy commonly considered clean. However, it is imperative to recognize that this perception does not imply that it lacks significant contributions to the impacts assessed. An example of this is evidenced in the context of global warming, explicitly concerning methane (CH_4) and carbon dioxide (CO_2) emissions from biogenic carbon degradation in hydropower reservoirs [68]. Research indicates that global average emissions associated with hydropower generation are around 85 gCO_2/kWh and three gCH_4/kWh. Notably, greenhouse gas (GHG) emissions from hydropower could be significantly reduced by refraining from building hydropower plants that require high land use per unit of electricity generated [69]. This finding underscores the importance of comprehensively considering the environmental impacts of energy sources, even those traditionally recognized as clean. Accurate assessment of greenhouse gas emissions associated with hydropower generation helps to inform energy decisions and guide efforts more fully toward solutions that minimize the environmental impacts of climate change.

4. Discussion

LCA can provide valuable information about algal production's potential environmental benefits and disadvantages of using wastewater as culture media [18]. Several LCA studies have shown that microalgae cultivation can have a reduced environmental footprint compared to traditional animal food production methods. For example, cultivating microalgae from wastewater could be integrated with other agricultural practices, such as aquaponics, to create a closed-loop system that reduces waste and improves resource efficiency [14,70] while producing new raw materials that can be used within the aquaponics production facility as plant fertilizer or bio-stimulants. Another significant environmental challenge relates to greenhouse gas emissions. While microalgae have the potential to capture carbon dioxide during their growth, they also generate emissions during their processing and conversion into final products. Evaluating and reducing these emissions such as CO_2, N_2, and others is essential to ensure that microalgae are a sustainable alternative to reduce the initial environmental impact of the production chain.

According to the literature, over the years, the focus of the application of microalgal biomass has shifted significantly. Some studies have focused on the sustainability of algal-based feed produced on wastewater [14,37,54]. In contrast, others have analyzed the generation of multiple value-added components, including protein for animal feed [10,55], and various studies focused solely on algae-based algae for partial or total substitution in animal feed, especially in fish farming [41,56].

One of the main problems in the sustainable usage of inland fisheries wastewater is its low nitrogen concentration (especially nitrate) and phosphate (orthophosphate) bioavailable to produce large concentrations of algal biomass [31,32]. Therefore, there is a chance that the extra addition of NO_3^- and PO_4^- into the production system may be found in the exhausted media, which, in turn, can contribute directly to freshwater eutrophication and marine eutrophication indicators, generating a high pollution load to the system under assessment (Figure 4). In the optimized scenarios for Pelletized Biomass (Figure 3c) and live feed (Figure 3d), the recirculation of the exhausted media into the system reduces the concentration of NO_3^- and PO_4^- up to 96% (w/w), significantly reducing the environmental impact. According to Thielemann et al. [71], cultivating red algae in heterotrophic systems combined with recirculating the consumed culture medium presents a crucial opportunity to contribute to mitigating environmental impacts while improving the consumption of critical resources. Therefore, producing microalgal biomass in wastewater can significantly enhance the economic and sustainability aspects of producing high-value metabolites by decreasing the demand for external nutrient inputs and reducing the freshwater footprint [72]. When comparing the systems for producing microalgae biomass from fish farming wastewater, it can be identified that nutrient reuse had the lowest environmental impacts for the categories mentioned above. These results are like those reported by Nasir et al. [73], where all the evaluated scenarios that added algal biomass into the feedstock presented negative values for the eutrophication categories, including freshwater and marine eutrophication.

Similarly, Mu et al. [74] obtained negative values for eutrophication (−0.052 kg N-eq/km vehicle transport) when producing algal biomass for energy purposes (fuels from pyrolytic processes). The above establishes that algal biomass produced using wastewater is a critical player in the sustained reduction of eutrophication impacts (especially N and P nutrients) from waste effluents. Another significant aspect is evaluating the water resource and the necessary adjustment for its reuse within the process. The input water (wastewater_IN) and the process output water (wastewater_OUT) were evaluated, and the impacts that these generate for the scenarios proposed. Figure 4 shows the effects of these flows, highlighting the negative values for the input water, both for the liquid and pellet systems as well as for the optimized version, specifically in freshwater and marine eutrophication, human carcinogenic toxicity, and freshwater and marine ecotoxicity due to the use of wastewater and its removal from the environment. Similar studies found that mineral resource scarcity, stratospheric ozone depletion, and water consumption categories were favored due to the reduction in clean water and fertilizers for algal growth, which reduced the overall impacts of the process [75].

On the other hand, Schneider et al. [76] compared the impact between wastewater and a synthetic culture medium (NPK) on microalgae growth, where the scenario that used wastewater had a lesser impact in 17 out of 18 categories analyzed. Similarly, Raghuvanshi et al. [77] compared the production of algal-based biodiesel between clean and wastewater, finding lower environmental impacts when wastewater was used. It should be noted that wastewater treatment has a high impact but cannot be avoided; therefore, the different negative impacts should be reduced through water reuse, energy production, and nutrient recovery [78]. As the demand for sustainable animal food production increases, the economic viability of cultivating microalgae from wastewater is likely to improve. Furthermore, expanding the cultivation of microalgae from wastewater to reduce the environmental footprint of animal food production on a larger scale presents opportunities for innovation and collaboration. It can be identified that for the four scenarios evaluated, the liquid and pellet systems show adverse environmental effects in all impact categories, especially carcinogenic toxicity in humans, while the liquid-optimized and pellet-optimized systems offer positive effects, which allows selecting these scenarios as the ones with the minor adverse impact on the environment. Thus, it is understood that using fish farming wastewater becomes a fundamental element that improves the production process of microalgal biomass and has a positive impact on fish farming systems, generating a sustainable process framed within a circular economy.

5. Conclusions

The life cycle analysis carried out identified that the addition of $NaNO_3$ into the wastewater is the component that generates the most pressure on the environment in both liquid and pellet systems. However, recirculating the liquid waste reduces the impacts in both liquid and pellet optimized scenarios. Future studies should focus on alternatives to improve the concentration of critical nutrients in the wastewater to maximize biomass production without affecting the environmental impact of the proposed process.

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Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

LCA	Life Cycle Assessment
ALF	Algal Life Feed
ALF+Rn	Algal Life Feed with Recycled nutrients
PB	Pelletized Biomass
PB+Rn	Pelletized Biomass with Recycled nutrients
LCIA	Life Cycle Inventory Assessment
kg 1,4-DCB	kg 1,4 dichlorobenzene
kg CO_2 eq	kg of carbon dioxide
kg oil eq	kg of oil
kg N eq	kg of Nitrogen
kg P eq	kg of Phosphate
kg CFC11 eq	Kg of fluorocarbonate

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