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Seaweed Cosmetics under the Spotlight of Sustainability

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Abstract: Seaweeds represent a diverse and valuable source of cosmetic compounds such as vitamins, minerals, trace elements, amino acids, antioxidants, etc., with moisturizing, anti-inflammatory, and regenerative effects. The so-called "blue cosmetics" represent a line of products related to the use of natural active ingredients and an important market share in major international cosmetic brands. To be recognised as environmentally sustainable, it is essential to ensure that algae-derived products comply with environmentally sound harvesting, production, and extraction practices. In this work, Life Cycle Assessment (LCA) methodology was used to carry out an environmental impact assessment of the processing of the brown algae extract from *Fucus vesiculosus* and its comparative profile with the most used antioxidants in cosmetics: vitamin C and green tea extracts. Considering an equivalent formulation in antioxidant content, the results showed that seaweed has the lowest environmental load while green tea extracts have the highest environmental impact. Furthermore, to further reduce emissions from seaweed processing, the use of renewable energy sources and the valorisation of biomass residues as fertilisers in a circular economy approach are proposed.

Keywords: macroalgae; algae; *Fucus*; green tea; antioxidant; LCA; process simulation

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1. Introduction

The cosmetics industry is a sector in constant evolution, from formulations based on chemical and mineral principles to natural ingredients with bioactive properties [1]. As in many other sectors, the terms "natural" and "organic" are in vogue. Descriptions such as "paraben-free", "sulphate-free", or "silicone-free" are the most demanded by consumers when choosing a cosmetic product. Many brands already include a range of natural cosmetics, and many others are already specialising in this type of product.

The development of multifunctional cosmetic formulations has encouraged the search for improved cosmetic products with antioxidant properties to improve skin appearance and UV protection [2]. In this regard, ascorbic acid (vitamin C) is often used in skin care products alone or in combination with other active substances. The optimal concentration of ascorbic acid depends on its formulation, usually no more than 15% [3]. Although this component can be found in natural extracts (e.g., orange), in the cosmetics industry it is mainly found in its pure form, chemically synthesised, or produced by microbial fermentation [4]. Certain plant extracts are also natural sources of antioxidants [5]. Cosmetic formulations generally incorporate a variety of plant extracts, such as green tea, rosemary, or grape seed [5]. The tea plant constitutes a centuries-old tradition for medicinal uses and the use of its extracts plays an important role in the cosmetics market [6], mainly due to its antioxidant properties and phenolic compound content [7].

Another group recognised as a source of natural ingredients is algae (both microalgae and seaweeds), which have been used in formulations for medicinal and cosmetic purposes [8]. Their cosmetic applications are often associated with their bioactive potential, such as their antioxidant, anti-inflammatory, anti-ageing, and whitening capabilities, together with cosmetic characteristics such as moisturising and stabilising agents, and their composition of bioactive compounds (e.g., fucoxanthin and florotannin) [9,10]. The three most common genera of algae used in cosmetics are *Laminaria*, *Fucus* (brown algae), and *Chondrus* (red algae) [10].

To be recognised as environmentally sustainable, cosmetics must comply with environmental practices and objectives. Thus, a holistic study of the environmental impacts associated with the production of extracts is proposed; in particular, those from *Fucus vesiculosus* in comparison with the most commonly used antioxidants in cosmetics (vitamin C and green tea extracts). This seaweed extract is characterised by its content in phenolic compounds and carotenoids, and its recognised antioxidant potential [10]. The environmental aspects of the process and potential impacts were assessed using a Life Cycle Assessment (LCA) methodology, as it is a systematic approach to analyse the environmental impacts associated with the consumption of materials and energy during the life cycle of a product or process [11]. Life-cycle thinking represents the fundamental qualitative notion of analysing the entire life cycle of the system, as the main goal of sustainability is to improve the overall standard of living without exceeding sustainable levels of resource use [12].

2. Materials and Methods

2.1. Goal and Scope

The aim of this report is to evaluate seaweed extracts as a sustainable alternative to common ingredients used in natural cosmetics (i.e., in comparison to green tea extract and ascorbic acid) in terms of environmental impact, as well as to identify hotspots in seaweed processing and propose improvements for this process.

Two functional units were chosen to evaluate the proposed scenarios, the first is based on 1 kg of a cosmetic product containing 3% extract/ascorbic acid, as formulations with natural extracts include low concentrations, while ascorbic acid can be added up to 15% [3], and the second is based on the minimum antioxidant concentration (IC_{50}, defined as the concentration able to scavenge 50% of free radicals) for 1 kg of cosmetic product. The antioxidant capacity was evaluated for samples of each evaluated scenario using the $ABTS^{+}\cdot$ scavenging assay. The assay was performed in triplicate following the method described by Guedes et al. [13], with the average IC_{50} values observed equal to 38, 51, and 10 mg kg^{-1} for seaweed, green tea, and ascorbic acid, respectively.

2.2. Process Description

Three natural cosmetic scenarios were evaluated in this report (Figure 1): seaweed extract, green tea extract, and ascorbic acid. The LCA inventory includes the consumption of materials, water, and energy but excludes infrastructure, as it is assumed that for a long operating time, its contribution to the environmental impact is not particularly relevant.

The seaweed scenario starts with *Fucus vesiculosus* harvesting on the northern Portuguese coast (Viana do Castelo), 80 km from the processing facility. Harvesting is conducted manually in the subtidal zone. Seaweed harvesting is a traditional practice in Portugal and is carried out only at appropriate developmental stages and by removing the upper base zone, which allows regrowth and is carried out in a dispersed and scattered manner, avoiding the catastrophic loss of local habitats in several areas and the instability of marine ecosystems [14].

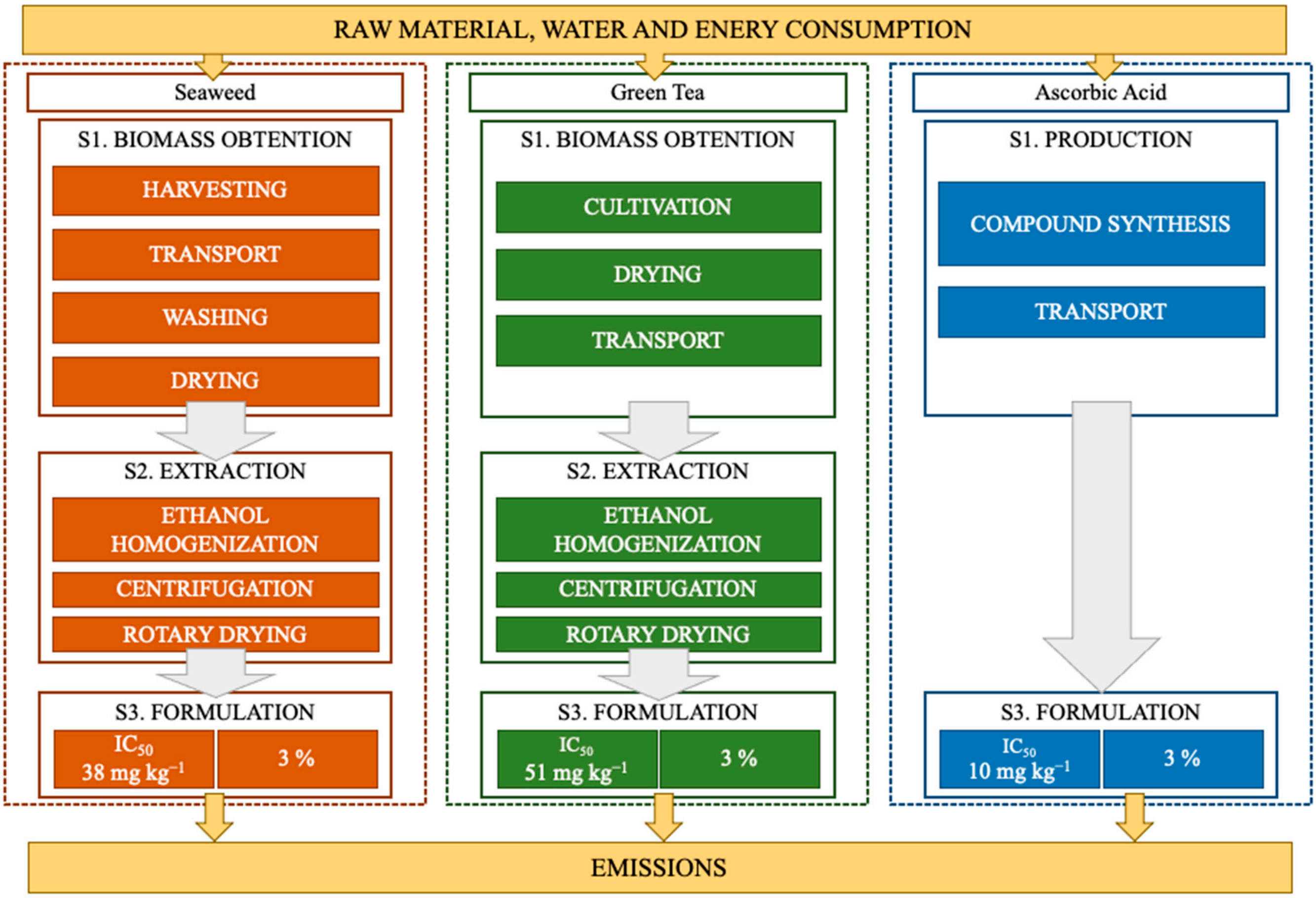

Figure 1. Description of the bioprocess and system boundaries assessed by applying the LCA methodology.

The extraction phase has been modelled taking into account a large-scale production facility, using SuperPro Designer® (Scotch Plains, NJ, USA) as a modelling tool to obtain the mass and energy balances necessary for the life-cycle inventories of the overall process. In detail, the dried biomass was subjected to extraction using ethanol as a solvent and homogenisation (bead milling) as a method of cell disruption, then the solution was centrifuged and the extract dried in a rotary dryer. Based on laboratory-scale experimental trials, this yielded the final extract (220 g kg^{-1}).

The EcoInvent® (Zurich, Switzerland) database was used as the main database for the inventory data of the background processes involved in the production of the inputs required within the green tea cultivation and ascorbic-acid synthesis process. Tea is a perennial crop, and the database includes nutrients, water and land consumption, and transport. The extraction step is equivalent to that described for seaweed, and the simulation was based on laboratory-scale experimental trials, leading to a final extract (210 g kg^{-1}). Ascorbic acid is produced via the Reichstein synthesis, from the hydrogenation of glucose over a nickel catalyst. The database also includes global transport.

2.3. Inventory Analysis

Comprehensive data on the production of natural cosmetics were collected for seaweed, green tea, and ascorbic acid. Table 1 includes the life-cycle inventory considered for the three scenarios. The electricity values considered for the inventory were based on the Portuguese mix (57% renewables) [15].

Table 1. Global inventory for the three scenarios (functional unit: 3% active ingredient in cosmetic formulation, 30 g kg^{-1}).

Inputs from Nature					
Seaweed		Green Tea		Ascorbic Acid	
Seawater (cleaning): 340 g		-		-	
Inputs from technosphere					
Seaweed		Green Tea		Ascorbic Acid	
Biomass Obtention		*Biomass Obtention*		*Production*	
Transport	8.50 g km	Tea leaves [a]	143 g	Ascorbic acid [a]	30 g
Drying	1.36 kJ				
Extraction [b]		*Extraction* [b]			
Ethanol [c]	8.16 L	Ethanol [c]	8.58 L		
Homogenization	0.36 kJ [d]	Homogenization	0.38 kJ [d]		
Homogenization	7.40 Wh	Homogenization	7.80 Wh		
Centrifugation	108.80 Wh	Centrifugation	114.40 Wh		
Drying	201.96 kJ	Drying	212.35 kJ		
Output to technosphere					
Cosmetic product: 1 kg					

[a] Data obtained from the Ecoinvent® database; [b] Data simulated using SuperPro Design®; [c] Ethanol is recovered in 90% after drying; [d] Heat from steam.

For the impact assessment, SimaPro 7.3 was used, and the Ecoinvent® database version 3.5 [16] was employed as a secondary data source. For the selection of characterisation factors required to estimate the environmental loads, the ReCiPe 2016 hierarchist Midpoint/Endpoint approaches in V1.03 World (2010) [17] were used, and a set of impact categories was selected to report the environmental profiles (Midpoint: global warming (GW), stratospheric ozone depletion (SOD), ionizing radiation (IR), ozone formation (OF) terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TET), freshwater ecotoxicity (FET), marine ecotoxicity (MET), human carcinogenic toxicity (HCT), human non-carcinogenic toxicity (HNCT), land use (LU), mineral resource scarcity (MRS) fossil resource scarcity (FRS) and water consumption (WC). Endpoint: Human health (HH), Ecosystems (ECO), Resource Scarcity (RS)).

2.4. Sensitivity Analysis

A sensitivity analysis based on alternative scenarios was carried out for each proposed scale considering the main hotspots identified in the environmental profiles of the alternatives under assessment, i.e., the stages and/or materials that contributed the most to the environmental loads. The objective was to improve the proposed seaweed processing in terms of environmental sustainability.

3. Results and Discussion

3.1. Evaluation of the Environmental Impact

The characterisation results for the three scenarios and the two functional units are presented in Table 2, considering the midpoint and endpoint impact categories. Regarding the impact of 1 kg of a cosmetic product containing 3% of extract/ascorbic acid, seaweed extract had the lowest values for all evaluated categories compared to green tea extracts, as the impact is more than 80% lower. In the ME, LU, MRS, and WC midpoint categories, the low environmental load of seaweed extract is remarkable, accounting for less than 1%. Compared to ascorbic acid, the impact of seaweed extract is even lower in all categories, especially ME, LU, and MRS. For the endpoint categories, the damage to the ecosystem of seaweed extracts is 97% lower than the green tea extract and 55% lower than ascorbic acid.

Table 2. Impact assessment results associated with the three evaluated scenarios (seaweed, green tea, and ascorbic acid) and the two functional units (1 kg of product containing 3% extract/ascorbic acid, and minimum antioxidant concentration IC_{50}). Bold letters represent the lowest value for each functional unit.

Impact [1]	Unit	3% incorporation			IC_{50}		
		Seaweed	Green Tea	Ascorbic Acid	Seaweed	Green Tea	Ascorbic Acid
	Midpoint impacts						
GW	kg $CO_{2\ eq}$	$\mathbf{6.81 \times 10^{-2}}$	3.48×10^{-1}	9.60×10^{-2}	8.63×10^{-5}	5.92×10^{-4}	$\mathbf{3.20 \times 10^{-5}}$
SOD	kg CFC11 $_{eq}$	$\mathbf{2.34 \times 10^{-8}}$	1.82×10^{-6}	1.97×10^{-7}	$\mathbf{2.96 \times 10^{-11}}$	3.09×10^{-9}	6.56×10^{-11}
IR	kBq Co-60 $_{eq}$	$\mathbf{3.38 \times 10^{-3}}$	9.92×10^{-3}	6.88×10^{-3}	4.29×10^{-6}	1.69×10^{-5}	$\mathbf{2.29 \times 10^{-6}}$
OF	kg NOx $_{eq}$	$\mathbf{1.46 \times 10^{-4}}$	8.21×10^{-4}	2.27×10^{-4}	1.83×10^{-7}	1.36×10^{-6}	$\mathbf{7.46 \times 10^{-8}}$
TA	kg $SO_{2\ eq}$	$\mathbf{2.95 \times 10^{-4}}$	2.80×10^{-3}	5.83×10^{-4}	3.74×10^{-7}	4.75×10^{-6}	$\mathbf{1.94 \times 10^{-7}}$
FE	kg P $_{eq}$	$\mathbf{1.93 \times 10^{-5}}$	1.14×10^{-3}	3.43×10^{-5}	2.45×10^{-8}	1.93×10^{-6}	$\mathbf{1.14 \times 10^{-8}}$
ME	kg N $_{eq}$	$\mathbf{1.20 \times 10^{-6}}$	8.82×10^{-4}	4.10×10^{-5}	$\mathbf{1.52 \times 10^{-9}}$	1.50×10^{-6}	1.37×10^{-8}
TET	kg 1.4-DCB	$\mathbf{5.99 \times 10^{-2}}$	4.87×10^{-1}	1.65×10^{-1}	7.58×10^{-5}	8.28×10^{-4}	$\mathbf{5.51 \times 10^{-5}}$
FET	kg 1.4-DCB	$\mathbf{5.64 \times 10^{-4}}$	2.25×10^{-2}	2.25×10^{-3}	$\mathbf{7.15 \times 10^{-7}}$	3.83×10^{-5}	7.49×10^{-7}
MET	kg 1.4-DCB	$\mathbf{8.12 \times 10^{-4}}$	7.86×10^{-3}	2.82×10^{-3}	1.03×10^{-6}	1.34×10^{-5}	$\mathbf{9.39 \times 10^{-7}}$
HCT	kg 1.4-DCB	$\mathbf{1.21 \times 10^{-3}}$	5.06×10^{-3}	2.20×10^{-3}	1.53×10^{-6}	8.61×10^{-6}	$\mathbf{7.34 \times 10^{-7}}$
HNCT	kg 1.4-DCB	$\mathbf{3.15 \times 10^{-2}}$	1.82×10^{-1}	5.11×10^{-2}	3.99×10^{-5}	3.09×10^{-4}	$\mathbf{1.70 \times 10^{-5}}$
LU	m^2a crop $_{eq}$	$\mathbf{1.04 \times 10^{-3}}$	7.71×10^{-1}	2.19×10^{-2}	$\mathbf{1.32 \times 10^{-6}}$	1.31×10^{-3}	7.28×10^{-6}
MRS	kg Cu $_{eq}$	$\mathbf{3.70 \times 10^{-6}}$	5.61×10^{-4}	3.33×10^{-4}	$\mathbf{4.69 \times 10^{-9}}$	9.54×10^{-7}	1.11×10^{-7}
FRS	kg oil $_{eq}$	$\mathbf{2.03 \times 10^{-2}}$	5.35×10^{-2}	2.60×10^{-2}	2.57×10^{-5}	9.09×10^{-5}	$\mathbf{8.68 \times 10^{-6}}$
WC	m^3	$\mathbf{4.37 \times 10^{-4}}$	3.77×10^{-1}	1.42×10^{-3}	5.54×10^{-7}	6.40×10^{-4}	$\mathbf{4.73 \times 10^{-7}}$
	Endpoint impacts						
HH	DALY	$\mathbf{1.35 \times 10^{-7}}$	9.28×10^{-7}	2.36×10^{-7}	1.71×10^{-10}	1.58×10^{-9}	$\mathbf{7.88 \times 10^{-11}}$
ECO	Species yr^{-1}	$\mathbf{2.97 \times 10^{-10}}$	9.92×10^{-9}	6.58×10^{-10}	3.77×10^{-13}	1.69×10^{-11}	$\mathbf{2.19 \times 10^{-13}}$
RS	USD2013	$\mathbf{5.35 \times 10^{-3}}$	1.51×10^{-2}	7.08×10^{-3}	6.78×10^{-6}	2.57×10^{-5}	$\mathbf{2.36 \times 10^{-6}}$

[1] Impact categories. Midpoint: global warming (GW), stratospheric ozone depletion (SOD), ionizing radiation (IR), ozone formation (OF), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TET), freshwater ecotoxicity (FET), marine ecotoxicity (MET), human carcinogenic toxicity (HCT), human non-carcinogenic toxicity (HNCT), land use (LU), mineral resource scarcity (MRS), fossil resource scarcity (FRS), and water consumption (WC). Endpoint: human health (HH), ecosystems (ECO), and resource scarcity (RS).

When it comes to the minimum antioxidant concentration (IC_{50}), ascorbic acid has the lowest impact in almost all midpoint and all endpoint categories, although in the midpoint categories of SOD, ME, FET, LU, and MRS, the seaweed extract is still the one with the lowest impact.

Furthermore, in order to identify emissions hotspots for each cosmetic product, the relative contribution of each subsystem is represented in Figure 2. The results show that for seaweed (Figure 2A), the drying of the extract represented nearly 95% of the environmental load of the evaluated categories (midpoint), followed by the centrifugation step (ca. 5%). Both subsystems are influenced by energy consumption (heat and electricity). For the green tea extract (Figure 2B), the cultivation of the tea plant is the subsystem with the highest impact in all impact categories: 80–100%, especially in SOD, FE, ME, FET, LU, MRS, and WC. Finally, regarding the ascorbic acid (Figure 2C), the use of chemicals, in particular glucose, is responsible for a major part of emissions (50–98%), particularly for the SOD, ME, LU, and MRS categories.

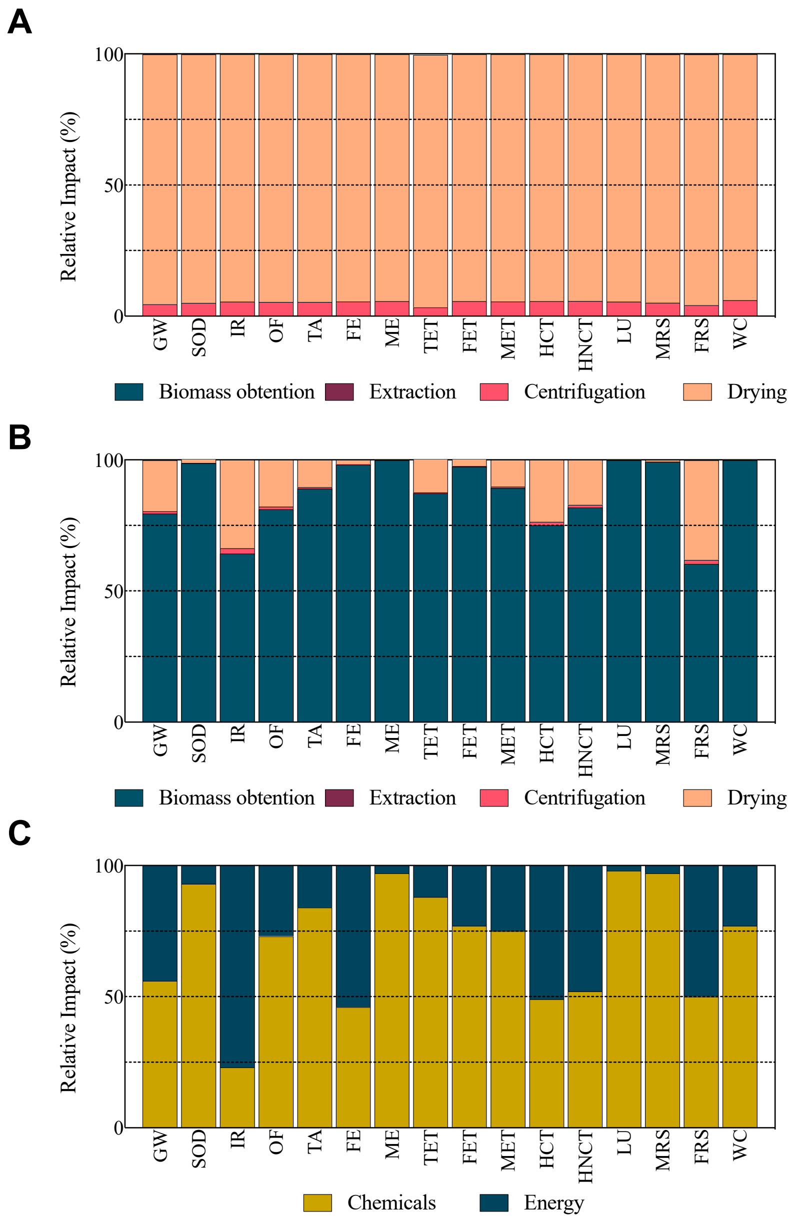

Figure 2. Detailed analysis of the three evaluated cosmetic products scenarios considering midpoint impact categories: (**A**) seaweed; (**B**) green tea; (**C**) ascorbic acid. Impact categories: global warming (GW), stratospheric ozone depletion (SOD), ionizing radiation (IR), ozone formation (OF), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TET), freshwater ecotoxicity (FET), marine ecotoxicity (MET), human carcinogenic toxicity (HCT), human non-carcinogenic toxicity (HNCT), land use (LU), mineral resource scarcity (MRS), fossil resource scarcity (FRS), and water consumption (WC).

Notably, the impact of green tea extract is the highest found in all categories assessed in both functional units. Mila et al. [18] conducted an LCA on tea leaf production, and the environmental burdens of the green tea production stage are the result of background activities associated with cultivation and harvesting, i.e., fertilisation, machinery, organic waste, and freshwater consumption.

The use of harvested seaweed may give an advantage compared to cultivated tea plants; however, seaweed cultivation in the sea has several advantages compared to terrestrial plants. For example, it does not need terrestrial cultivable fertilizers or freshwater inputs, requires minimal human intervention, and has a much higher growth rate and biomass yield [19]. Moreover, as highlighted by Gaspar et al. [14], seaweed harvesting in Portugal is performed in a specific period of the year, considering the availability of biomass and allowing the regrowth of harvested areas, providing a feasible scenario for this type of process.

Compared to ascorbic acid, seaweed extracts have a similar or even lower environmental load, considering both functional units. However, seaweeds have a clear advantage, as they could be considered as natural sources of antioxidant products, leading to more attractive biological resources for the cosmetics industry and consumers in general. Furthermore, when assessing the impact of the minimum antioxidant concentration, seaweeds still have an advantage in key categories such as ME and WC.

The environmental impact of the seaweed extract production process is concentrated in the biomass processing subsystems. Again, the question can be raised whether biomass is harvested and not cultivated; however, an LCA conducted for the production of cultivated *Gracilaria edulis* extracts shows that processing accounts for more than 80% in most of the impact categories. The report also includes the fact that electricity requirements lead to a higher impact on processing [20].

Furthermore, the use and disposal of seaweed waste is fundamental to the preservation of the marine environment and the conscious use of organic matter, contributing to the concept of a circular economy rather than the linear model of manufacture, use, and waste. Traditionally, waste products were collected and often used as food, indicating that they were underutilised [19]. As an alternative, a biorefinery concept can be proposed for the use of these wastes in new products, for cosmetics (as a second extract), fertiliser (as a biostimulant and biopesticide), or biogas production.

3.2. Sensitivity Analysis for Seaweed Extract Production

The use of seaweed extract as a cosmetic product is the focus of this report; thus, the improvement of environmental emissions is only focused on this product. Furthermore, based on the results of the overall impact and the identification of hotspots, a sensitivity analysis was carried out considering five scenarios: the use of more renewable energy (using the Norwegian mixture as an example) (SA1), the use of the seaweed residue after extraction for biogas production (SA2), the use of the residue as a fertiliser (SA3), the use of the residue in a second extraction with the separation of a water extract (SA4), and the use of spray drying instead of rotary drying for the drying subsystem (SA5). The results of the sensitivity analysis are shown in Figure 3, for the midpoint (Figure 3A) and endpoint (Figure 3B) categories.

As energy requirements are the reason for most of the seaweed extract emissions, both scenarios SA1 and SA2 seem to be the best option for a more sustainable process. SA1 indicates that by switching from the Portuguese to the Norwegian electricity mix, the impact would be reduced by approximately 80% in most categories. The reduction is less pronounced in IR, OF, and MRS (approximately 40%), and, for water consumption, this scenario had an increase of 26% compared to the baseline scenario. Norway purchases about 97% of its electricity from hydropower sources and is considered the cleanest energy in the world [21]. In Portugal (the baseline scenario), hydropower and wind account for a considerable share of energy consumption, but coal and natural gas still magnify the overall impact of this electricity mix [15]. Alternatively, energy agencies (such as the Portuguese EDP—Energias de Portugal) give the option to provide only renewable energy for the processing plant, which can also decrease the environmental impact.

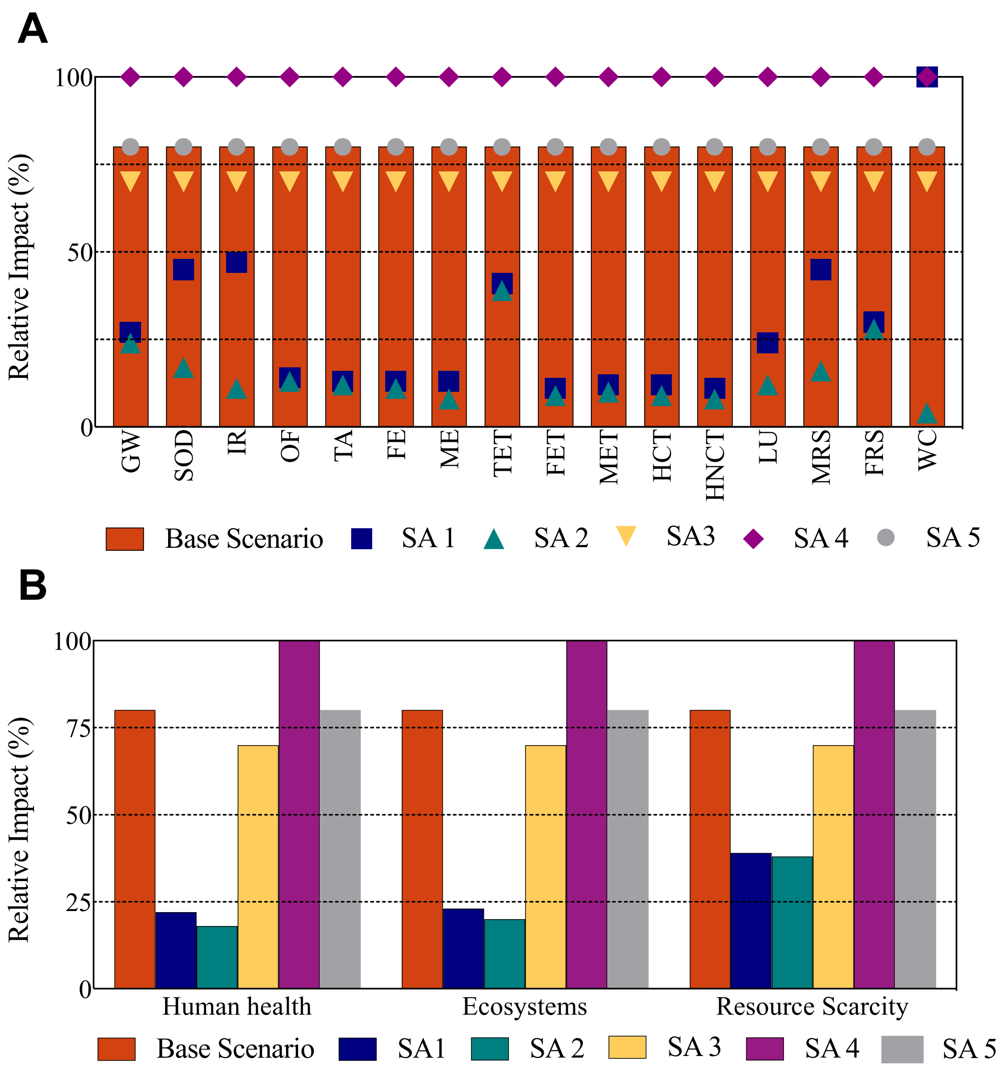

Figure 3. Sensitivity analysis considering seaweed extracts for cosmetic formulation regarding (**A**) midpoint impact categories and (**B**) endpoint impact categories, considering the proposed scenarios: SA1—renewable energy mix (Norway); SA2—use of residue for energy production (fermentation/co-generation); SA3—use of residue as fertiliser (economic allocation); SA4—use of residue for a second antioxidant product (mass allocation); SA5—use of spray drying instead of rotary drying. The impact categories are as follows. Midpoint: global warming (GW), stratospheric ozone depletion (SOD), ionizing radiation (IR), ozone formation (OF), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TET), freshwater ecotoxicity (FET), marine ecotoxicity (MET), human carcinogenic toxicity (HCT), human non-carcinogenic toxicity (HNCT), land use (LU), mineral resource scarcity (MRS), fossil resource scarcity (FRS), and water consumption (WC). Endpoint: human health (HH), ecosystems (ECO), and resource scarcity (RS).

In the case of SA2, the use of waste biomass for biogas production, impact reduction is observed in all categories, with an even more accentuated effect, reaching values close to 90%. Ertem et al. [22] suggest seaweed biomass as an alternative for biogas production. The process of fermentation and energy co-generation can recover 1.6 kW kg^{-1} of seaweed residue, as simulated using SuperPro Design®. However, limitations related to the higher moisture and ash content of seaweed compared to lignocellulosic plants are the main obstacles to the competitive utilisation of seaweed for energy production [19]. In addition, the requirements for the processing and co-generation of energy demand a high associated plant installation cost, which is generally avoided in the cosmetic ingredients industry due to a reduced amount of annual production compared to other systems, such as the food industry.

For the third scenario, an economic allocation was made using the market price of seaweed extract and the residue as a fertiliser, reducing the impact of the extract by 2%. This scenario could be applied simultaneously with the first scenario, leading to a more circular process. Furthermore, seaweed has been used for many centuries as an ingredient in animal feed and fertiliser in agriculture and horticulture [14,19]. Moreover, market examples of this scenario can already be found, such as the Spanish company Ficosterra, which processes waste biomass from the agar industry, to obtain biostimulants and biofertilizers.

The fourth scenario (SA4) proposed the production of a second extract using the remaining biomass and water as a solvent. By producing a second extract, the biorefinery strategy pursues a higher economic income by considering all components and, at the same time, maximising biomass utilisation [23]. However, SA4 is the only one that has a higher impact than the baseline scenario. Although this strategy reduces biomass collection, where two extracts are produced instead of one, the need for a second extraction and drying process for the second antioxidant extract implies an energy input that negatively influences the final environmental impact. Therefore, from an environmental point of view, this scenario is not recommended. Finally, the fifth scenario (SA5) considered spray drying as an alternative to rotary drying, However, no differences were observed in the overall impact of the system. Overall, the scenario SA1 together with SA3 seem to lead the process to a reduction in overall emissions and to a strategy of circular economy and biomass valorisation.

In addition, environmental awareness has changed the demands on the cosmetics industry, both directly in the market (as in the case of ecolabels and environmental certifications of products) and politically, as in the case of the EU Green Deal, which aims to harness the significant market potential of low-emission technologies, sustainable goods, and services to achieve climate neutrality by 2050. As reviewed above [9,10], seaweed provides a practical solution for the sustainable scenario that the natural cosmetics sector aims to achieve. Overall, this study has laid the groundwork for an environmentally driven assessment of seaweed for cosmetic use. In addition, other optimisations can be made using LCA as a decision tool, e.g., for the optimisation of extraction (disruption methods and solvents), drying methods, or even biomass production: Integrated Multi-Trophic Aquaculture (IMTA).

4. Conclusions

Natural cosmetics and sustainability are often linked, although there is a need for scientific evidence to support the premise that the use of plants can lead to a lower or higher environmental impact. The results of this report show that seaweed has a lower environmental impact compared to green tea or ascorbic acid, ensuring that its effectiveness as an antioxidant is comparable. In addition, changes for an even more sustainable process were suggested, such as the use of renewable energy and the use of waste as a fertilizer. Finally, the findings described here highlight the relevance of environmental studies in the field of cosmetics.

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