SUPPLEMENTARY MATERIAL

The high-value product, bio-waste, and eco-friendly energy as the tripod of the microalgae biorefinery: Connecting the dots

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Table S1. Overview of potential applications and market estimation of microalgae-based bioproducts.

Table S2. Characterization factors of the environmental impacts for onshore wind, photovoltaic from amorphous silicon solar cells (a-Si), and coal-based fossil energy.

Table S3. Characterized values of the environmental impact associated with the biorefinery from *Dunaliella salina*.

Table S1. Overview of potential applications and market estimation [1] of microalgae-based bioproducts.

Product	**Relevant segments**	**Application potential**	**Market demand (million USD)**
β-carotene	food industries	enhance color in juices, yogurts and bakeries;	1,105.00
	animal feed	Poultry diet - contribute to the desirable color of the egg yolk; Aquaculture - promotes the desirable pink/red color of crustaceans, salmons, and other farmed fish; Preservation agents – slow down the oxidation process, thereby reducing food degradation and the development of off-flavors;	
	cosmetics	active ingredients with biological activity in creams and lotions;	
	nutracêuticos	source of dietary supplements;	
Defatted biomass	animal and human feed; bioenergy;	protein feed source; additive or as a macro-ingredient; bioethanol	720.51
Bulk oil	food industries; soap industries; bioenergy	food supplement; biodiesel; feedstocks;	

Table S2. Characterization factors of the environmental impacts for onshore wind, photovoltaic from amorphous silicon solar cells (a-Si), and coal-based fossil energy. Obtained from Milousi et al. [2] and Hosseini et al [3].

Impact Category	**Unit**	**a-Si**	**Coal**	**Onshore wind**
Global warming	kg CO_2-eq/kWh	4.35E-2	1.08	1.55E-02
Stratospheric ozone depletion	kg CFC11-eq/kWh	1.70E-8	1.67E-7	6.76E-09
Ionizing radiation	kBq Co-60-eq/kWh	3.95E-3	2.53E-3	8.90E-04
Ozone formation, human health	kg NO_x-eq/kWh	9.83E-5	1.66E-3	4.65E-05
Fine particulate matter formation	kg $PM_{2.5}$-eq/kWh	1.09E-4	1.18E-3	2.92E-05
Ozone formation, terrestrial ecosystems	kg NO_x-eq/kWh	1.01E-4	1.66E-3	4.85E-05
Terrestrial acidification	kg SO_2-eq/kWh	2.25E-4	3.84E-3	5.33E-05
Freshwater eutrophication	kg P-eq/kWh	3.55E-5	2.45E-3	7.20E-06
Terrestrial ecotoxicity	kg 1,4-DCB-eq/kWh	4.69E-1	3.55E-1	8.33E-02
Freshwater ecotoxicity	kg 1,4-DCB-eq/kWh	1.11E-2	6.04E-2	7.96E-03
Marine ecotoxicity	kg 1,4-DBC-eq/kWh	1.43E-2	8.30E-2	9.80E-03
Human carcinogenic toxicity	kg 1,4-DBC-eq/kWh	6.50E-3	1.21E-1	2.34E-02
Human non-carcinogenic toxicity	kg 1,4-DBC-eq/kWh	1.46E-1	2.42	3.82E-02
Land use	m^2a crop-eq/kWh	1.13E-3	1.91E-3	1.81E-03
Mineral resource scarcity	kg Cu-eq/kWh	6.60E-4	1.24E-4	3.67E-04
Fossil resource scarcity	kg oil-eq/kWh	1.04E-02	2.37E-1	4.20E-03
Water consumption	m^3/kWh	4.51E-4	2.17E-3	1.92E-04

Table S3. Characterized values of the environmental impact associated with the biorefinery from *Dunaliella salina*.

Impact Category	Unit	Total	β-carotene	Bulk oil	Defatted biomass
Coal					
Fine particulate matter formation	kg $PM_{2.5}$ eq.	6.04E+02	6.00E+02	3.58E+00	1.09E+00
Fossil resource scarcity	kg oil eq.	1.21E+05	1.20E+05	7.18E+02	2.19E+02
Freshwater ecotoxicity	kg 1,4-DCB eq.	3.09E+04	3.07E+04	1.83E+02	5.57E+01
Freshwater eutrophication	kg P eq.	1.25E+03	1.25E+03	7.42E+00	2.26E+00
Global warming potential	kg CO_2 eq.	5.53E+05	5.49E+05	3.27E+03	9.97E+02
Human carcinogenic toxicity	kg 1,4-DCB eq.	6.20E+04	6.15E+04	3.67E+02	1.12E+02
Human non-carcinogenic toxicity	kg 1,4-DCB eq.	1.24E+06	1.23E+06	7.33E+03	2.23E+03
Ionizing radiation	kbq Co-60 eq.	1.30E+03	1.29E+03	7.67E+00	2.33E+00
Land use	m^2a crop eq.	9.78E+02	9.71E+02	5.79E+00	1.76E+00
Marine ecotoxicity	kg 1,4-DCB eq.	4.25E+04	4.22E+04	2.51E+02	7.66E+01
Mineral resource scarcity	kg Cu eq.	6.35E+01	6.30E+01	3.76E-01	1.14E-01
Ozone formation affecting human health	kg NOx eq.	8.50E+02	8.44E+02	5.03E+00	1.53E+00
Ozone formation affecting terrestrial ecosystems	kg NOx eq.	8.50E+02	8.44E+02	5.03E+00	1.53E+00
Stratospheric ozone depletion	kg CFC11 eq.	8.55E-02	8.49E-02	5.06E-04	1.54E-04
Terrestrial acidification	kg SO_2 eq.	1.97E+03	1.95E+03	1.16E+01	3.54E+00
Terrestrial ecotoxicity	kg 1.4-DCB eq.	1.82E+05	1.80E+05	1.08E+03	3.28E+02
Water consumption	m^3	1.11E+03	1.10E+03	6.57E+00	2.00E+00
a-Si					

Fine particulate matter formation	kg $PM_{2.5}$ eq.	5.58E+01	5.54E+01	3.30E-01	1.01E-01
Fossil resource scarcity	kg oil eq.	5.33E+03	5.29E+03	3.15E+01	9.60E+00
Freshwater ecotoxicity	kg 1,4-DCB eq.	5.69E+03	5.64E+03	3.36E+01	1.02E+01
Freshwater eutrophication	kg P eq.	1.82E+01	1.80E+01	1.08E-01	3.28E-02
Global warming potential	kg CO_2 eq.	2.23E+04	2.21E+04	1.32E+02	4.01E+01
Human carcinogenic toxicity	kg 1,4-DCB eq.	3.33E+03	3.30E+03	1.97E+01	6.00E+00
Human non-carcinogenic toxicity	kg 1,4-DCB eq.	7.48E+04	7.42E+04	4.42E+02	1.35E+02
Ionizing radiation	kbq Co-60 eq.	2.02E+03	2.01E+03	1.20E+01	3.64E+00
Land use	m^2a crop eq.	5.79E+02	5.74E+02	3.42E+00	1.04E+00
Marine ecotoxicity	kg 1,4-DCB eq.	7.32E+03	7.27E+03	4.33E+01	1.32E+01
Mineral resource scarcity	kg Cu eq.	3.38E+02	3.35E+02	2.00E+00	6.09E-01
Ozone formation affecting human health	kg NOx eq.	5.03E+01	5.00E+01	2.98E-01	9.07E-02
Ozone formation affecting terrestrial ecosystems	kg NOx eq.	5.17E+01	5.13E+01	3.06E-01	9.32E-02
Stratospheric ozone depletion	kg CFC11 eq.	8.71E-03	8.64E-03	5.15E-05	1.57E-05
Terrestrial acidification	kg SO_2 eq.	1.15E+02	1.14E+02	6.82E-01	2.08E-01
Terrestrial ecotoxicity	kg 1.4-DCB eq.	2.40E+05	2.38E+05	1.42E+03	4.33E+02
Water consumption	m^3	2.31E+02	2.29E+02	1.37E+00	4.16E-01
Onshore wind					
Fine particulate matter formation	kg $PM_{2.5}$ eq.	1.50E+01	1.48E+01	8.85E-02	2.69E-02
Fossil resource scarcity	kg oil eq.	2.15E+03	2.13E+03	1.27E+01	3.88E+00
Freshwater ecotoxicity	kg 1,4-DCB eq.	4.08E+03	4.05E+03	2.41E+01	7.34E+00
Freshwater eutrophication	kg P eq.	3.69E+00	3.66E+00	2.18E-02	6.64E-03

Global warming potential	kg CO_2 eq.	7.94E+03	7.88E+03	4.70E+01	1.43E+01
Human carcinogenic toxicity	kg 1,4-DCB eq.	1.20E+04	1.19E+04	7.09E+01	2.16E+01
Human non-carcinogenic toxicity	kg 1,4-DCB eq.	1.96E+04	1.94E+04	1.16E+02	3.52E+01
Ionizing radiation	kbq Co-60 eq.	4.56E+02	4.52E+02	2.70E+00	8.21E-01
Land use	m^2a crop eq.	9.27E+02	9.20E+02	5.48E+00	1.67E+00
Marine ecotoxicity	kg 1,4-DCB eq.	5.02E+03	4.98E+03	2.97E+01	9.04E+00
Mineral resource scarcity	kg Cu eq.	1.88E+02	1.87E+02	1.11E+00	3.39E-01
Ozone formation affecting human health	kg NOx eq.	2.38E+01	2.36E+01	1.41E-01	4.29E-02
Ozone formation affecting terrestrial ecosystems	kg NOx eq.	2.48E+01	2.47E+01	1.47E-01	4.48E-02
Stratospheric ozone depletion	kg CFC11 eq.	3.46E-03	3.44E-03	2.05E-05	6.24E-06
Terrestrial acidification	kg SO_2 eq.	2.73E+01	2.71E+01	1.61E-01	4.92E-02
Terrestrial ecotoxicity	kg 1.4-DCB eq.	4.27E+04	4.23E+04	2.52E+02	7.69E+01
Water consumption	m^3	9.83E+01	9.76E+01	5.82E-01	1.77E-01

References

[1] Mordor Intelligence. (2023). Algae products market size & share analysis - growth trends & forecasts (2023 - 2028), from https://www.mordorintelligence.com/.

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[3] Hosseini, S.M.; Kanagaraj, N.; Sadeghi, S.; Yousefi, H. Midpoint and endpoint impacts of electricity generation by renewable and nonrenewable technologies: A case study of Alberta, Canada. *Renew. Energy* **2022**, 197, 22-39.