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Research article

Bioenergy relations with agriculture, forestry and other land uses: Highlighting the specific contributions of artificial intelligence and co-citation networks

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A R T I C L E I N F O

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A B S T R A C T

The concerns with the environment and sustainability have promoted options for energy sources that mitigate the footprint of human life. The use of biomass from agriculture, forestry and other land uses (AFOLU) has enormous potential for the production of bioenergy as a renewable source of energy. In this context, this research aims to analyse the interrelationships between bioenergy and agriculture, forestry and other land uses, highlighting the contributions of the digital transition for these dimensions. To achieve these objectives, a bibliometric analysis through co-citation links (and items related to cited authors, references and sources) was carried out for the dimensions associated with the bioenergy and the AFOLU and after a specific literature survey was performed for the contributions from the digital transition for these frameworks. With this study, top authors, references and sources were identified for the topics assessed and it was highlighted the importance of digital transitions for more efficient bioenergy use and production in the worldwide contexts.

1. Introduction

AFOLU (agriculture, forestry and other land uses) sector is confronted with several challenges, namely those related to the need to increase the food supply (as demand is increasing with increasing population), mitigate the impacts on biodiversity and minimize carbon emissions [1]. AFOLU is, indeed, interrelated with diverse dimensions, specifically those related to urban planning, energy use and production and water management [2].

Agriculture, forestry and other land uses represent a relevant part of the greenhouse gas emissions worldwide, particularly in Latin America, depending on the role of bioenergy and how this energy is produced and used [3]. In fact, bioenergy may contribute to mitigate carbon emissions, but these contributions can be limited if the changes in land use are not sustainable. In addition, the use of land for bioenergy production may compete with agricultural production, with consequences on food prices. The discussion about the contributions of the AFOLU and bioenergy for sustainable development highlights diverse perspectives [4]. Nonetheless, there are still fields that need deeper research [5] and opportunities to be explored [6]. In any case, the bioenergy emissions could be lower than those from fossil fuels [7].

Since the seventies, several countries have searched for alternative sources of energy, where biofuels appear with a relevant

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importance in some cases. Brazil, the United States of America and the European Union are among the main producers of biofuel through corn and sugar cane for ethanol (Brazil and the United States of America) and oilseeds for biodiesel (European Union). The production of these biofuel sources was promoted through policies supported by subsidies and adjusted legislation [8].

The national and international policies play a fundamental role to mitigate the carbon emissions from the economic sectors and the different land uses. The main problems here are the difficulties to implement an integrated policy framework that allows to reduce the heterogeneity in the associated policy measures and instruments [9]. On the other hand, for effective mitigation of carbon emissions through bioenergy, the related policies must consider all chain from the agricultural sector to the final consumer [10]. In these scenarios and for appropriate policy design, it is important to consider adjusted carbon accounting methods and emission inventory approaches [11].

There is already a lot of information in the scientific literature on bioenergy and the respective efforts developed in the last decades in these fields, but not so much on the interconnections with AFOLU. New technologies are other dimensions that deserve special attention in these frameworks. The digital transition and the associated technologies and approaches may bring interesting contributions to promote the bioenergy production potentials from agriculture, forestry and other land uses [12]. In bioenergy-related fields, the land-water-energy nexus approach has been addressed in scientific literature [13–15], nonetheless, there are still subjects to be explored further.

The framework described above highlights that there is a field to be explored in the literature on the relationship between bioenergy and the AFOLU dimensions. This reduced number of scientific documents related to these two topics is visible in a quick search on Scopus [16] and Web of Science [17]. In this context, this study intends to highlight insights related to the relationships (the AFOLU sector can contribute to the production of bioenergy and can benefit from this renewable energy for more sustainable development). worldwide among bioenergy and agriculture, forestry and other land uses. Contributions from the digital transition and the associated approaches for these contexts were addressed more specifically, namely in the systematic literature review. The Agriculture 4.0 technologies appear as an opportunity to improve the efficiency in the AFOLU sector and in this way to promote a more sustainable development, particularly in the responses to the current challenges. Indeed, the literature review revealed that there is still a field to be explored in the interrelations between bioenergy, AFOLU and digital approaches. There are not many scientific studies on the topic “AFOLU" and even less on the topics “AFOLU" and “bioenergy". To achieve the proposed objectives, systematic literature review and bibliometric analysis approaches were considered. The systematic literature review will be carried out in section two. The methodology for bibliometric analysis and respective results will be presented in sections 3 and 4. The specificities of the methodology for bibliometric analysis justify a section on these issues.

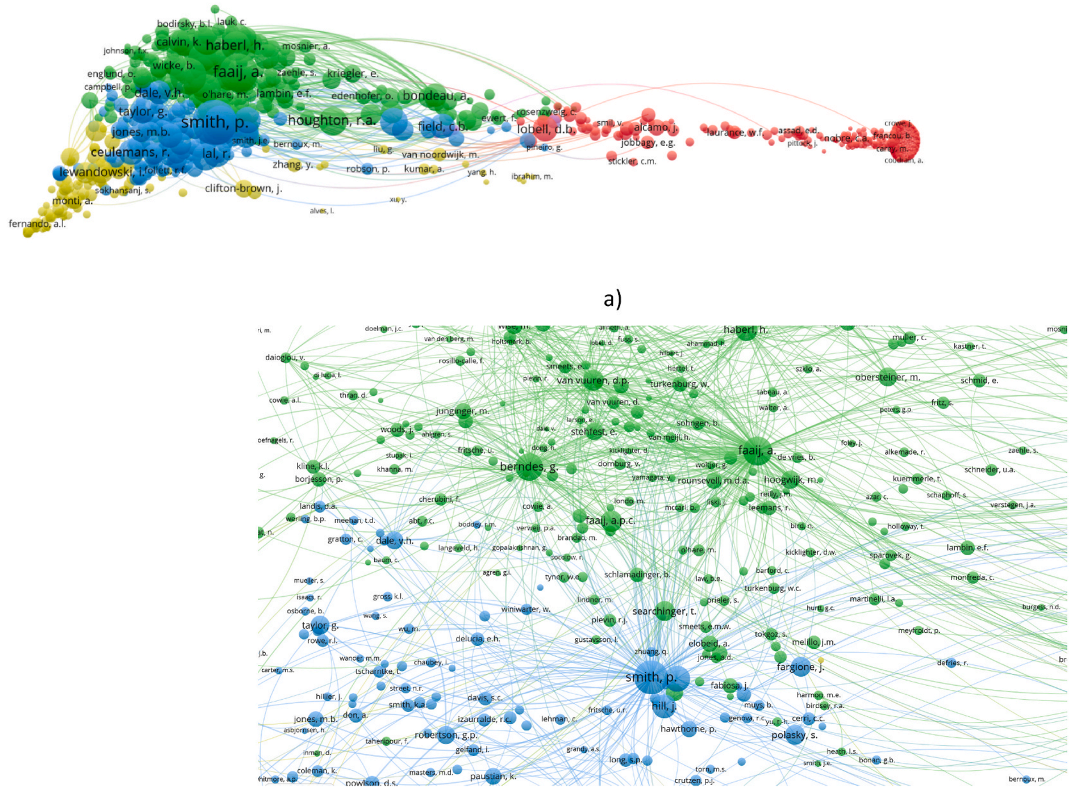
2. Systematic literature review on the specific contributions of artificial intelligence for the interrelationships between bioenergy and agriculture, forestry and other land uses

This section aims to focus on the contributions of smart technologies to the dynamics among bioenergy and AFOLU (agriculture, forestry and other land uses). For that, 26 documents were considered from a search carried out on 30 April 2023 for the following topics: bioenerg*; and agricultur*; and “artificial intelligence". In this search, 28 documents were obtained from Scopus and 10 studies were found on the Web of Science. These topics were chosen because no documents were found for the topics AFOLU and “artificial intelligence" on the Scopus and Web of Science platforms. However, even for the topics considered, the number of documents is small. In any case, this section will seek to highlight the contributions of artificial intelligence to the relationships between bioenergy and agriculture evidenced in the literature. After removing the duplicate, books and conference articles, 26 documents were taken into account for the literature survey presented in the following paragraphs. For this assessment, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [18] approach was followed, specifically to identify the topics of search, removing the duplicate and select the documents to be surveyed.

New technologies associated with the digital transition may bring relevant contributions to bioenergy use and production, namely by improving the efficiency of the respective processes. Specifically, the artificial intelligence approaches (artificial neural networks, Bayesian networks, decision tree and multivariate regression) were used to deal with the difficulties related to the conversion of biowaste (biomass waste from agriculture and algal residues, for example) in bioenergy, particularly those associated with the feedstock unpredictability, conversion costs and supply chain specificities [19]. In fact, the variability of bio-resources used in the production of bioenergy brings added difficulties for the supply chains [20]. Additionally, the bioenergy conversion structures still need more technological advances, namely to overcome economic constraints [21]. Technical and political changes are also needed in some circumstances [22]. Usually, it is cheaper and easier to burn biomass residues from agricultural practices [23].

The new technologies and methodologies may support the decision makers to identify adjusted feedstock, facilities location [24] and mitigate risks and costs [25]. These approaches include those related to the geographical information system (GIS) [26], support vector regression [27], artificial intelligence-SARIMA integrated models [28], random forest regression [29] and spatial modelling [30], for instance. These methodologies are taken into account namely to assess statistical information related to use a production of bioenergy. These methods can contribute to a more efficient biomass supply management [31] and an integrated manure system [32].

The smart approaches may provide relevant insights [33], including on biohydrogen production with algal [34]. They are used too to promote a more circular economy [35], to predict and simulate alternative scenarios [36], as well as to analyse data [37] with useful outputs for agricultural and bioenergy productions [38]. Considering the vulnerability of the sources of biomass to the soil, weather conditions [39] and farming management [40], the prediction models play a crucial role in these frameworks. These methodologies associated with artificial intelligence open new potentialities and overcome some of the constraints found on predictions carried out by the linear empirical models [41]. For the successful implementation and adoption of more sustainable agricultural plans, national and



a)

b)

Fig. 1. Cited authors, considering co-citation links and documents from the Scopus database. a) All information exported from VOSviewer; b) Information around authors with higher metrics.

international policies play a determinant role [42]. In any case, there are several constraints that may limit the application of these approaches, namely those related to the necessary skills, the availability of equipment and infrastructure. This may be a serious challenge, namely for the small farms.

The agricultural activities are simultaneously producers and consumers of energy, making this sector strategic for energy management and a better interrelationship of this resource with sustainability. This explains the concerns of several stakeholders to improve the use of energy in the sector. There have been relevant efforts to better manage the use of energy in farming systems [43]. Several crops (Miscanthus, *Arundo donax* and Switchgrass) may be considered sources of biomass [44].

After this literature survey the following three questions may arise:

- How does artificial intelligence contribute to understanding the relationship between bioenergy and AFOLU?
- Why does artificial intelligence contribute to understanding, modelling or explaining the bioenergy-AFOLU relationship?
- What approaches and discoveries are generated by artificial intelligence for bioenergy-AFOLU?

Trying to consider these issues, it should be noted that this systematic review provides some insights into how the digital transition can contribute to a better understanding of the relationships among bioenergy and AFOLU frameworks, namely in terms of decision support, scenario forecasting and efficiency improvement. More specifically on why artificial intelligence can contribute to these contexts, it is worth noting that the literature shows that artificial intelligence is related, for example, to machine learning models, automation and IoT (Internet of Things) technologies. Machine learning models allow us to identify the most important variables to predict bioenergy production by the AFOLU sector. This is important for more adjusted and efficient management and planning of the sector, reducing costs and promoting more sustainable development. On the other hand, IoT technologies allow information to be collected and analysed more quickly and accurately. The importance of having a more sustainable agri-food sector while dealing with the growing demand for food is reflected in the CSA (Climate-Smart Agriculture) [45] concept promoted by the FAO (Food and Agricultural Organisation) [46]. The idea is to use smart approaches to increase production with a more precise use of resources (water, energy, soil, fertilisers and phytopharmaceuticals). Artificial neural networks, Bayesian networks, decision tree, multivariate regression, support vector regression and random forest regression are among the approaches considered by researchers. There are, however, constraints that prevent the effective implementation of these new technologies, namely those related to the necessary skills,

Table 1
Top 50 cited authors with the highest total link strength, considering co-citation links and documents from the Scopus database.

Cited authors	Links	Total link strength	Citations
Faaij, A.	921	40590	234
Smith, P.	943	33709	311
Berndes, G.	634	32519	207
Haberl, H.	586	20922	136
Popp, A.	567	20427	125
Van Vuuren, D.P.	589	18920	124
Rodriguez-Morales, A.J.	442	16950	15
Tilman, D.	655	16759	180
Lobell, D.B.	911	16568	100
Hastings, A.	979	15741	116
Marengo, J.A.	574	15226	17
Havlik, P.	570	14170	132
Stehfest, E.	623	13790	85
Calvin, K.	547	13560	78
Faaij, A.P.C.	606	13446	128
Hill, J.	639	13429	153
Lal, R.	631	13013	121
Foley, J.A.	902	12999	119
Field, C.B.	916	12750	96
Wise, M.	525	12678	75
Bondeau, A.	885	12566	86
Romero-Lankao, P.	442	12474	11
Wicke, B.	549	12455	58
Dale, V.H.	602	12405	85
Houghton, R.A.	929	11931	129
Lucht, W.	893	11621	69
Turkenburg, W.	489	11369	63
Smeets, E.	561	10768	45
Taylor, G.	580	10388	97
Junginger, M.	580	10304	74
Creutzig, F.	552	10275	44
Edmonds, J.	542	10270	71
Franco-Paredes, C.	442	10224	9
Francou, B.	442	10224	9
Robertson, G.P.	585	10004	91
Beringer, T.	584	9720	63
Paustian, K.	565	9663	78
Clarke, L.	843	9459	56
Hoogwijk, M.	536	9376	93
Erb, K.-H.	552	9316	69
Searchinger, T.	615	9280	110
Fujimori, S.	514	9253	50
Kriegler, E.	855	9251	50
Fargione, J.	641	9216	111
Kline, K.L.	550	9146	54
Daioglou, V.	452	9109	32
Carey, M.	442	9096	8
Espinoza, J.C.	442	9096	8
Lemos, M.C.	442	9096	8
Mark, B.G.	442	9096	8

equipment and infrastructures. In any case, the literature does not yet seem to fully answer the three questions presented above and they could serve as guidance for future studies. For future research, it could be important also to further explore the relevance of artificial intelligence for sustainable development and the climatic adjustment, in the context of the relationships between the bioenergy and AFOLU.

To better support future research into the relationship between bioenergy and the AFOLU sector, including the dimensions of artificial intelligence, it is considered important to highlight networks between bioenergy and the various parts of the AFOLU context, which will be developed in the following sections.

3. Material and methods for the bibliometric analysis

The documents assessed were obtained from the Scopus [16] (364 documents) and Web of Science Core Collection [17] (289 documents) databases on a search carried out on 30 April 2023 for the following topics: "bioenerg*"; and "agricultur*"; and "forest*"; and "land use". These documents were obtained from the respective databases without any restrictions (for the years, type of publication, for example). For the search, only the topics referred were considered. Considering the reduced number of documents for the

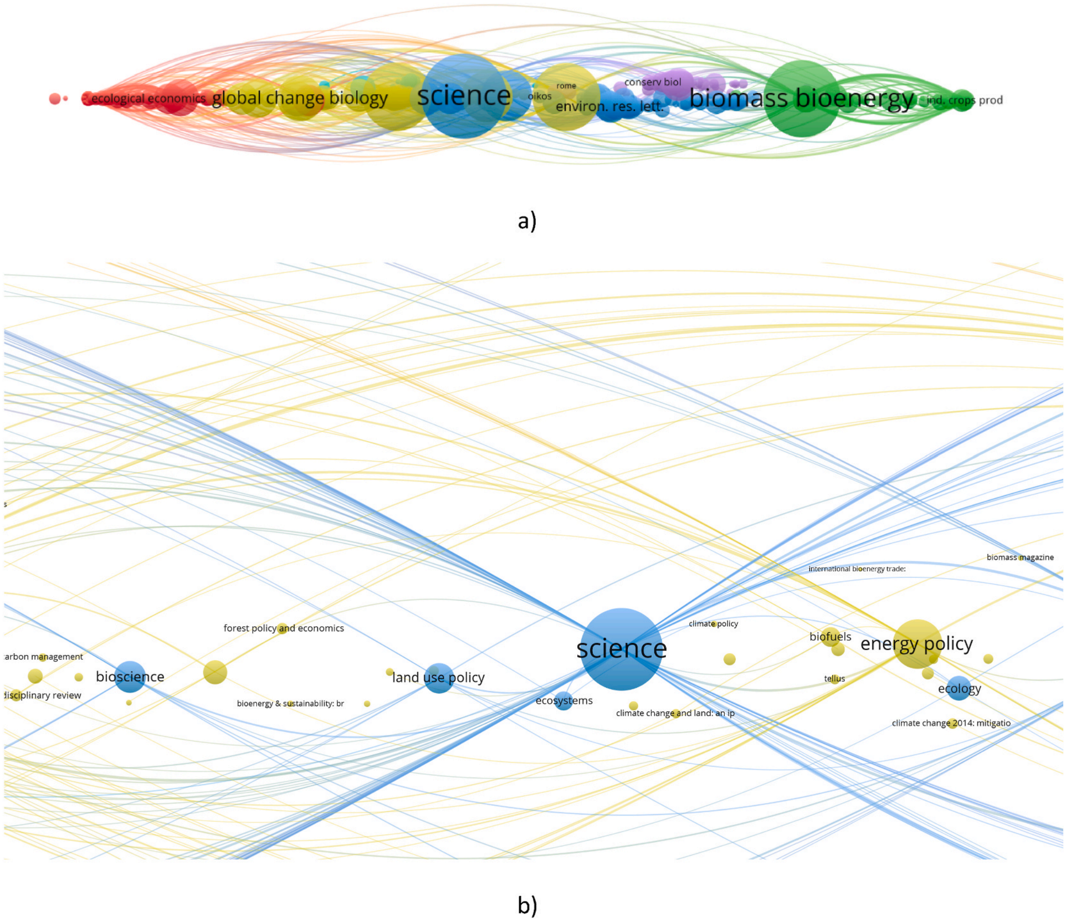


Fig. 2. Cited sources, considering co-citation links and documents from the Scopus database. a) All information exported from VOSviewer; b) Information around with higher metrics.

topics "bioenerg*" and "AFOLU", the expression AFOLU was replaced in the search by the respective sectors (agriculture, forest and land use). To cover more documents in the search, expressions related to artificial intelligence were also not considered.

Taking into account the objectives proposed, bibliometric metrics were considered for co-citation links and considering cited authors, references and sources as items. This approach allows obtaining top items related to the topics addressed. The metrics considered to identify the most relevant items were the total link strengths (total strength of the links between an item and other items), because they capture relatedness (based on the number of times the items are cited together) among the items analysed and their relevance for the topics studied, such as shown by Martinho [47]. The consideration of these links (co-citation) with the respective relatedness (based on the number of times the items are cited together) is based on the idea that if the documents are cited together, they are related to the same issue.

These documents were analysed following VOSviewer [48–50] software procedures. The information presented in the next section was obtained through this software and considering full counting and 1 as the minimum number of citations of a cited reference, a cited source and a cited author. In figures, the dimension of the circles represents the number of citations for each item and the distance between items symbolizes the degree of relatedness (number of times the items are cited together).

4. Bibliometric analysis considering co-citation links

This section for co-citation links obtained with bibliographic data is divided into two subsections, one for the data obtained from the Scopus database and the other for the information found on the Web of Science Core Collection data.

4.1. Scopus database

The cited authors with the biggest total link strength (greatest relatedness with other cited authors) are the following: Faaij, A.; Smith, P.; Berndes, G.; Haberl, H.; Popp, A.; Van Vuuren, D.P.; Rodriguez-Morales, A.J.; Tilman, D.; Lobell, D.B.; Hastings, A.; Marengo, J.A.; Havlik, P.; Stehfest, E.; and Calvin, K. Some of these cited authors are also among those with the highest citations (Fig. 1 and

Table 2
Top 50 cited sources with the highest total link strength, considering co-citation links and documents from the Scopus database.

Cited Sources	Links	Total link strength	Citations
Science	994	45201	697
Biomass Bioenergy	569	37754	577
GCB Bioenergy	657	32464	447
Climatic Change	616	30652	136
Biomass and Bioenergy	328	26651	451
Bioresour. Technol	236	20337	50
Nature	803	17509	253
Environmental Research Letters	565	17270	99
Ind. Crops Prod	200	17094	37
Global Change Biology	570	16686	207
Energy Policy	781	16189	253
Geophysical Research Letters	516	14997	35
Proceedings of the National Academy of Sciences of the United States of America	577	14796	91
Forest Ecology and Management	530	13753	146
Renewable and Sustainable Energy Reviews	548	12951	105
International Journal of Climatology	449	12821	24
Global and Planetary Change	415	11856	18
Ecology and Society	496	10931	19
Global Environmental Change	560	10551	62
Plos One	692	10537	95
Bioscience	777	9370	104
Journal of Hydrology	448	9368	31
Journal of Climate	469	9243	17
Fuel	384	8877	34
American Journal of Tropical Medicine and Hygiene	395	8624	11
Ecological Economics	504	8475	42
Energy	541	8417	71
Nature Climate Change	528	8308	66
Climate Dynamics	418	8003	13
Theoretical and Applied Climatology	395	7850	10
Renew. Sustain. Energy Rev	233	7810	26
Renew. Energy	298	7443	30
Global Change Biology Bioenergy	534	7339	120
Energies	457	7045	47
Environmental Science & Technology	227	7039	61
Land Use Policy	728	7033	97
J. Clean. Prod	233	6937	16
Current Opinion in Environmental Sustainability	512	6906	24
Conservation Biology	516	6856	37
Water Resources Research	455	6758	15
Biofuels, Bioproducts And Biorefining	228	6140	60
Bioresource Technology	517	5845	65
Ambio	666	5775	39
Bioenergy Res	386	5729	48
Mitigation and Adaptation Strategies for Global Change	562	5518	30
Global Environmental Change: Human and Policy Dimensions	395	5516	7
Climate Research	457	5183	18
Soil Sci Soc Am J	130	5152	41
Hydrological Processes	440	5031	14
Hydrology and Earth System Sciences	437	4908	11

Table 1).

Considering the specific context for the network associated with the cited references, where a relevant number of documents has the same metrics for the variables related to links, total link strength and citations, these results were not presented. These outputs need a deeper assessment in future research to better understand this framework for the network obtained.

The cited sources with the biggest metrics for the total link strength variable (some of them with the highest numbers for the variables links and citations) are the following (Fig. 2 and Table 2): Science; Biomass Bioenergy; GCB Bioenergy; Climatic Change; Biomass and Bioenergy; Bioresour. Technol; Nature; Environmental Research Letters; Ind. Crops Prod; Global Change Biology; Energy Policy; Geophysical Research Letters; Forest Ecology and Management; Renewable and Sustainable Energy Reviews; and International Journal of Climatology. These outputs show that the cited sources with the highest scores in the metrics taken into account are focused on energy and environmental issues, for example, showing that there is a field to be addressed by sources focused on the agricultural sector and economics, for instance.

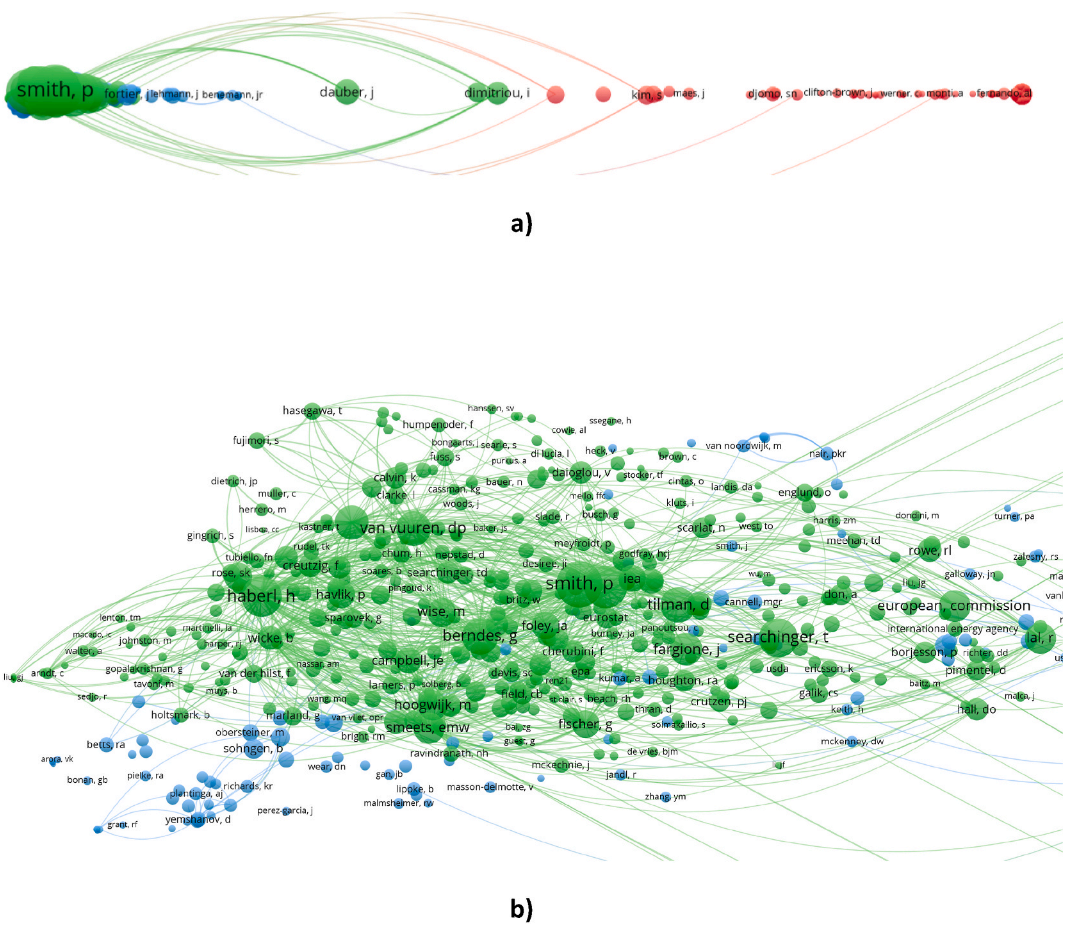


Fig. 3. Cited authors, considering co-citation links and documents from the Web of Science database. a) All information exported from VOSviewer; b) Information around authors with higher metrics.

4.2. Web of Science database

Fig. 3 and Table 3 reveal that the top cited authors (with the greatest values for the total link strength) are the following: Haberl, H; Berndes, G; Smith, P; Wicke, B; Smeets, EMW; Van Vuuren, DP; FAO; Fernando, AL; Popp, A; Erb, KH; Tilman, D; Dimitriou, I; Searchinger, T; IEA; and Nunes, LJR. Some of these cited authors were identified in the assessment for the Scopus database.

The top cited sources for the Web of Science database (some of them also identified for Scopus) are the following (Fig. 4 and Table 4): Biomass Bioenerg; GCB Bioenergy; Science; Renew Sust Energ Rev; Bioresource Technol; Forest Ecol Manag; Global Change Biol; P Natl Acad Sci USA; Energ Policy; Environ Res Lett; Climatic Change; J Clean Prod; Agr Ecosyst Environ; Ind Crop Prod; Environ Sci Technol; Nature; Nat Clim Change; Biofuel Bioprod Bior; and Appl Energ. Again, this assessment shows that there is potential for studies focused on agricultural and economic issues.

4.2.1. Specific contributions from the Web of Science database

Table 5 presents the top 50 cited references with the highest total link strength and Table 6 highlights insights from these documents. The top 50 cited documents with higher relatedness confirm that the real contributions of bioenergy for greenhouse gas emissions are controversial between the researchers. These researchers show that the contributions of bioenergy for carbon emissions mitigation depend on the way the respective biomass is obtained and converted, as well as on the accounting methodologies taken into account. The abandoned and marginal land may contribute to a positive balance, in terms of carbon emissions, from the bioenergy use. The same happens with adjusted agricultural practices. Nonetheless, the potential to produce bioenergy worldwide is limited, more when marginal and abandoned land is considered. Table 5 reveals also the efforts made by the scientific community to improve the processes of biomass conversion.

5. Discussion and conclusions

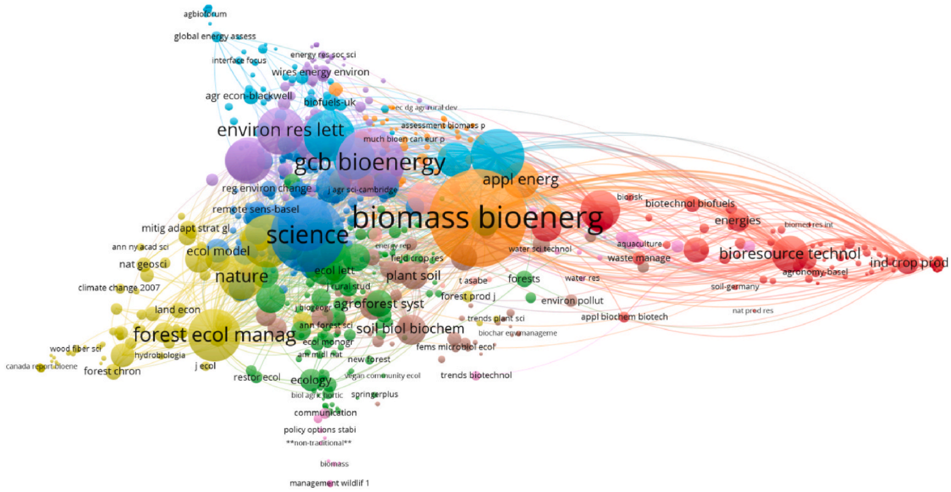
This study intended to investigate the relationships among bioenergy and AFOLU (agriculture, forestry and other land uses),

Table 3
Top 50 cited authors with the highest total link strength, considering co-citation links and documents from the Web of Science database.

Cited Authors	Links	Total link strength	Citations
Haberl, H	437	4044	80
Berndes, G	416	3373	65
Smith, P	445	3172	106
Wicke, B	345	2751	28
Smeets, EMW	402	2744	48
Van Vuuren, DP	423	2635	61
FAO	492	2623	91
Fernando, AL	466	2479	6
Popp, A	392	2439	57
Erb, KH	377	2218	39
Tilman, D	428	2107	63
Dimitriou, I	764	2083	21
Searchinger, T	483	2079	76
IEA	404	1968	35
Nunes, LJR	447	1968	4
Creutzig, F	372	1907	27
Hoogwijk, M	354	1881	44
Fischer, G	321	1776	38
Lal, R	412	1620	48
Fargione, J	441	1589	53
Dale, VH	392	1567	33
Kim, S	630	1531	14
Cherubini, F	410	1512	26
Antonopoulou, G	447	1479	3
Barbosa, B	447	1479	3
Prade, T	447	1479	3
Yanez, R	447	1479	3
Dauber, J	775	1443	25
Van Dam, J	296	1435	17
Daioglou, V	296	1345	25
Searchinger, TD	381	1319	26
Campbell, JE	374	1317	34
Van Der Hilst, F	259	1302	17
Havlik, P	362	1293	38
Marland, G	388	1264	18
De Wit, M	312	1191	19
Dornburg, V	322	1177	24
Calvin, K	312	1175	24
Wise, M	347	1174	41
European, Commission	346	1159	51
Foley, JA	361	1153	38
Rowe, RL	280	1137	28
Miao, XL	469	1126	5
Sassner, P	476	1084	4
Borjesson, P	316	1078	23
Davis, SC	355	1075	16
Monti, A	492	1053	5
Gibbs, HK	364	1032	25
Mehmood, MA	471	1012	3
Gopalakrishnan, G	205	1002	8

showing the importance of the artificial intelligence approaches for these issues. For that, bibliographic data, co-citation links and literature survey were taken into account to highlight metrics and insights from scientific documents. For the bibliometric analysis, a search on 30 April 2023 was carried out on the Scopus and Web of Science (Core Collection) databases for the following topics: “bioenerg*”; and “agricultur*”; and “forest*”; and “land use”. For these topics, 364 documents were found on Scopus and 289 studies were identified on Web of Science. For this bibliometric assessment, the VOSviewer procedures were followed. To identify the top items (cited authors, references and sources), the total link strength metric was considered.

The preliminary literature review revealed the current challenges of the AFOLU sector, particularly those associated with the sustainability impacts and the interrelationships of the related activities with energy and water use, for example. Such as highlighted in previous sections, the scarcity of some resources is a real concern for several stakeholders. Depending on the way as the AFOLU sector is managed, the sustainability may be improved or worsened. The production of bioenergy with the biowaste from this sector may contribute to mitigate the environmental impacts, depending on how this energy is produced, namely due to the competition, in some circumstances, for land between energy crops and food production. Brazil, the United States and European Union are between the main producers of bioenergy. In these frameworks, governments and international organizations need to deal with the heterogeneity of policy instruments and measures and the complexity of agrifood chains. Considering the importance of Brazil, the United States and



a)

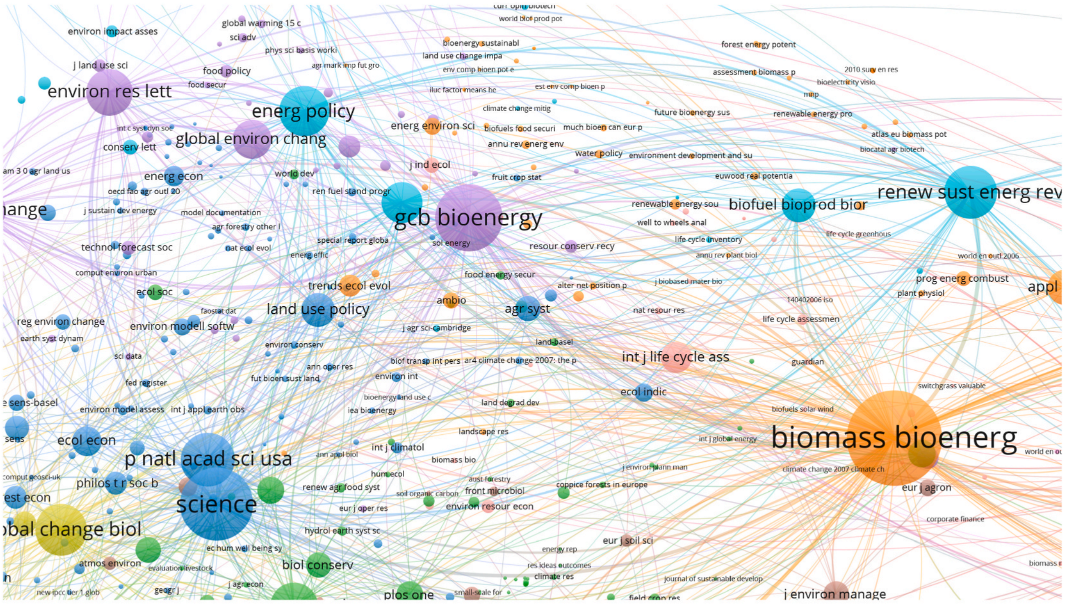


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Fig. 4. Cited sources, considering co-citation links and documents from the Web of Science database. a) All information exported from VOSviewer; b) Information around with higher metrics.

European Union for the bioenergy production, and some level of concentration currently, there are important opportunities to better regulate the associated supply chains, with an emphasis on sugarcane activities, cellulose and paper manufacturing, grain productions and wood industry.

The specific systematic literature survey about the contributions from the digital transition to the relationships among bioenergy and AFOLU highlights the following that several artificial intelligence approaches have been considered in studies related to bioenergy and AFOLU, specifically the following [19]: artificial neural networks; Bayesian networks; decision tree; and multivariate regression. Some of these approaches are usually used by the literature for prediction studies. Some of the main constraints associated with biomass conversion to bioenergy are related to the feedstock variability (because of the great diversity of sources) [20], costs (of collection, transport and conversion), chain particularities, technical difficulties and political challenges [22]. There is a noticeable scarcity of artificial intelligence approaches that measure the economic viability of bioenergy in AFOLU contexts. These findings are relevant insights that may be considered by the stakeholders (mainly from the investor's point of view), namely in the design of policies, legislation, management plans and resource allocation, whether public or private. The new methodological approaches are

Table 4
Top 50 cited sources with the highest total link strength, considering co-citation links and documents from the Web of Science database.

Cited Sources	Links	Total link strength	Citations
Biomass Bioenerg	942	86363	1053
GCB Bioenergy	928	46005	524
Science	994	39722	614
Renew Sust Energ Rev	890	35298	325
Bioresource Technol	641	30460	155
Forest Ecol Manag	690	25287	313
Global Change Biol	912	24670	313
P Natl Acad Sci USA	936	23524	333
Energ Policy	775	22093	296
Environ Res Lett	716	21302	251
Climatic Change	681	20132	242
J Clean Prod	732	19959	180
Agr Ecosyst Environ	784	19107	270
Ind Crop Prod	360	18611	60
Environ Sci Technol	912	18498	195
Nature	742	17605	226
Nat Clim Change	627	16092	181
Biofuel Bioprod Bior	781	14968	136
Appl Energ	701	11880	149
Energy	783	11625	88
Renew Energ	735	11248	74
Soil Biol Biochem	549	10947	105
Bioenerg Res	751	10923	106
Global Environ Chang	586	10477	175
Fuel	584	10005	38
Land Use Policy	632	9893	136
Energies	501	8703	54
Can J Forest Res	459	8626	63
Environ Sci Policy	680	8459	85
Sustainability-Basel	599	8217	89
Ecol Econ	635	7921	105
Ecol Appl	662	7850	98
J Environ Manage	816	7775	75
Plant Soil	491	7736	92
Int J Life Cycle Ass	578	7366	115
Agroforest Syst	377	6920	82
J Environ Qual	556	6728	56
Soil Sci Soc Am J	514	6193	77
Bioscience	574	6135	85
Sci Total Environ	619	6049	56
Forest Policy Econ	515	5959	82
Front Ecol Environ	564	5895	67
Energ Convers Manage	609	5667	35
Forest Chron	309	5592	30
Conserv Biol	595	5488	76
Plos One	512	5447	87
Curr Opin Env Sust	632	5301	59
Agr Syst	664	5148	76
Biol Conserv	498	4924	75
J Chem Technol Biot	382	4853	14

important to support the different stakeholders in the following processes: identification of feedstock; design and location of conversion facilities; mitigation costs and risks; design of more efficient biomass chains; prediction and simulation alternative proposals; data processing; economic viability; and sustainable investment opportunities in the sector. These are important findings to support improvements in the methodologies and algorithms that have been designed [41]. The biomass may be obtained from biowaste (algal, agricultural and livestock residues), or may be produced through various crops, such as Miscanthus, *Arundo donax* and Switchgrass [44]. There is still some work to do about sustainable sources of biomass and the digital methodologies may bring relevant insights, including investment opportunities, depending on the economic viability of the activity.

The bibliometric analysis reveals that some of the cited authors with the highest total link strength are also those with the biggest number of citations. The same happens for the other items (cited documents and sources). On the other hand, the top cited sources are, generally, focused on topics related to energy, climate and environment, for instance, showing that there is a field to be deeper explored by sources associated with agricultural and economic issues (measuring profitability and highlighting the opportunities of the bioenergy business). The issues related to bioenergy and AFOLU are wide-ranging and deserve be considered by interdisciplinary teams and sources, not only those focused on energy, climate and environment. These are here social and economic dimensions, for example, that need to be deeper addressed.

Table 5
Top 50 cited references with the highest total link strength and DOI provided by the database, considering co-citation links and documents from the Web of Science.

Cited references	Links	Total link strength	Citations
Searchinger T, 2008 [51]	386	933	65
Fargione J, 2008 [52]	372	864	52
Dauber J, 2012 [53]	740	772	6
Blanco-Canqui H, 2010 [54]	632	652	5
Schmer MR, 2008 [55]	598	650	12
Campbell JE, 2008 [56]	326	610	29
Zatta A, 2014 [57]	567	578	5
Haberl H, 2010 [58]	305	569	19
Dimitriou I, 2012 [59]	546	554	4
Sannigrahi P, 2010 [60]	549	550	3
Sassner P, 2008 [61]	541	541	2
Raghu S, 2006 [62]	538	539	4
Djomo SN, 2011 [63]	534	538	3
Mehmood MA, 2017 [64]	533	533	2
Raud M, 2019 [65]	530	530	2
Williams PRD, 2009 [66]	525	526	2
Clifton-Brown J, 2017 [67]	524	525	2
Field CB, 2008 [68]	295	525	19
Dote Y, 1994 [69]	521	524	2
Miao Xl, 2004 [70]	521	524	2
Miao Xl, 2006 [71]	521	524	2
Minowa T, 1995 [72]	521	524	2
Beringer T, 2011 [73]	306	522	17
Werner C, 2012 [74]	522	522	2
Von Cossel M, 2019 [75]	521	521	2
Rosso L, 2013 [76]	519	519	2
Abreu M, 2020 [77]	517	517	1
Ahmad M, 2011 [78]	517	517	1
Ahmad T, 2019 [79]	517	517	1
Akanksha K, 2016 [80]	517	517	1
Al Chami Z, 2014 [81]	517	517	1
Alba LG, 2012 [82]	517	517	1
Alexandropoulou M, 2017 [83]	517	517	1
Allwright MR, 2016 [84]	517	517	1
Alvarez-Alvarez P, 2018 [85]	517	517	1
Amna, 2015 [86]	517	517	1
Amutio M, 2013 [87]	517	517	1
Antonopoulou G, 2008 [88]	517	517	1
Antonopoulou G, 2010 [89]	517	517	1
Antonopoulou G, 2013 [90]	517	517	1
Appiah-Nkansah NB, 2019 [91]	517	517	1
Asad M, 2017 [92]	517	517	1
Astolfi AL, 2020 [93]	517	517	1
Aswie V, 2021 [94]	517	517	1
Athar M, 2020 [95]	517	517	1
Ba YX, 2020 [96]	517	517	1
Babich IV, 2011 [97]	517	517	1
Bacenetti J, 20174 [98]	517	517	1
Bai Y, 2010 [99]	517	517	1
Balch ML, 2020 [100]	517	517	1

In terms of practical implications, this research reveals that there is still a field to be explored to become biomass conversion in bioenergy more economically profitable, particularly becoming the several processes associated with this transformation more efficient. The approaches and algorithms associated with the digital transition may contribute significantly for these frameworks. For policy recommendations, it could be important to design instruments and measures that incentive the land owners (specifically the smaller ones) to collect and send the biomass to conversion facilities. In parallel, it would be crucial to incentive the governments to create conditions for the installation of new conversion facilities. This is and will be particularly important for the fuel load management in the landscapes and to prevent the risks of forest fires. For future research, it is suggested to explore the economic dimensions of these conversion processes, highlighting ways to become this transformation of biomass into bioenergy more economically attractive for investors and showing the economic viability of energy-generating activities. It would also be important to explore the sustainability of bioenergy alternatives within the framework of land-water-energy nexus approach.

Table 6
Insights from the top 50 cited references with the highest total link strength and DOI provided by the database, considering co-citation links and documents from the Web of Science.

Cited references	Some insights
Searchinger T, 2008 [51]	The use of biofuels may increase the GHG, highlighting some controversial among authors
Fargione J, 2008 [52],	Biofuels must be produced from waste biomass or from abandoned land, avoiding competition with food production
Dauber J, 2012 [53]	It is important to identify the most adjusted bioenergy cultivation system, to better use the resources
Blanco-Canqui H, 2010 [54]	Marginal land may contribute for a more sustainable bioenergy production, to avoid competition with the agri-food chains
Schmer MR, 2008 [55]	Switchgrass, among others, may be an important source of biomass for bioenergy
Campbell JE, 2008 [56]	The potential of biomass production in abandoned land is limited, despite its relevance for a more sustainable land use
Zatta A, 2014 [57]	The bioenergy may have less emissions impacts than the fossil fuels, depending on the way this source of energy is used and produced
Haberl H, 2010 [58]	Residues from agriculture and forestry are important sources of biomass, mitigating the carbon emissions
Dimitriou I, 2012 [59]	Short rotation coppice may increase the organic carbon concentration
Sannigrahi P, 2010 [60]	Poplar may be considered as an important source of biomass for bioenergy
Sassner P, 2008 [61]	The sources of biomass are diverse, nonetheless some are more adjusted for a more effective sustainable development
Raghu S, 2006 [62]	It is important to assess ecological risks before introducing bioenergy crops
Djomo SN, 2011 [63]	Poplar and willow are relevant sources of biomass for bioenergy
Mehmood MA, 2017 [64]	Marginal land may be an important resource for biomass production
Raud M, 2019 [65]	Overview about lignocellulosic biomass and bioenergy obtained
Williams PRD, 2009 [66]	More research is needed to ensure sustainable bioenergy production.
Clifton-Brown J, 2017 [67]	Miscanthus has potential as feedstock in the European bio-economy
Field CB, 2008 [68]	The global potential for biomass is not enough to replace fossil fuel usage.
Dote Y, 1994 [69]	Recovery of liquid fuel from microalgae by thermochemical liquefaction
Miao Xl, 2004 [70]	Creation of a system to obtain bioenergy from microalgae
Miao Xl, 2006 [71]	Microalgal oil may be an important source for biodiesel production
Minowa T, 1995 [72]	Oil production may be carried out considering algal cells
Beringer T, 2011 [73]	The energy crops may be a threat for the biodiversity and sustainability
Werner C, 2012 [74]	Potential from short rotation poplar for biomass production was highlighted
Von Cossel M, 2019 [75]	Marginal land may be taken into account for biomass production
Rosso L, 2013 [76]	Bioenergy feedstock sources were tested to identify the more sustainable
Abreu M, 2020 [77]	Cardoon, paulownia and microalgae are viable for biomass in degraded soils
Ahmad M, 2011 [78]	Hemp oil may be considered as a potential new source for bioenergy
Ahmad T, 2019 [79]	Flaxseed oil may be taken into account as a viable option for biodiesel
Akanksha K, 2016 [80]	Conversion of sorghum stover to bioenergy was assessed
Al Chami Z, 2014 [81]	Processing approaches for metal contaminated biomass were analysed
Alba LG, 2012 [82]	Hydrothermal treatment as conversion process in an algae biorefinery was considered
Alexandropoulou M, 2017 [83]	Fungal pretreatment and alkaline treatment for biogas production was investigated
Allwright MR, 2016 [84]	Association genetics in biomass and bioenergy production
Alvarez-Alvarez P, 2018 [85]	Selection of tree species for biomass production
Amna, 2015 [86]	Phyto-extraction of heavy metals was considered
Amutio M, 2013 [87]	Flash pyrolysis of forestry wastes was taken into account
Antonopoulou G, 2008 [88]	Bioenergy production from sweet sorghum was analysed
Antonopoulou G, 2010 [89]	Influence of pH bioenergy production from sweet sorghum was investigated
Antonopoulou G, 2013 [90]	Pretreatment of sweet sorghum biomass and methane generation was analysed
Appiah-Nkansah NB, 2019 [91]	Sweet sorghum may be a relavant source of bioenergy
Asad M, 2017 [92]	Pretreatment of element-enriched biomasses developed on phytomanaged soils was investigated
Astolfi AL, 2020 [93]	Saccharification and fermentation of corn starch for the production of bioenergy was taken into account
Aswie V, 2021 [94]	Activated carbon as catalyst for bioenergy production was analysed
Athar M, 2020 [95]	Feedstocks and catalysts may be taken into account for sustainable bioenergy production
Ba YX, 2020 [96]	*Arundo donax* as a relevant renewable and sustainable energy source
Babich IV, 2011 [97]	Using catalytic pyrolysis of microalgae to bioenergy production
Bacenetti J, 2017 [98]	Biomass production in Mediterranean conditions was assessed
Bai Y, 2010 [99]	LCA of switchgrass ethanol was carried out in the framework of sustainable assessments
Balch ML [100]	Fermentation for several cellulosic feedstocks was assessed

CRediT authorship contribution statement

Vítor João Pereira Domingues Martinho: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Raimundo Nonato Rodrigues:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Vítor Martinho is Associate Editor of the Heliyon Journal. This fact did not affect the peer-review process.

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