Review of literature on social life cycle assessment of bioenergy

IEA Bioenergy: Task 36

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Foreword

IEA Bioenergy Task 36 - Material and Energy Valorisation of Waste in a Circular Economy - seeks to raise public awareness of sustainable energy generation and resource recovery from biomass residues and waste fractions as well as to increase technical information dissemination. As outlined in the 3-year work programme, Task 36 seeks to understand the effect that initiatives along the waste and value chain have in the deployment of bioenergy and the roles of energy recovery in a circular economy, as well as identify technical and non-technical barriers and opportunities needed to achieve this vision.

The Task held a workshop series to identify sustainability indicators to enable a proper decision framework integrating all the main aspects of sustainability to ensure that waste management strategies are not sub-optimized in favour of short-term solutions. Three Regional Sustainability Workshops were held, with each workshop focusing on different sectors facing challenges for sustainability; waste-to-energy in South Africa, organic and plastic waste resource recovery in North America, and food waste in Ireland. Further, Task 36 participated in a Working Group to highlight the socio-economic benefits of bioenergy within the broader bioeconomy, especially for (but not limited to) rural areas and developing economies. This review on social life cycle assessment as a methodology to assess the sustainability of bioenergy systems complements the outputs of the Working Group.

See http://task36.ieabioenergy.com/ for links to the workshops/webinars.

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Summary

A holistic and comprehensive sustainability assessment of bioenergy systems needs to include the consideration of environmental, economic and social factors. Among these, the social dimension has been the least developed and analysed.

Social Life Cycle Assessment (S-LCA) is a methodology used to assess the social impacts of products and services across their life cycle, e.g. from extraction of raw materials to disposal (Benoît Norris et al., 2020:20). S-LCA applies LCA methodology and systematic assessment but combines it with social science methodologies; with impact categories focusing on direct positive and/or negative impact on key stakeholders during the life cycle of a product. The S-LCA methodology and application is continuously developing, however some challenges still need to be addressed before it can reach its full potential. For example, difficulties in measuring social impacts which cannot be easily quantified (Stamford, 2020); lack of data availability and difficulties in the interpretation of results (Rebolledo-Leiva et al., 2023); a lack of technical know-how in social assessment methods and complexity of supply chains, and cultural issues (Huertas-Valdivia et al., 2020).

For the purpose of this report, a systematic literature review on social impacts, with a particular focus on S-LCA of bioenergy was carried out using the Scopus database. Focusing on the period between 2009 and 2024, the literature review highlighted a growing interest in social impact assessment, especially since the publication of the first S-LCA guidelines in 2009. The initial search resulted in 141 publications with 30 papers deemed relevant for review. Among the studies reviewed, only 17 explicitly utilized S-LCA methodologies, highlighting a research gap in the area.

Overall, studies varied in the rigour applied to S-LCA methodology, selection of indicators, consideration of social sustainability, and interpretation of results. Works which focussed on hypothetical case studies showed the highest adherence to the standard of S-LCA methodology, highlights the challenges that researchers may encounter when applying S-LCA to real-life cases. A variety of data sources were employed by the studies, including secondary sources, statistical databases, stakeholder interactions, primary data collection and specific social indicator databases such as Social Hotspots Database. Impact assessment and interpretation varied across studies. Generally studies found mixed social impacts, with a fewer number of works focussing on either positive or negative social hot spots. Some studies linked their analyses to the UN SDGs, thus allowing for a more straightforward interpretation of their results.

In summary, the literature review found that most studies on bioenergy focus on environmental impacts using LCA, with economic factors receiving secondary attention, and social considerations being the least addressed. In addition, studies which combined S-LCA with environmental and/or economic assessments were more likely to include a smaller number of social indicators thus highlighting greater importance placed on environmental and economic considerations in overall assessments of bioenergy. Some studies made assumptions about social benefits, such as job creation and rural development, without rigorous S-LCA analysis. Others misclassified non-social metrics (e.g., technical performance or opportunity costs) as social indicators. A few studies incorporated stakeholder participation, however this was generally limited. Furthermore, some indicators such as employment and working conditions were the most commonly assessed social indicators, likely due to their quantifiability.

Reviewed works have called for a more thorough incorporation of social sustainability, with greater consideration of social impacts. The review emphasises the need for interdisciplinary approaches to overcome barriers in S-LCA application; in particular in relation to data availability (both quantitative and qualitative). Methodological advancements in S-LCA regarding incorporation of the non-quantifiable impacts and improvement of result interpretation would also enhance the overall social assessment. Social acceptance, in particular, was noted as a barrier to expansion of bioenergy production (e.g. Fanourakis et al., 2024). This could be addressed by ensuring there is greater stakeholder inclusion in order to enhance engagement with communities and other stakeholders to ensure a comprehensive and relevant social assessment which considers social acceptance. Interdisciplinary approaches which include social sciences are likely to be needed in order to address some of the current challenges in social impact assessment.

The social dimension is integral to the overall sustainability of bioenergy, as it interconnected with environmental and economic impacts. Neglecting social aspects may compromise the accuracy and relevance of sustainability assessments. With the recent updates to S-LCA guidelines and increased awareness of the importance of social sustainability it is likely that future research will increasingly focus on incorporating S-LCA, leading to a rise in studies employing this approach.

Background

Holistic sustainability assessment of any system, process or product, including bioenergy, includes the consideration of environmental, economic and social factors (Padi et al., 2022). Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life cycle Assessment (S-LCA) methods can be used to assess environmental, economic and social dimensions of products and systems, respectively. Regarding sustainability, which consists of environmental, economic and social pillars, the latter is the least developed area in terms of assessment methodology and techniques (Stamford, 2020). The social dimension, in comparison to environmental and economic ones, is also the least analysed one (Meyer and Leckert, 2018, Santos et al., 2019). The focus of this report is to review the literature on social life cycle assessment of bioenergy.

Social Life Cycle Assessment

Social Life Cycle Assessment (S-LCA) is a methodology used to assess the social impacts of products and services across their life cycle, e.g. from extraction of raw materials to disposal (Benoît Norris et al., 2020:20). In 2009, the UNEP/SETAC Life Cycle Initiative published a first set of guidelines for S-LCA (UNEP, 2009); with updated guidelines published in 2020 (Benoît Norris et al., 2020). S-LCA applies LCA methodology and systematic assessment but combines it with social science methodologies; with impact categories focusing on direct positive and/or negative impact on key stakeholders during the life cycle of a product (Benoît Norris et al., 2020:20). The steps used in S-LCA are closely derived from LCA, and are as follows (Rebolledo-Leiva et al., 2023, Ashby, 2024):

i. Goal and scope definition which determines a product or organisation assessment and includes considerations such as functional unit, system boundaries, data requirements and assumptions.

ii. Inventory compilation which includes selection of impact assessment methods, decisions regarding the use of generic or site-specific data, key stakeholders, and social themes.

iii. Social impact assessment is carried out based on the inventory results with inputs and outputs assigned specific characterisation factors.

iv. Interpretation and communication of S-LCA results.

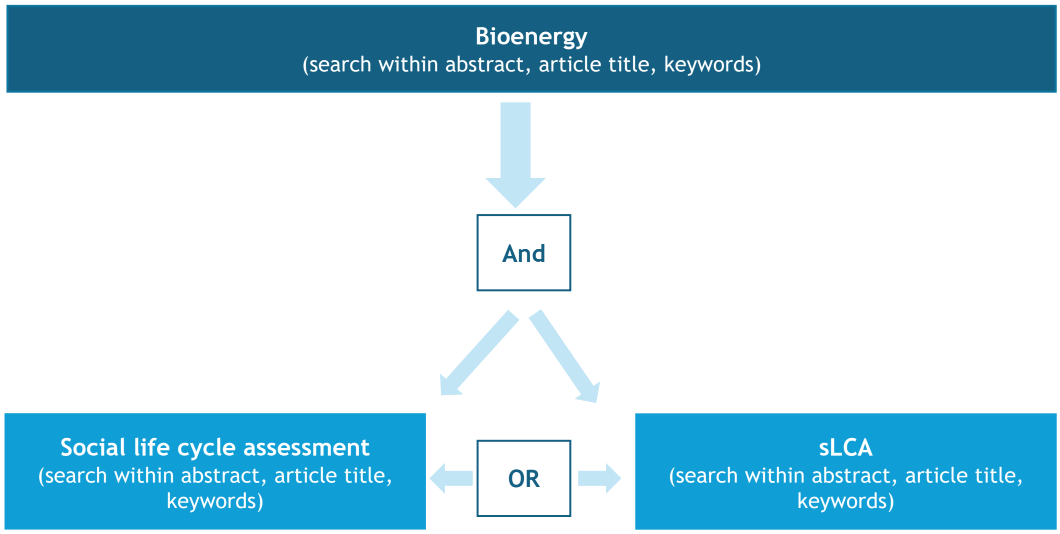
The key stakeholder groups include workers, local community, consumers, society, children, and value chain actors. Different impact categories may need to be considered for different stakeholders, for example employment related impacts may be of most importance to workers while cultural heritage impacts may matter more for local communities. The broad impact categories focus on human rights, working conditions, health and safety, cultural heritage, governance, and socio-economic repercussions. All impact categories have sub-indicators (see Benoît Norris et al., 2020 for more information).

S-LCA is a useful tool to measure social impacts but as it is still evolving, some challenges remain (Rebolledo-Leiva et al., 2023); in particular difficulties in measuring social impacts which cannot be easily quantified (Stamford, 2020), lack of data availability (Stamford, 2020, Rebolledo-Leiva et al., 2023, Huertas-Valdivia et al., 2020), boundary definitions (Rebolledo-Leiva et al., 2023), complexity of supply chains and complexity of social and cultural issues (Huertas-Valdivia et al., 2020), result interpretation, particularly qualitative data (Rebolledo-Leiva et al., 2023) and a lack of technical know-how in social assessment methods (Huertas-Valdivia et al., 2020).

Literature review

A systematic literature review on social impacts, with a particular focus on S-LCA of bioenergy was carried out using the Scopus database. The graph below illustrates the keywords used for the search.

Figure 1: *Scopus database search*



The search was limited to peer-reviewed articles, books, book chapters and editorials published in English[1]. Reviews of literature were excluded from the search. The initial search resulted in 141 documents[2] covering the period 2009-2024[3]. This highlights a relatively recent academic interest in incorporating social impacts or social life cycle assessment into bioenergy research, emerging around the time the first S-LCA guidelines were published in 2009. 30 papers were identified as relevant (approximately 21 per cent); with 17 papers specifically focussing or including S-LCA. The criteria for inclusion in the literature review first related to social impact assessment or S-LCA mentioned in the paper and secondly further criteria were applied such as inclusion of social indicators related to bioenergy in the assessment method, data collection and analytical approaches. Some papers were excluded as social impact assessment or S-LCA were mentioned in the abstract, introduction or discussion sections, however not included in the actual assessment. Figure 2 illustrates the number of studies considering social impacts and/or S-LCA for every year; pointing to an increased interest since 2018.

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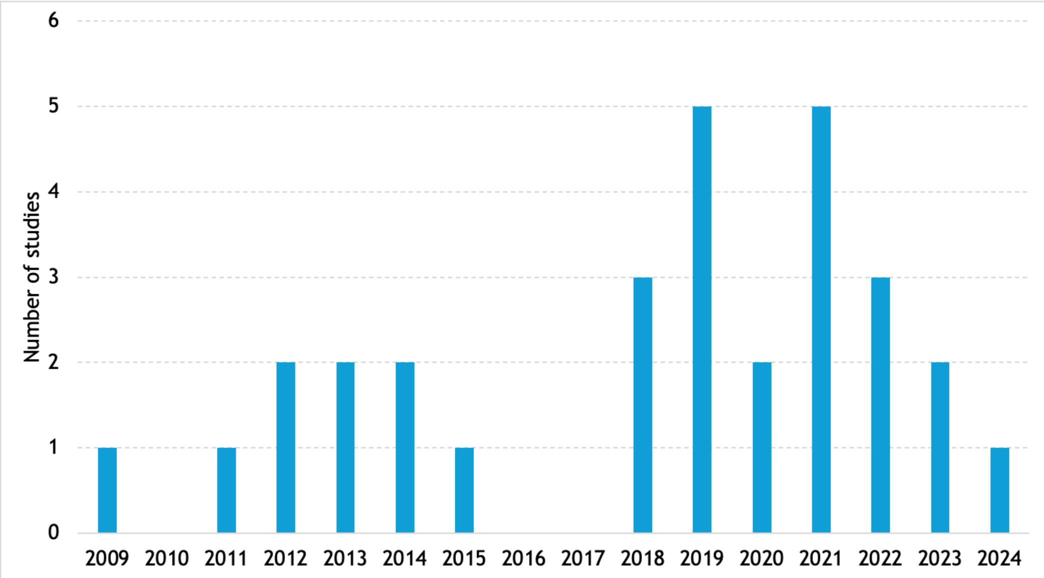
[1] Henke and Theuvsen (2013) provide a S-LCA of biogas plants and short rotation coppices but as the article is in German it is excluded from this review.
[2] Please note that some articles were introductions to special reviews, and if any relevant articles were identified in the special issue these were also included for consideration.
[3] 2024 period covers the period from January to September.

Figure 2: *30 studies considering social impacts and/or S-LCA of bioenergy in the Scopus database identified as relevant (2009-2024)*



Note: 2024 is not a full calendar year.

Table 1 provides a summary of all relevant studies, highlighting research focus, geographical location, type of methods employed (including whether S-LCA was used) and indicators used. In summary, the literature review found that most studies on bioenergy focus on environmental impacts using LCA, with economic factors receiving secondary attention, and social considerations being the least addressed. In addition, the review found that some studies[4]:

- Adopt a broader approach to the traditional life cycle assessment by considering economic and social aspects, however these are not rigorously assessed through S-LCA methodologies (Thornley et al., 2009, Lijó et al., 2018, Wang et al., 2019, Prasad et al., 2020, Fernández-Tirado et al., 2021).
- Treat non-social indicators such as opportunity costs (Gabisa and Gheewala, 2019), economic indicators, for example job creation, (Thornley et al., 2009, Den Herder et al., 2012, von Doderer and Kleynhans, 2014) or technical/environmental factors, for example unit energy values and technical merit (Zhang et al., 2022) as if they were social impacts; and presenting these as key measures of social outcomes.
- Include stakeholder experiences and opinions but do not utilise social assessment. For example, Thornley et al. (2009) included two forms of stakeholder consultations to supplement the LCA in examining bioenergy power generation systems, Lopolito et al. (2011) focussed on the perceptions of and social acceptance of the implementation of biorefinery schemes in rural areas, while Den Herder et al. (2012) used stakeholder consultations to identify indicators. This is a missed opportunity to include social impact assessment in social sustainability of technical systems.
- Discuss social impacts in the considerations but do not carry out social impact assessment (Thornley et al., 2009, Lee and Den, 2016, Taylan et al., 2018, Gabisa and Gheewala, 2019, Hoehn et al., 2020, Nisa, 2023, Morya et al., 2022, Saravanan et al., 2023).

[4] Note not all of these are included in Table 1 as some did not include sufficient information on social impacts/indicators or did not assess social indicators in adequate detail.

- Consider social impacts as the key focus of the study but do not utilise S-LCA (Rantala et al., 2012, Hazelton et al., 2013) or examine social acceptance but neglect to include considerations of social and economic impacts (Paletto et al., 2019).

Table 1: *Studies which consider social impacts, including S-LCA*

Research focus	Geographical focus	Using S-LCA	Methodology (regarding social impacts)	Social aspects	Reference
Bioenergy power generation system/ bioelectricity	UK	No	Stakeholder consultations	Economic impact (job creation); stakeholder engagement	(Thornley et al., 2009)
Biorefinery industry	Italy	No	Stakeholder interviews; fuzzy cognitive map	Local economic system; socio-political and territorial context; local environmental status; scientific research; technological transfer.	(Lopolito et al., 2011)
Forest resource management	Finland	No	Multi-criteria method based on existing empirical data, expert evaluation, performance, weighting and an additive utility model.	Forest owners' authority and legitimacy; opportunity to participate by other stakeholder; acceptability of operations for all stakeholder, local knowledge and vitality of the local community; control of transitions; acceptability; social diversity.	(Rantala et al., 2012)

Research focus	Geographical focus	Using S-LCA	Methodology (regarding social impacts)	Social aspects	Reference
Woody biomass-based energy production chains	Finland	No	Stakeholder consultations; Tool for Sustainability Impact Assessment	Local employment.	(Den Herder et al., 2012)
Palm oil biodiesel	Indonesia	Yes	S-LCA	Human rights; Working conditions; Cultural heritage; Socio-economic repercussion; Governance.	(Manik et al., 2013)
Stakeholder dynamics in bioenergy feedstock production	India	No	Structured approach to analysing stakeholder dynamics based on elements of Social Impact Assessment and Sustainability Assessment	Employment opportunities; energy access; education; income diversity; local ownership and management; plantation management advice and support; institutional structures and funding mechanisms; communal rights.	(Hazelton et al., 2013)
Biomass energy supply alternatives in steelmaking	Australia	Yes	S-LCA	Land use; Employment; Health and safety; stakeholder identified issues.	(Weldegiorgis and Franks, 2014)
Biofuels for vehicles	Sweden	Yes	Literature review; Stakeholder workshops; S-LCA	Human rights; Labour; Health and safety; Community; Governance	(Ekener-Petersen et al., 2014)

Research focus	Geographical focus	Using S-LCA	Methodology (regarding social impacts)	Social aspects	Reference
Bioethanol production pathways	China	Yes	S-LCA; stakeholder consultations; fuzzy sets.	Social benefits; Contribution to economic development; Food security	(Ren et al., 2015)
Perennial Crops Production for Bioenergy and Bioproducts	The Mediterranean region	No	Integrated Sustainability Assessment	Employment; Contribution to rural economy; Local embedding; Proximity to markets	(Fernando et al., 2018)
Environmental performance and sustainability of different management options for livestock waste	Cyprus	No	Analytic Hierarchy Process	Employment; Visual impact; Odour exposure; Risk perception	(Lijó et al., 2018)
Biodiesel Production	Canada	Yes	sLCA	Human rights; Working conditions; Society/health and safety; Cultural heritage; Socio-economic repercussions	(Sajid and Lynch, 2018)
Sugarcane biorefinery scenarios	South Africa	Yes	S-LCA	Employment	(Nieder-Heitmann et al., 2019)

Research focus	Geographical focus	Using S-LCA	Methodology (regarding social impacts)	Social aspects	Reference
Bioenergy production from household waste and agri-waste	Nigeria (Lagos) and South Africa (Johannesburg)	Yes	S-LCA	Economic, Physical, emotional, intellectual, social, cultural and environmental wellbeing	(Dunmade, 2019)
Biogas production	Ethiopia	No	Mathematical equations and calculations	Women's opportunity cost of firewood collection and cooking on efficient stoves	(Gabisa and Gheewala, 2019)
Wood-Based Bioenergy Alternatives for Residential Heating	Portugal	No	Literature reviews and statistical data	Annual working hours; Annual number of days of absence due to non-fatal work-related accidents.	(Martín-Gamboa et al., 2019)
Agriculture residues-based bioenergy technologies	China	No	Secondary data analysis	Policy adaptability; Social acceptability; Job creation	(Wang et al., 2019)
Resource-food-bioenergy nexus	South Africa, the Philippines, Thailand	Yes***	Life cycle sustainability assessment; optimisation; agent-based simulation.	Food security; local green job creation (the Philippines); urban mobility, employment (South Africa) *	(Guo et al., 2020)
Bioelectricity	Portugal	Yes	S-LCA; Methodological protocol based on the combined use of trade and LCI databases	Child labour; Forced labour; Gender wage gap; Women in the sectoral labour force; Health and safety.	(Martín-Gamboa et al., 2020)

Research focus	Geographical focus	Using S-LCA	Methodology (regarding social impacts)	Social aspects	Reference
Comparative Assessment of Biomass-to-Electricity Systems	Portugal	Yes	S-LCA	Child labour; Forced labour; Gender wage gap; Women in the sectoral labour force; Health expenditure; Contribution to economic development.	(Martín-Gamboa et al., 2021)
Biodiesel	Spain	No	LCA, Multiple-Criteria Decision Analysis	Employment	(Fernández-Tirado et al., 2021)
Social sustainability of treatment technology for conversion of municipal solid waste into bioenergy	Iran	No	Best-Worst Multi-Criteria Decision Making Method	Occupational injury potential; job creation potential; Environmental pollution potential; Waste consumption rate; Government-friendly policy; The impact on the decline in non-renewable energy imports; The impact of increasing renewable energy exports; The amount of fossil energy consumption per unit of generated bioenergy; The added value of replaced fossil energy by bioenergy; Efficiency of treatment technology; Technology complexity; Social acceptance rate; The content of	(Alidoosti et al., 2021)

Research focus	Geographical focus	Using S-LCA	Methodology (regarding social impacts)	Social aspects	Reference
				energy produced per unit of bioenergy generated; Reduction rate of greenhouse gas compared to the previous situation	
Energy utilization of crop residue	China	Yes	S-LCA	Job creation; Physical working condition; Health and safety	(Zhang et al., 2021)
Synthetic biofuels from date palm waste	Tunisia	Yes	S-LCA	Child labour; Forced labour; Gender wage gap; Women in the sectoral labour force; Health expenditure; Contribution to economic development.	(Ben Hnich et al., 2021)
Forestry-based bioenergy systems	Mexico	Yes	S-LCA; Community impact assessment	Labour rights; Health and safety; Human rights; Governance; Community infrastructure.	(Martinez-Hernandez et al., 2022)
Bioenergy Development for Landfills	Columbia	Yes	S-LCA	Local employment; Community engagement; Safe and healthy living conditions; Fair salary; Health and safety; Social benefits; Public commitment to sustainability issue; Contribution to economic development	(Ruiz and Diaz, 2022)

Research focus	Geographical focus	Using S-LCA	Methodology (regarding social impacts)	Social aspects	Reference
Electricity from biomass	Brazil	Yes	S-LCA	Number of jobs; Occurrence of occupational accidents; Wages profile; Schooling profile; Gender distribution in the workforce	(Souza et al., 2022)
Bioenergy production utilizing agricultural residues	China	No	Impact quantification using a multi-resource-technology-output life cycle framework	New employment created; New income of farmers	(Song et al., 2023)
Microalgae-based systems for wastewater treatment and bioproducts recovery	Hypothetical case studies in Spain	Yes	S-LCA	Health and safety; Working conditions; Quality and performance; Acceptability; Liveability; Socio-economic repercussion; Promotion of social responsibility; Public commitment to sustainability issues; Technological development	(Josa and Garfí, 2023)
Lignocellulosic biorefineries	Columbia	Yes	S-LCA	Fair salary; Working time; Access to material resources; Local employment; GHG Footprints	(Poveda-Giraldo and Cardona Alzate, 2024)

*Note: *** S-LCA is mentioned but it is not clear how it was carried out.*

The review identified 17 studies that included S-LCA in their analysis. These studies varied in the rigour applied to LCA methodology, selection of indicators, consideration of social sustainability, and interpretation of results. 11 studies included the functional unit used (see Table 2 for more details), while some studies included a discussion on the difficulty of applying a functional unit to social indicators (Manik et al., 2013, Souza et al., 2022).

Table 2: *Functional units used in studies which utilised S-LCA*

Research focus	Functional Unit	References
Biomass energy supply alternatives in steelmaking in Australia	1 tonne of steel	(Weldegiorgis and Franks, 2014)
Bioethanol production pathways in China	1 tonne of bioethanol	(Ren et al., 2015)
Biodiesel Production in Canada	1 kg of biodiesel	(Sajid and Lynch, 2018)
Bioenergy production from household waste and agri-waste in Nigeria and South Africa	Net wellness of the impact of the bioenergy production system on each stakeholder category and customers' satisfaction resulting/derived from the product delivered	(Dunmade, 2019)
Bioelectricity in Portugal	1 kWh of bioelectricity	(Martín-Gamboa et al., 2020)
Biomass-to-Electricity Systems in Portugal	Working hours	(Martín-Gamboa et al., 2021)
Energy utilization of crop residue in China	1 megajoule of energy for the consumer	(Zhang et al., 2021)

Research focus	Functional Unit	References
Synthetic biofuels from date palm waste in Tunisia	1 gigajoule of synthetic diesel and gasoline	(Ben Hnich et al., 2021)
Forestry-based bioenergy systems in Mexico	Medium-risk hour in terms of labour-hours for a given production rate	(Martinez-Hernandez et al., 2022)
Electricity from biomass in Brazil	1 kilowatt-hour of electricity	(Souza et al., 2022)
Microalgae-based systems for wastewater treatment and bioproducts recovery (hypothetical case studies)	1 cubic metre of water	(Josa and Garfí, 2023)

Methodological and data challenges in applying S-LCA

The majority of studies in the review do employ the S-LCA methodology based on the LCA guidelines (Manik et al., 2013, Ren et al., 2015, Sajid and Lynch, 2018, Dunmade, 2019, Martín-Gamboa et al., 2020, Martín-Gamboa et al., 2021, Zhang et al., 2021, Ben Hnich et al., 2021, Martinez-Hernandez et al., 2022, Souza et al., 2022, Josa and Garfí, 2023, Poveda-Giraldo and Cardona Alzate, 2024); however with different degrees of rigour and clarity.

Josa and Garfí's (2023) work demonstrates the highest adherence to the standard of S-LCA methodology as outlined in the UNEP guidelines, however since their research is based on a hypothetical case study, it highlights the challenges that researchers may encounter when applying S-LCA to real-life cases. Some of the studies in the review also incorporated stakeholder consultations and input (Manik et al., 2013, Weldegiorgis and Franks, 2014, Ekener-Petersen et al., 2014, Ren et al., 2015, Sajid and Lynch, 2018, Ruiz and Diaz, 2022) which is a promising step in ensuring that accurate and relevant social indicators are included. However, generally limited information was provided on the sample size or the nature of stakeholder engagement. For example, a study by Sajid and Lynch (2018) includes only 2 stakeholders, while work by Ruiz and Diaz (2022) incorporates interviews with landfill workers but no further information on how these were utilised in the S-LCA.

The data sources used in the studies are varied and are derived from literature, secondary sources, global/national statistics, stakeholder interactions, primary data collection and databases such as Social

Hotspots Database[5]. A range of social indicators have been employed across the studies (see Table 3 for a summary), with employment and working conditions being the most commonly used, followed by health and safety. This may be the result of ease in measuring some indicators (e.g. wages, hours worked, number of work injuries) compared to others, which may not always be quantifiable or more difficult to assess. In addition, studies which combined S-LCA with environmental and/or economic assessments were more likely to include a smaller number of social indicators (Ren et al., 2015, Nieder-Heitmann et al., 2019, Guo et al., 2020, Zhang et al., 2021, Poveda-Giraldo and Cardona Alzate, 2024), thus highlighting greater importance placed on environmental and economic considerations in overall assessments of bioenergy.

Table 3: *Social indicators used in studies which utilised S-LCA*

Social indicators	Studies
Working conditions/Employment	(Manik et al., 2013, Weldegiorgis and Franks, 2014, Ekener-Petersen et al., 2014, Sajid and Lynch, 2018, Nieder-Heitmann et al., 2019, Guo et al., 2020, Martín-Gamboa et al., 2020, Martín-Gamboa et al., 2021, Zhang et al., 2021, Ben Hnich et al., 2021, Martinez-Hernandez et al., 2022, Ruiz and Diaz, 2022, Souza et al., 2022, Josa and Garfí, 2023, Poveda-Giraldo and Cardona Alzate, 2024)
Cultural heritage	(Manik et al., 2013, Sajid and Lynch, 2018)
Socio-economic repercussion	(Manik et al., 2013, Sajid and Lynch, 2018, Josa and Garfí, 2023)
Governance	(Manik et al., 2013, Ekener-Petersen et al., 2014, Martinez-Hernandez et al., 2022)
Land use	(Weldegiorgis and Franks, 2014)
Health and safety/Health expenditure	(Weldegiorgis and Franks, 2014, Ekener-Petersen et al., 2014, Sajid and Lynch, 2018, Martín-Gamboa et al., 2020, Martín-Gamboa et al., 2021, Zhang et al., 2021, Ben Hnich et al., 2021, Martinez-Hernandez et al., 2022, Ruiz and Diaz, 2022, Souza et al., 2022, Josa and Garfí, 2023)

[5] See http://www.socialhotspot.org/

Social indicators	Studies
Human rights/Gender **	(Manik et al., 2013, Ekener-Petersen et al., 2014, Sajid and Lynch, 2018, Martín-Gamboa et al., 2020, Martín-Gamboa et al., 2021, Ben Hnich et al., 2021, Martinez-Hernandez et al., 2022, Souza et al., 2022)
Community/ Promotion of social responsibility	(Ekener-Petersen et al., 2014, Martinez-Hernandez et al., 2022, Ruiz and Diaz, 2022, Josa and Garfí, 2023)
Social benefits	(Ren et al., 2015, Ruiz and Diaz, 2022)
Economic development/Job creation	(Ren et al., 2015, Guo et al., 2020, Martín-Gamboa et al., 2021, Zhang et al., 2021, Ben Hnich et al., 2021, Ruiz and Diaz, 2022, Souza et al., 2022, Song et al., 2023, Poveda-Giraldo and Cardona Alzate, 2024)
Food security	(Ren et al., 2015, Guo et al., 2020)
Well-being ***	(Dunmade, 2019)
Public commitment to sustainability issues	(Ruiz and Diaz, 2022, Josa and Garfí, 2023)
Education	(Souza et al., 2022)
Quality and performance/Technological development	(Josa and Garfí, 2023)
Acceptability	(Josa and Garfí, 2023)
Liveability	(Josa and Garfí, 2023)

Social indicators	Studies
Access to material resources	(Poveda-Giraldo and Cardona Alzate, 2024)
Environmental footprints	(Poveda-Giraldo and Cardona Alzate, 2024)

Note: See specific studies for more detailed information on the indicators.

*** Child and forced labour are included under human rights category*

**** 7 types of well-being are considered. Well-being as a concept may be interpreted and understood in different ways depending on the individual.*

The impact assessment and interpretation varied across studies. Generally, studies found mixed social impacts (Weldegiorgis and Franks, 2014, Dunmade, 2019, Zhang et al., 2021, Josa and Garfí, 2023), with a fewer number of works focussing on either positive (Sajid and Lynch, 2018, Souza et al., 2022) or negative social hot spots (Manik et al., 2013, Ben Hnich et al., 2021). Some more recent studies linked their analyses to the UN SDGs, thus allowing for a more straightforward interpretation of their results (Souza et al., 2022).

Concluding remarks

A comprehensive assessment of bioenergy requires an approach which considers all three pillars of sustainability: environmental, economic and social. The review presented here highlights that social impacts are the least analysed in comparison to environmental and economic dimensions of bioenergy. Consideration of social impacts is key as they are interrelated with economic and environmental impacts and neglecting one dimension may affect the accuracy and relevance of the overall assessment (Sharno and Hiloidhari, 2024).

Reviewed works have called for a more thorough incorporation of social sustainability, with greater consideration of social impacts (Muench, 2015, Boschiero et al., 2016, Ramos Huarachi et al., 2023, Sinkko et al., 2023, Salas et al., 2024). Some studies highlighted the need for greater inclusion of S-LCA (Ding et al., 2023, Moktadir et al., 2023, Hiloidhari et al., 2023), greater use of both quantitative and qualitative data (Stamford, 2020, Longo et al., 2024) as well as integration of additional social indicators (Hiloidhari et al., 2023, Salas et al., 2024). Social acceptance, in particular, was noted as a barrier to expansion of bioenergy production (Buonocore et al., 2019, Garcia-Freites et al., 2020, Fanourakis et al., 2024). Interdisciplinary approaches which include social sciences are likely to be needed in order to address some of the current challenges in social impact assessment (Stamford, 2020). Studies have also underscored the importance of greater consideration of stakeholders' views and a further inclusion of stakeholder engagement in social impact assessment (Rebolledo-Leiva et al., 2023, Sharno and Hiloidhari, 2024), including local community (Longo et al., 2024).

In order to overcome some of the current limitations of S-LCA, researchers and other users may consider working in interdisciplinary teams when conducting holistic assessments which include social, economic and environmental impacts. In addition, following more rigorously the S-LCA guidelines regarding indicator categories may allow for greater standardisation across the studies. Considering wider stakeholder groups and their inclusion in the assessment would also strengthen and evolve S-LCA methodology. Most of the studies also assess social impacts on national or country levels, adding research which focusses on either micro (local levels) or macro (international levels) would also enhance the current state of the art. With the recent updates to S-LCA guidelines and increased awareness of the importance of social sustainability it is likely that future research will increasingly focus on incorporating S-LCA, leading to a rise in studies employing this approach.

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