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The scientometric research on macroalgal biomass as a source of biofuel feedstock

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ABSTRACT

We performed a scientometric analysis to determine the main trends and gaps in the studies on macroalgal biomass as a source of biofuel feedstock conducted between 1945 and 2013. We used the database from the Thomson Institute for Scientific Information. We found 160 papers published in 78 journals. The number of papers on using macroalgal biomass as a source of biofuel feedstock over the years has increased, especially in the last four years of the study period. The majority of the publications were from Asia (79 papers) and Europe (60 papers). *Ulva* spp. and *Saccharina* spp. were the most studied genera of macroalgae. Nine biofuel types (bio-oil, bioethanol, biodiesel, biogas, biomethane, biohydrogen, biochar, bio-crude and hydrochar) produced from macroalgae were studied, with bioethanol being the most studied. The important gaps in the research that need to be addressed are that few studies have been conducted in countries situated in climatic zones that favor the large-scale cultivation of algae for biofuel production (particularly countries from Africa and South America), as well as on some types of biofuels (e.g., biohydrogen, biochar, and hydrochar).

1. Introduction

Over the last few decades, the world has been facing serious environmental and economic problems, such as non-renewable fossil fuel depletion (e.g., coal, oil, and natural gas) and global climate change [1]. Therefore, the generation of energy from sources other than fossil fuels is necessary for the reduction of global greenhouse gas (GHG) emissions, as well as for addressing issues regarding energy security [2]. Biofuels are a potential alternative energy source [3] because they offer various benefits related to economics, energy security, and the environment (see Table 1 given in Hoekman [4] for an overview of the major benefits of biofuels in each of these areas). In this context, studies have been conducted to identify promising biomass sources of biofuel feedstock [5,3], including macroalgal biomass [6–8].

Macroalgal biomass has several favorable traits and advantages as a source of biofuel feedstock, such as fast growth rate and large biomass yield with superior productivity compared with many terrestrial crops. For example, 3.3.–11.3 kg dry weight m^{-2} yr^{-1} for non-cultured and up to 13.1 kg dry weight m^{-2} over 7 months for cultured brown algae can be produced, compared with 6.1–9.5 kg fresh weight m^{-2} yr^{-1} for sugar cane (see Ross et al. [9] and Wei et al. [8] for more traits and advantages and Kraan [10] for more values of productivity). However, each species has its characteristic life history strategy that must be understood [11]. For instance, large-scale kelp cultivation could have unknown impacts (e.g., biomass losses, dissolved polysaccharide losses or an undesirably high nutrient uptake) with consequences for local primary productivity. Moreover, the end use of algae cultivation would involve carbon dioxide (CO_2) emissions; during its use, the nutrients extracted by kelp cultivation, for example, may be transferred to other ecosystem compartments (e.g., some nutrients are released back into the ocean) [12]. Algal cultivation not only provides biofuel feedstock but also has a high potential for carbon dioxide (CO_2) remediation [13], once macroalgae biomass reaches a higher rate of CO_2 fixation compared with terrestrial biomass [14]; however, this idea remains controversial (see Buschmann et al. [12] for discussion). Furthermore, in comparison to other feedstocks (e.g., crops, food waste, and trees), macroalgal biomass can provide a high-yield source of biofuels without compromising arable land, food supplies or rainforests [15], and it is known as the third-generation feedstock for the production of biofuels [3]. Although macroalgal biomass has several favorable traits and advantages as a source of biofuel feedstock, its large-scale, low-cost production still faces numerous challenges [11,16]. It is necessary to find technologies capable of making each step of the process economically feasible, including macroalgae cultivation, harvesting, transport, pretreatment and the effective conversion of biomass (or its specific components) into high-yielding biofuels [8]. At the same time, large-scale algal cultivation can cause both negative and positive impacts in marine and coastal environments [6,8]; thus, a balance between the production of biofuels from macroalgae and their environmental cost must be attained [8].

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Table 1
Journals that published about macroalgal biomass as a source of biofuel feedstock during the period of 1945–2013.

	Journal title	Publication numbers	Publication numbers (%)	(IF[a])
1	Bioresource Technology	41	25.62	5.039
2	Journal of Applied Phycology	10	6.25	2.492
3	Energy and Fuels	6	3.75	2.733
4	Journal of Analytical and Applied Pyrolysis	4	2.50	3.070
5	Energies	3	1.87	1.602
6	Greenhouse Gas Control Technologies	3	1.87	3.821
7	Renewable and Sustainable Energy Reviews	3	1.87	5.510
8	Brazilian Journal of Pharmacognosy	2	1.25	0.796
9	Energy	2	1.25	4.159
10	Biotechnology and Bioprocess Engineering	2	1.25	1.220
11	Journal of Microbiology and Biotechnology	2	1.25	1.320
12	Plos One	2	1.25	3.534
13	Journal of Supercritical Fluids	2	1.25	2.571
14	Journal of Bioscience and Bioengineering	2	1.25	1.790
15	Journal of Thermal Analysis and Calorimetry	2	1.25	2.206
16	Energy Conversion and Management	2	1.25	3.590
17	Science	2	1.25	31.477
18	Bioprocess and Biosystems Engineering	2	1.25	1.823
19	Journal of Industrial Microbiology and Biotechnology	2	1.25	2.505
20	Energy Sources Part A-Recovery Utilization and Environmental Effects	2	1.25	0.358
21	Renewable Energy	2	1.25	3.361
22	Biomass and Bioenergy	2	1.25	3.411
23	Marine Policy	2	1.25	2.621
24	Applied Energy	2	1.25	5.261
25	Water Science and Technology	2	1.25	1.212
26	Process Biochemistry	2	1.25	2.524
27	(Other journals[b])	52	32.50	

IF[a], impact factor of the journals for 2013.
Other journals[b], journals that contained only one publication.

Globally, there is a very large number of macroalgae species classified as brown (Phaeophyta), green (Chlorophyta), and red (Rhodophyta) [17]. Similar to other feedstocks, the macroalgal biomass has also been used for the production of different types of biofuels, such as gaseous fuels (e.g., biogas, biomethane and biohydrogen) [6,7] or liquid fuels (e.g., biodiesel, bio-oil, biobutanol and bioethanol) [18,19]. Macroalgal biomass has either been converted to biofuels through techniques, including fermentation, gasification, hydrothermal liquefaction, and pyrolysis [18], or it is used as biofuel for direct combustion [20].

Scientometric analysis is a research method used to quantify the state-of-the-art of a particular field [21]. In the field of new emerging renewable energies, scientometric studies have been widely used to identify patterns and trends as well as to detect gaps [22–24,15]. For instance, Konur [22] conducted a scientometric study on algae (microalgae and macroalgae) and bio-energy based on publications from 1980 to 2010 and found that the literature on this issue has grown exponentially, reaching a total of 717 papers that use academic journal publications regarding the use of algae for biofuels and the extent to which these capabilities exist in developing countries. Adenle et al. [15] showed that the USA and Europe are responsible for the majority of the papers published and patented on algae biofuels.

In this context, a precise view on macroalgal biomass as a source of biofuel feedstock is necessary to reach a reliable evaluation of its scientific production. In this study, we performed a scientometric analysis of macroalgal biomass as a source of biofuel feedstock on papers from the period of 1945 to 2013. More specifically, this analysis aims to i) identify the patterns and trends in this research, and ii) demonstrate the main gaps on this subject, which may serve as a potential guide for future research.

2. Material and methods

The literature used in this study was found in the Web of Knowledge online database (v.4.10 — Web of Science) from the Thomson Reuters Inc. (available at www.isiknowledge.com), in April 2014. We used the following combination of words: "macroalgae" or "seaweed" and "biofuel*" or "green energy*" or "renewable energy*" or "hydrogen*" or "biohydrogen*" or "bio-oil*" or "pyrolysis*" or "biogas*" or "bioenergy" or "biomethan*" or "bioethanol*" or "biodiesel*" for the topic search. The majority of these search terms were designed based on previous scientometric studies on algae and bio-energy [22] and related research [23].

Our scientometric analysis of macroalgal biomass as a source of biofuel feedstock differs from the study conducted by Konur [22] on algae and bio-energy on different points. For instance, Konur [22] conducted the scientometric analysis on bio-energy and algae (microalgae and macroalgae), but his study did not quantify the number of papers published on bioenergy and microalgae nor on bioenergy and macroalgae. Here we evaluated new components (e.g., the genera of macroalgae and the type of biofuel studied). Moreover, Konur [22] conducted the search of the terms related to algae in the topic and the terms related to bio-energy in the title, while we conducted the survey to include both algae and bio-energy in the title. The search for publications is sensitive to the keywords used as well as to the location of the keywords (e.g., in the topic or in the title) (see Konur [23] for more explanations).

Initially, the search resulted in a total number of 385 papers. Next, we analyzed each of the 385 papers to identify only the studies on macroalgal biomass as a source of biofuel feedstock. A total of 225 papers were excluded because many studies were on the impacts of oil/petroleum on macroalgae and/or the use of microalgae for biofuel production. Therefore, 160 papers were used for our scientometric analysis of macroalgal biomass as a source of biofuel feedstock in the period between 1945 and 2013.

For each paper, we identified i) the document type, ii) the year of publication, iii) the journal of publication and its impact factor for 2013, iv) the Web of Science category of the journal, v) the number of citations, vi) the country of publication, vii) the research institution, viii) the author, ix) the species and/or genera of macroalgae studied, and x) the type of biofuel studied. Papers originating from England, Scotland, Northern Ireland, and Wales were grouped under the United Kingdom heading [25]. As is common in other scientometric studies, we estimated the contribution of different countries and research institutions by the location of the affiliation of the first author of each publication [22,23]. We determined the contribution of authors based on the complete count strategy [25]. We obtained the journal impact factors reported in the 2013 Edition of the Journal Citation Reports (JCR). The species of macroalgae were classified within the major macroalgal taxonomic groups: brown (Phaeophyta), green (Chlorophyta) or red (Rhodophyta).

The Generalized Linear Model (family distribution = Poisson) was used to identify possible trends over time in the number of papers on macroalgal biomass as a source of biofuel feedstock. We generated multiple regression models in order to identify possible explanatory variables to explain the number of papers published on macroalgal biomass as a source of biofuel feedstock based on the contribution of the countries. We initially considered four explanatory variables as possible predictors. These were: (i) the Average Gross Domestic Product (GDP) (in dollars) from 2013, (ii) the CO_2 emissions (in metric tons per capita) from 2010, (iii) fossil fuel energy consumption (% of total) from 2011, and (iv) combustible renewables and waste (% of total energy) from 2011. These data were obtained from the database of the World Bank [26] (available at www.worldbank.org/data), in April 2014. We then employed Pearson correlations to verify multicollinearity among explanatory variables. We found a negative correlation (Pearson $r = -0.63$, $P < 0.001$, $N = 23$) between fossil fuel energy consumption and combustible renewables as well as between the CO_2 emissions and combustible renewables (Pearson