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Review

The Impact of Sustainability Certification Schemes and Labels on Greenhouse Gas Emissions: A Systematic Evidence Map

William J. Harvey [1,2,*], Naomi Black [3], Salma Essaouabi [3,4], Leo Petrokofsky [1], Vidya Rangan [3], Matt Stancliffe Bird [3], Daniel Villar [5], Marxine Waite [6] and Gillian Petrokofsky [1,7]

1 Oxford Systematic Reviews LLP, Oxford OX2 7DL, UK; leo.petrokofsky@oxsrev.org (L.P.); gillian.petrokofsky@oxsrev.org (G.P.)
2 School of Archaeology, University of Oxford, Oxford OX1 2PG, UK
3 ISEAL Alliance, London E2 9DA, UK; naomib@isealalliance.org (N.B.); essaouabi.salma@gmail.com (S.E.); vidya@isealalliance.org (V.R.); matthew@isealalliance.org (M.S.B.)
4 Kings College London, London WC2R 2LS, UK
5 Hertford College, University of Oxford, Oxford OX1 3BW, UK; daniel.villar@hertford.ox.ac.uk
6 Environmental Coalition on Standards (ECOS), Nairobi P.O. Box 283-00502, Kenya; marxine.waite@ecostandard.org
7 Department of Biology, University of Oxford, Oxford OX1 3SZ, UK
* Correspondence: william.j.harvey@oxsrev.org or william.harvey@arch.ox.ac.uk

Abstract: This systematic map explores the role of sustainability certification schemes and labels in reducing greenhouse gas emissions across biobased value chains. With increasing global and EU interest in transitioning to a sustainable bioeconomy, these certification mechanisms are seen as critical tools for promoting low-emission practices. This review maps the available evidence regarding the effectiveness of certification schemes, examining sector-specific variations and identifying knowledge gaps. A comprehensive search strategy was employed across three major databases and grey literature sources, yielding 41 relevant articles. There are significant disparities in the evidence on the impact of sustainability certification schemes and labels on greenhouse gas (GHG) emissions across biobased sectors. Agriculture has the most data, but studies are heavily focused on organic systems, limiting broader conclusions. Most research is concentrated in Southeast Asia and Europe, reducing generalizability to other regions. Additionally, most studies focus on the production stage, leaving value chain phases like processing and disposal under-represented. Knowledge gaps exist across sectors, certification schemes, and life cycle stages, highlighting the need for further research. While some schemes incorporate GHG management tools, evidence on their effectiveness remains insufficient and context-dependent, warranting more robust, targeted research. Though this research looked at all biobased feedstocks, it did not review schemes and labels specifically targeting biofuels, which presents an avenue for future research.

Keywords: certification; labels; greenhouse gas emissions; GHG emissions; bioeconomy; value chains; systematic map; environmental impact

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1. Introduction

1.1. Background

The European Union (EU) is undergoing a significant transition towards a biobased economy, which has sparked concerns about the potential adverse effects associated with the rising demand for biobased materials. According to the European Commission, the bioeconomy involves "using renewable biological resources from land and sea, such as crops, forests, fish, animals, and micro-organisms, to produce food, materials, and energy" [1]. However, it is increasingly evident that only sustainably developed, circular biobased systems can meet critical goals, such as climate neutrality and zero pollution. In response, new international and national regulations, initiatives, and agreements are being enacted to address trade-offs across biobased value chains [2].

Sustainability certification schemes and labels applicable to bioproduct value chains aim to drive change through various mechanisms, including socioeconomic impacts [3]. Some focus exclusively on the production of raw materials, certifying that specific practices or outcomes are achieved, while others cover the entire value chain, ensuring sustainable practices in both production and the processing of bioproducts. Additionally, certain certifications address end-of-life attributes, such as biodegradability and recyclability. While not all certification schemes explicitly target the reduction of greenhouse gas (GHG) emissions, mitigating GHG emissions remains a central priority for the bioeconomy in the EU and globally. In response, numerous voluntary sustainability systems and market-based instruments have been developed to address GHG emissions, operating at different stages of the supply chain.

1.2. Stakeholder Engagement

Stakeholders from the STAR4BBS consortium (principally TU Berlin, Unitelma, and organization representatives) shaped the thematic focus of the mapping and contributed keywords and concepts which were adapted for use in the search strategy. Stakeholders were consulted as a group formally and informally via 1-2-1s and e-mail, with formal presentations on 14th September 2022, 7th March 2023, 12th June 2023, and 27th June 2023.

A key decision made by the stakeholder group was to focus the project on biobased products other than biofuels and bioenergy. This targeted approach is aligned with the broader objective of assessing a diverse range of biobased innovations that contribute to the bioeconomy beyond energy production. A limit to articles published after 2010 was also agreed to capture the most relevant literature. Narrowing the scope ensured that the project remained feasible and allowed for a more detailed exploration of biobased materials, products, and processes.

With the stakeholders' input, a conceptual framework that considered the value chain, tools for change, and enabling practices was developed to indicate how GHG emissions are impacted by each stage of the bioeconomy (Figure 1). This was then translated into a systematic mapping protocol.

A conceptual framework was developed to convey how GHG emissions are influenced at each stage of the bioeconomy, considering the value chain, tools for change, and enabling practices (Figure 1). In the pursuit of reducing GHG emissions in the bioeconomy the establishment of assessment, monitoring, and guidance tools within credible certification schemes and labels, which act as guiding tools for bioeconomy products at all stages of the value chain, are central to this effort [4].

Certification schemes and labels are powerful tools for change within the bioeconomy and could provide a clear and standardized framework to promote low-GHG-emission practices [5]. These certifications incentivise producers and manufacturers to adhere to environmental standards and also empower consumers with the ability to make informed choices about products [4]. By highlighting and rewarding eco-friendly practices, certifications act as catalysts for systemic shifts towards environmentally responsible production and consumption [4].

Other market-based tools could also constitute part of the strategy through financial incentives and regulatory mechanisms [5]. Given the important role of sustainability certification schemes and labels in facilitating the transition to a sustainable biobased economy and ensuring compliance with emerging legislation—especially regarding GHG emissions—an evidence base was systematically constructed and analysed.

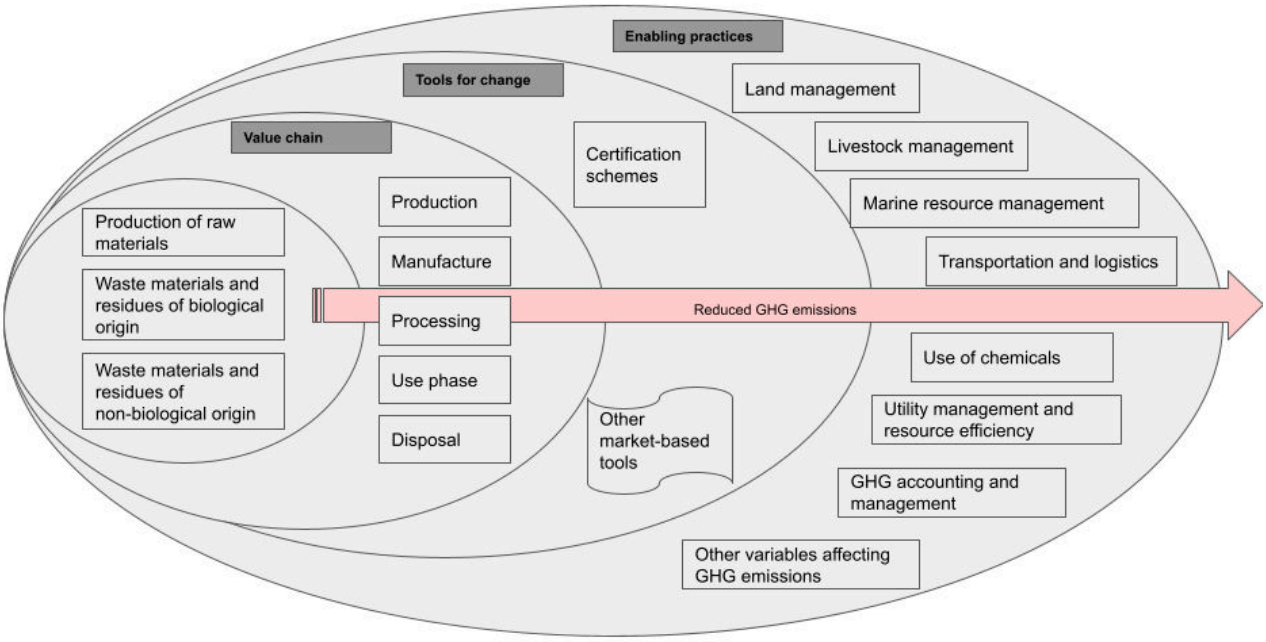

Figure 1. The conceptual framework for the systematic evidence map.

1.3. Objectives of the Review

While recognizing that there are many aspects to impacts of sustainability certification schemes, such as socioeconomic impacts [3], the primary aim of this systematic map was to assess the evidence surrounding sustainability certification schemes and labels relevant to biobased value chains and their potential to reduce GHG emissions in biobased value chains. It also sought to examine sector-specific variations in their effectiveness and to identify critical knowledge gaps and limitations in the current research landscape by answering the following questions:

Primary question:

1. Do sustainability certification schemes and labels, used in the bioeconomy, reduce greenhouse gas emissions?

Sub-question(s):

Are there differences between different sectors of the bioeconomy?

1. Are there differences between the production of raw materials compared with other parts of the value chain in the bioeconomy?
2. Are there differences in the primary tools adopted by certification schemes and labels to track GHG emissions?
3. Where are there significant knowledge gaps in the evidence base in this field of study?

2. Materials and Methods

2.1. Systematic Mapping Protocol

The systematic mapping protocol was developed based upon the conceptual framework (Figure 1) and the primary review question following best practice guidelines [4].

A Population-Intervention-Comparator-Outcome (PICO) framework was chosen and used to categorize the different aspects for both the primary and sub-questions (Table 1).

Table 1. Definitions of the questions (PICO).

Element	Description
Population	Value chains in the bioeconomy—from producers of primary feedstock to consumers of bioproducts, in any geographic location, excluding biofuels. Feedstock to include primary agriculture (including horticulture, beekeeping, silk production, etc.), forestry, marine products, biological waste material, or residues.
Intervention	Sustainability certification schemes and labels (applicable to the bioeconomy).
Comparator	A different/absence of sustainability certification scheme(s) or label(s) applicable to the bioeconomy (see further information in the inclusion criteria).
Outcome	Greenhouse gas emission measurement.

2.1.1. Search Strategy

A search strategy was developed and agreed with stakeholders that aimed to capture as many relevant articles of literature as possible whilst limiting bias. The search strategy was designed following best practice guidelines [6]. The adopted approach searched three online bibliographic databases, chosen for their high coverage rates of journals of relevance to the bioeconomy, and other publication types with relevant content.

An iterative approach was taken to identify, improve, and optimize keywords and search terms (see Supplementary Materials) following methods developed in Paivinen et al. [7]. A Test Set of articles was selected to cover the full range of aspects contained within the scope of the research questions. Stakeholders were involved in suggesting useful papers for the Test Set [6]. A total of 15 relevant articles were used to ensure the maximum return of relevant literature while reducing the overall quantity of irrelevant literature, striking a balance between precision and accuracy. The optimized keywords and search terms were then combined into Boolean strings used to search each online bibliographic database (Table 2).

Table 2. List of bibliographic databases searched.

Bibliographic Database	URL
Web of Science (Core collection)	www.webofscience.com/ (accessed on 7 June 2023)
CAB Abstracts	www.cabi.org/ (accessed on 7 June 2023)
Scopus	www.scopus.com/ (accessed on 7 June 2023)

Searches of the online bibliographic databases and aggregates were conducted in English only. While clearly limiting the complete comprehensiveness of the reviews, justification for imposing this common limitation is provided in research by Ramírez-Castañeda [8] that reports 98% of academic publications in science are written in English. A pragmatic decision, based on resource availability, to limit searches to the English language does not, therefore, overly limit the integrity of the current systematic map.

Recognizing the importance of including non-journal articles (grey literature) for minimizing possible biases in systematic reviews and maps [9], reports and conference proceedings were also considered alongside academic journal articles. CAB Abstracts is particularly rich in non-academic articles of literature, including individual papers from conference proceedings and reports from research institutions across the world as well as international organizations.

2.1.2. Article Screening and Study Inclusion Criteria

Following searches in each of the bibliographic databases, articles were uploaded into EndNote20 [10]. Duplicate articles were removed, and the resulting combined set of articles was uploaded into Rayyan [11], a free natural-language processing tool that employed machine learning to screen articles for systematic evidence evaluation. Articles were screened for eligibility at two stages: (i) title and abstract assessment, and (ii) full-text assessment. Articles were single-screened by four screeners. To check the consistency of screening at the title and abstract stage, sets of 50 articles were screened by all screeners, and inter-rater agreement was assessed using Cohen's kappa [12]. Differences in screening were discussed among the screeners, and the process was repeated with sets of 50 articles and 100 articles until a satisfactory level of agreement (>0.6) was reached. At the full-text screening stage, sets of two articles were similarly assessed by all screeners until inter-rater agreement was reached. Screeners assessed articles and made decisions about inclusion with reference to the inclusion and exclusion criteria (Table 3).

Table 3. Inclusion and exclusion criteria.

Element	Inclusion	Exclusion
Population	Value chains in the bioeconomy—from producers of primary feedstock to consumers of bioproducts. Feedstock to include primary agriculture (including horticulture, beekeeping, silk production, etc.), forestry, marine products, biological waste material, or residues.	Studies not addressing value chains in the bioeconomy. Biofuels and bioenergy, except where the focus is on the production of the feedstock.
Intervention	Studies examining certification schemes and labels relevant to the bioeconomy.	Studies not addressing sustainability certification schemes and labels applicable to the bioeconomy.
Outcomes	Any reported greenhouse gas emission, combination of gasses, or reports of unspecified greenhouse gasses.	Studies not reporting greenhouse gas emissions
Geographic Scope	All geographical regions	N/A
Publication Type	Published studies, reports, articles, and conference proceedings presenting original research data.	Unpublished materials, personal communications, opinions, editorials, and letters without original research data, systematic reviews, routine monitoring reports, descriptive resources, and modelling studies that examine future scenarios using third-party data
Date	Studies published after and including 2010.	Studies published before 2010.

Articles were always retained at the first stage of screening (where only the title and abstract of an article were assessed) if it was unclear whether the inclusion criteria had been fully met. These articles were then assessed for inclusion in full-text. At this stage, it became clear whether an article met the inclusion criteria in full, in which case it proceeded to the coding stage, or was excluded on the grounds of incorrect population, incorrect intervention, or absence of or incorrect outcome.

2.1.3. Risk of Bias Assessment

Full-text articles were evaluated for the appropriateness of the study design for the research question, and an assessment of specific criteria related to the study design was conducted using checklists adapted from the Joanna Briggs Institute [13]. The evaluation was carried out without consideration of the study results to avoid interpretation bias. The following questions were applied for the risk of bias assessment:

1. Are there any missing data? (Are data collected in the Methods section of a study all reported in the Results section).
2. Are all missing data accounted for? (If there are unreported data does the author explain why they have not reported them).
3. Are the study subjects and the setting described in detail?
4. Is the intervention(s) described including details of certification timing and duration?
5. Is there a clear account of the statistical methods used to compare groups for all outcome(s)?
6. Are all raw data available (in the published article or as Supplementary Material)?

The results of these assessments were not used to exclude articles from the evidence base but to make readers aware of the quality of the evidence included and to interpret with caution where necessary (see Supplementary Materials).

2.1.4. Data Coding and Extraction Strategy

Data from the included articles were extracted and summarized in a standardized evidence table (see Supplementary Materials). In addition to metadata about the article (authors, title, date of publication, source, abstract) taken directly from the bibliographic databases, and study design details coded by the review team, information based on the PICO elements was extracted by the review team. Geographic location data (latitude/longitude expressed in decimal degrees) were either taken directly from the article or added by looking up the locations of place names mentioned in the article and assigning latitude and longitude coordinates. Articles containing data for multiple interventions were considered as separate studies. Consistency among coders and data extractors was evaluated using the same approach as for full-text article screening, with any discrepancies resolved through repeated discussions until a consensus was reached.

3. Results

The results of the systematic mapping exercise are presented as the numbers of articles or numbers of measured outcomes. All data and results are available in the Supplementary Materials.

3.1. Studies in the Evidence Base

A total of 6286 articles of literature were processed in accordance with the protocol. Figure 2 shows the systematic filtering process at each stage, which resulted in the evidence mapping of 41 articles (39 journal articles and 2 conference papers) from 25 journals/other publications.

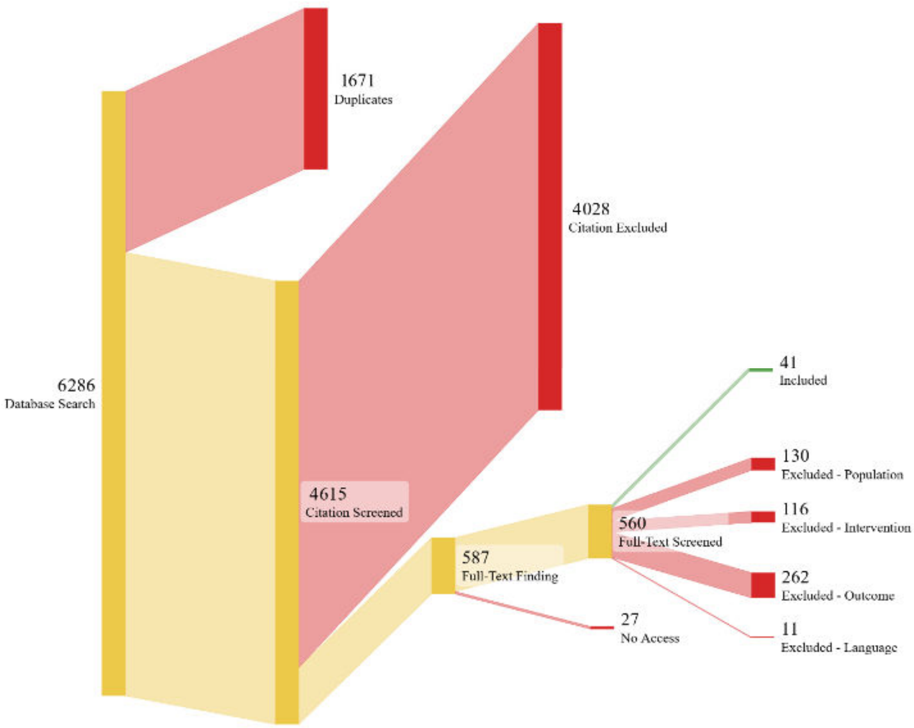

Figure 2. Selection and screening of articles detailing inclusion and exclusion at each stage of filtering process.

3.2. Access to Articles

Around three-quarters of the articles were subscription-only access only (71%), with only just over one-quarter of the articles (29%) presenting as open access (Figure 3).

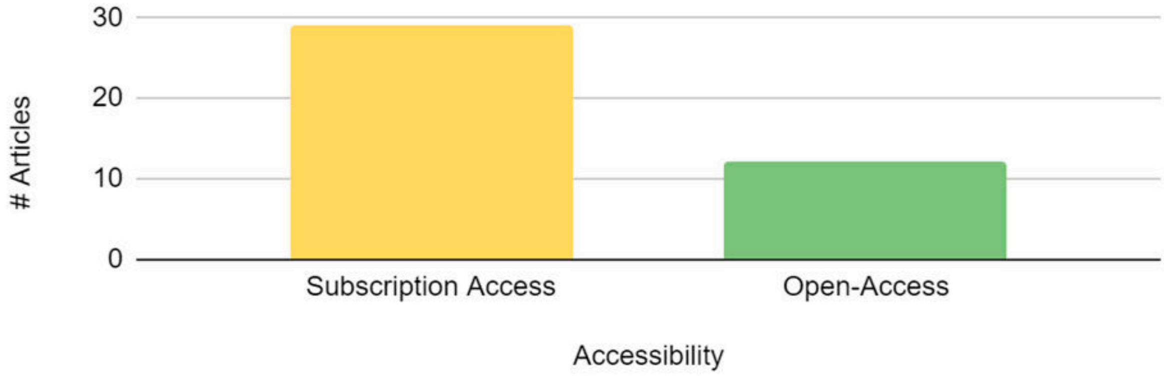

Figure 3. Accessibility of included articles through subscriptions services or open access.

3.3. Location of Studies from Articles

Figure 4 shows the location of the studies and the number of studies at the country level. Indonesia (n = 5) and Italy (n = 5) were best represented in the evidence base, followed by Malaysia (n = 3), Germany (n = 3), the United States of America (n = 3), and China (n = 3).

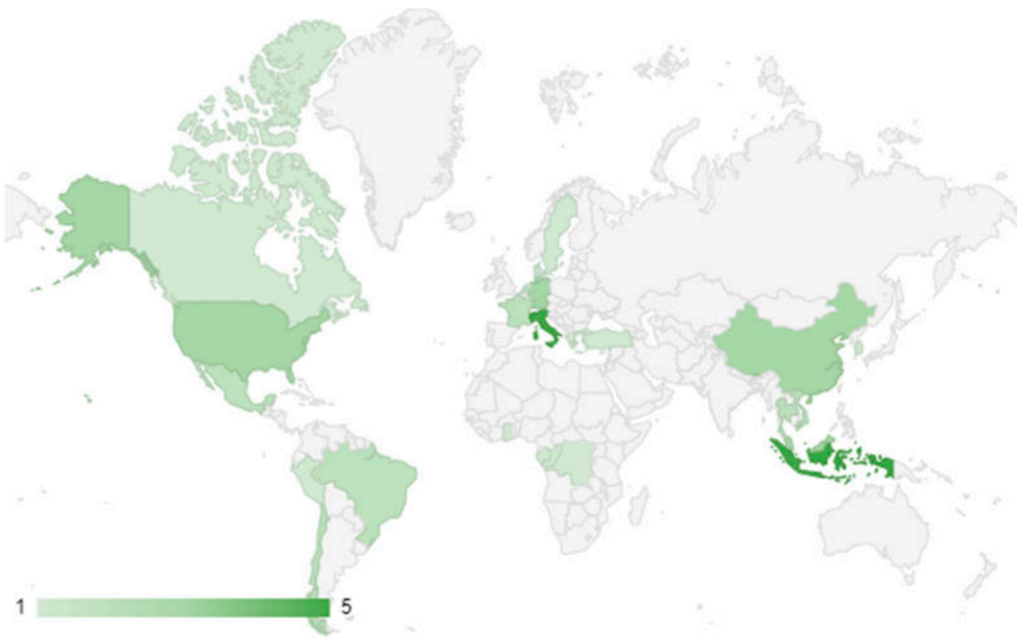

Figure 4. Location of studies included in evidence base.

3.4. Source of Articles

There was a total of 41 articles of literature that were included in the full-text stage, of which the vast majority were made up of journal articles (n = 39). Data from two conference papers were also included. A total of 25 journals/resources were represented across the included articles of literature. The Journal of Cleaner Production was the most prominent (n = 7), followed by Sustainability (n = 3), and Forest Ecology and Management (n = 3) (Table 4).

Table 4. Journal/resources with two or more articles.

Key Journals	Number
Journal of Cleaner Production	7
Sustainability	3
Forest Ecology and Management	3
Scientia Horticulturae	2
Science of the Total Environment	2
Journal of Dairy Science	2
IOP Conference Series: Earth and Environmental Science	2
Aquaculture	2

3.5. Publication Date

Figure 5 shows the publication dates for all included articles.

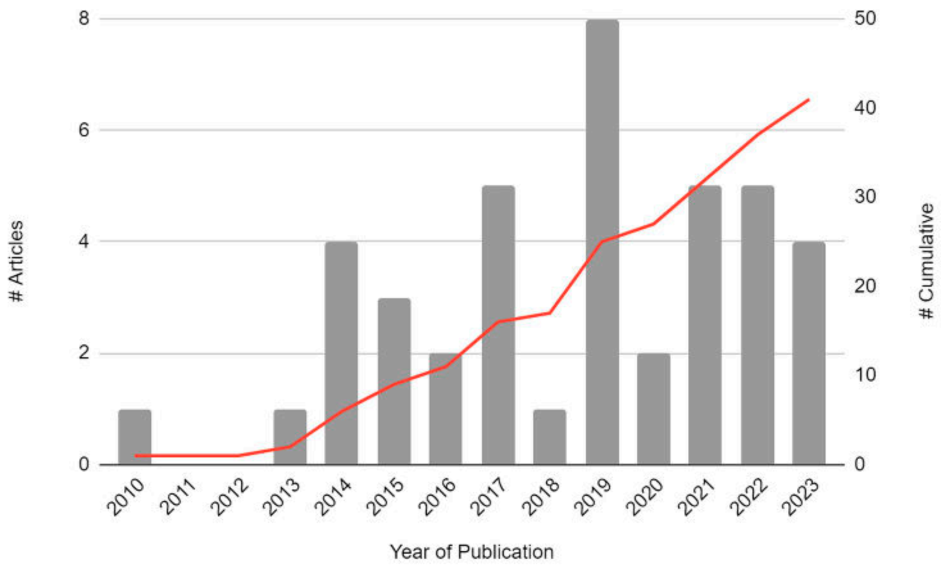

Figure 5. Number of articles of literature by date of publication of articles included in the evidence map by (i) individual year (bars) and (ii) cumulatively (line).

3.6. Certification Scheme/Label

There were 16 certification schemes/labels reported in the evidence base, of which the most common appears to be the International Federation of Organic Agriculture Movements (IFOAM) (n = 27) (Figure 6). The term 'organic' is used somewhat loosely in the literature: there are many different organic standards and authors do not always (or consistently) specify whether the subject is certified as organic, or, if it is certified, what that certification is. For the purposes of the current evidence mapping, all studies in organic systems (whether certification has been reported or not) were coded "IFOAM".

The other certification schemes that reported >1 instance are the Forest Stewardship Council (FSC) (n = 5), Roundtable on Sustainable Palm Oil (RSPO) (n = 4), VIVA (n = 2), USDA National Organic Program (n = 2), and Naturland (n = 2). The remaining 10 certification schemes/labels reported evidence from a single study: Sweden's organic certifier (KRAV), the Standard for Sustainable Cattle Production Systems, Rainforest Alliance (RA), Malaysia Sustainable Palm Oil Standard (MSPO), Label Rouge, Green Food Program (China), Danish Crown's sustainability certification scheme, the Aquaculture Stewardship Council (ASC), China Organic Agricultural Product Standard, and the Environmentally Friendly Agricultural Products Certification standard (Republic of Korea). IFOAM studies appeared across nine regions in the evidence base with the greatest instances coming from Western Europe (n = 5), Southern Europe (n = 5), Northern America (n = 4), and Southeastern Asia (n = 3). FSC certification was reported from four regions, and RSPO certification only from Southeastern Asia (n = 4). Geographic regions followed the grouping by the United Nations Statistical Division [14].

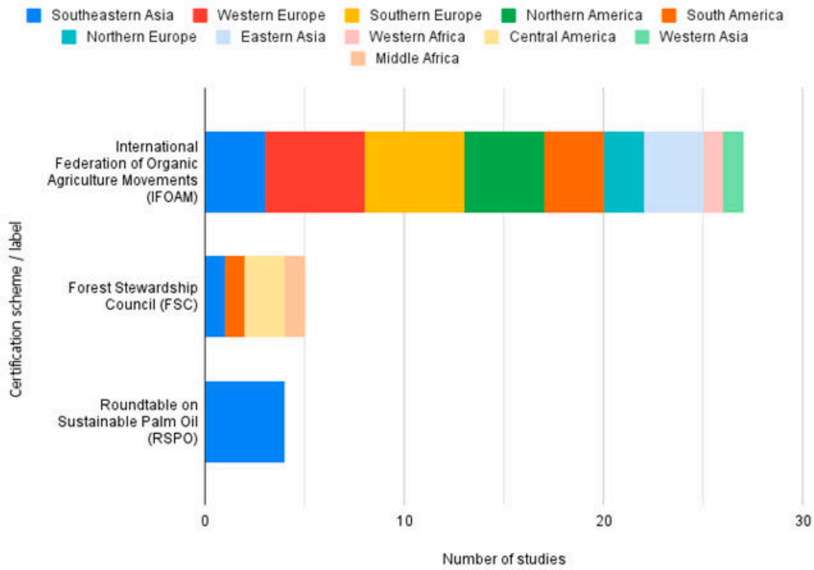

Figure 6. Number of articles addressing greenhouse gas emissions across certification scheme/label ($n \geq 3$) grouped by geographic region as defined by United Nations Statistical Division.

3.7. Sector

The number of articles addressing GHG emissions was highest for the sector of agriculture, followed by forestry and livestock (Figure 7). Although literature on other sectors (e.g., textiles, furniture, biobased chemicals, and construction) was captured in the original search, these did not meet the inclusion criteria outlined above. Within the agricultural sector, the geographic region of Southeast Asia comprises 33% (n = 9) of the studies, followed by Southern Europe (n = 4), Eastern Asia, (n = 4), and South America (n = 4). Forestry is best represented by Middle Africa (n = 3), and livestock by Western Europe (n = 3) (Figure 7). Processed food (n = 4) is represented in two studies from both Western Europe and Southern Europe, and fish—aquaculture (n = 4) is represented in two studies from both Western Europe and Southeastern Asia. There is one study examining textiles/garments (from Western Asia).

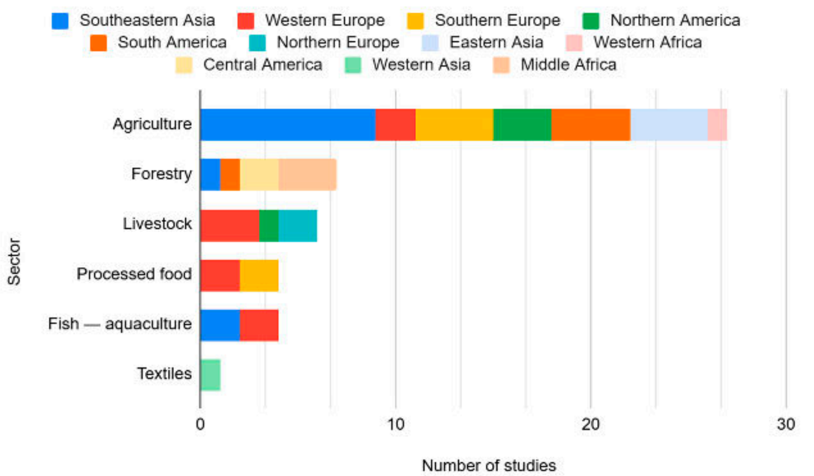

Figure 7. Number of articles addressing greenhouse gas emissions across sectors grouped by geographic region as defined by United Nations Statistical Division.

3.8. Feedstock/Product

Data were reported for 32 feedstocks/products, of which timber products, palm oil, rice, and dairy products had the highest number of studies. Most products were reported in a single study each.

Articles examining timber products are predominantly from Middle Africa (*n* = 3) and Central America (*n* = 2), with single studies from South America (*n* = 1) and Southeastern Asia (*n* = 1). Palm oil studies are exclusively from Southeastern Asia (*n* = 6). Rice production is mostly covered by Eastern (*n* = 3) and Southeastern (*n* = 2) Asia, with three studies coming from Western Europe (*n* = 1), Southern Europe (*n* = 1), and Northern America (*n* = 1). Dairy product studies are primarily from Western Europe (*n* = 4), with one from Northern America (*n* = 1) and another from Northern Europe (*n* = 1) (Figure 8). Studies reporting on pork meat (*n* = 3) are situated in Western Europe (*n* = 2) and Northern Europe (*n* = 1). There are two studies reporting evidence for each of the following feedstocks/products: wine, wheat, blueberries, finfish, beef meat, and agriculture products (multiple); and one study reporting evidence for the following products: sugar beet, soy shrimps, potato, peas, onions, oats, kale, garment, cucumber, cocoa, catfish, beans, cereals, fresh fruits and vegetables, nuts and oilseeds, sugar, poultry meat, livestock animals, eggs, and food products (unspecified).

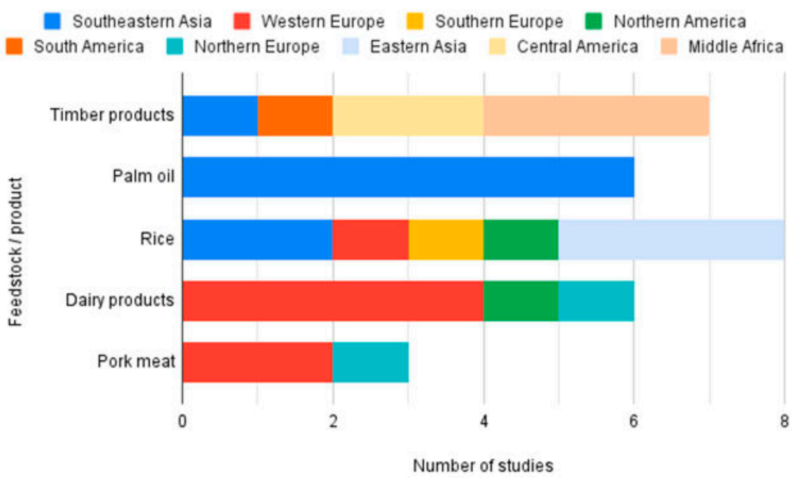

Figure 8. Number of articles addressing greenhouse gas emissions ($n \geq 3$) across feedstock/product grouped by geographic region as defined by United Nations Statistical Division.

3.9. Stage of Value Chain

The production phase had the largest number of studies, followed by processing, with disposal being the least represented life cycle stage (Figure 9). Studies in the production stage and processing stage were primarily from the agricultural sectors (*n* = 23 and *n* = 6, respectively).

Evidence for the production phase comes from 11 regions, with Southeastern Asia (*n* = 10) as the most prominent, followed by Southern Europe (*n* = 6), Western Europe (*n* = 5), and South America (*n* = 5). Evidence from Southeastern Asia is also most prominent for the processing phase (*n* = 4). For manufacturing, singular instances of GHG impact evidence is reported across four regions. Use phase evidence comes from Western Europe (*n* = 2), Eastern Asia (*n* = 1), and Western Asia (*n* = 1). The disposal stage presents single studies from Western Europe (*n* = 1), Eastern Asia (*n* = 1), and Western Asia (*n* = 1).

Studies in the production stage and processing stage were primarily from the agricultural sector (*n* = 23 and *n* = 6, respectively). Studies based in the use phase, manufacturing, and disposal phase of biobased products were mixed across agriculture, processed food, and textiles. In addition, the use phase has evidence for fish and livestock (Figure 10).

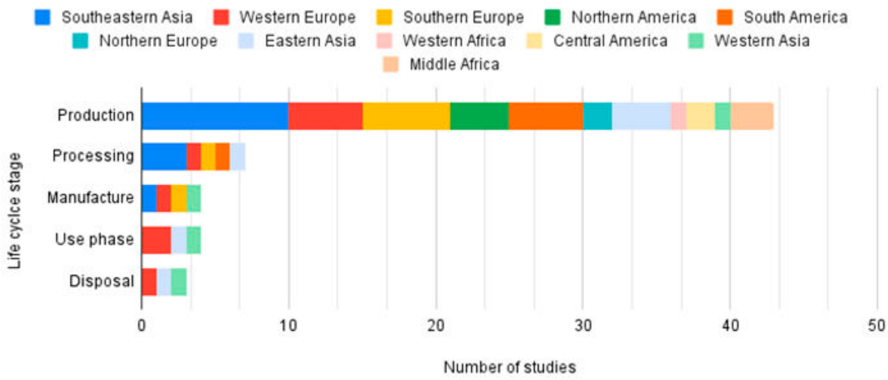

Figure 9. Number of articles addressing greenhouse gas emissions across certification scheme/label grouped by geographic region as defined by United Nations Statistics Division.

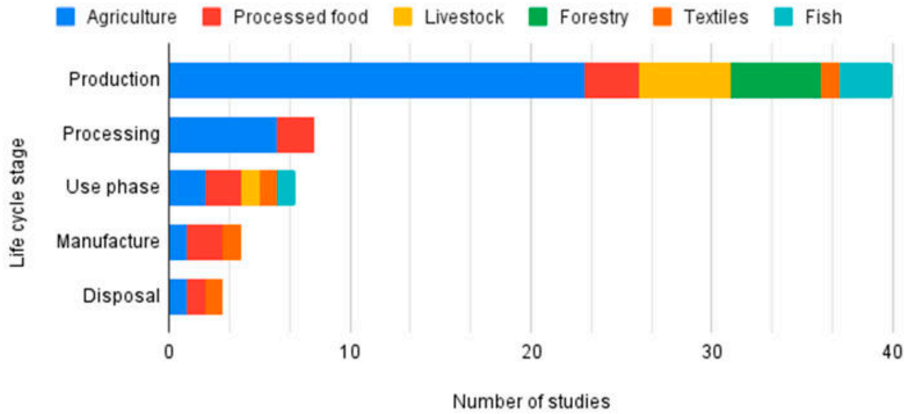

Figure 10. Number of articles addressing greenhouse gas emissions across certification scheme/label grouped by sector.

3.10. Study Design

Of the forty-one studies, all except one study were quantitative empirical; one study was qualitative. Of the 40 quantitative studies, 1 had data collected before and after the intervention; all others had data collected post-intervention. Twenty-nine of these had matched controls, six had no controls, and four had a control that was not matched.

3.11. Impact of Certification/Labels on GHG Emissions

There were 30 articles that the authors reported a positive (+) or negative (−) impact of the certification scheme on GHG emissions, while 11 articles either did not present a clear indication or presented a complex indication of GHG emissions. These claims were not independently reassessed, mainly owing to a lack of raw data from which to conduct meaningful statistical comparisons (e.g., meta-analysis).

3.12. Risk of Bias of the Evidence Base

The risk of bias assessment of the systematic map's evidence base revealed a spectrum of bias risk among the included articles (Figure 11). While there are studies with low risk of bias, according to the critical appraisal criteria (adapted from the Joanna Briggs Institute), a significant portion of the evidence base exhibits medium to high bias risk. These findings highlight the need for a discerning approach when using this evidence base to inform research and decision-making. The evidence mapping enables policymakers and practitioners to filter out studies with a high risk of bias in favour of studies with a low risk of bias when using the evidence base to understand the implications of certification on GHG emissions. Ultimately, promoting robust research practices and transparency in conducting and reporting primary research remains important for ensuring the credibility of evidence for decision-making.

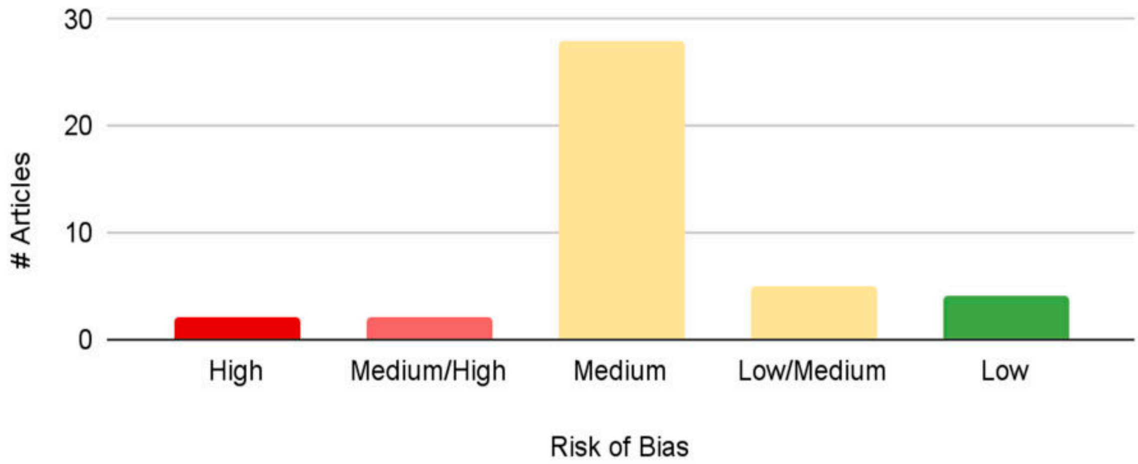

Figure 11. The risk of bias in the evidence base.

Only 4 out of the 41 articles coded in the evidence base scored in the lowest risk of bias considering (i) accountability of any missing data; (ii) the study subjects and setting being described in detail; (iii) the intervention(s) described, including details of certification timing and duration; (iv) a clear account of the statistical/analytical methods used to compare groups for all GHG outcome(s); and (v) the availability of all raw data (Figure 11), adapted from the Joanna Briggs Institute. A further five articles placed in the low/medium risk of bias category. The majority of articles scored a medium risk of bias (n = 28). Three articles scored in the medium/high risk of bias and two articles scored in high risk (Figure 11).

4. Discussion

4.1. Evidence Gaps

Only sixteen certification schemes and labels were captured for the evidence mapping, of which only IFOAM, FSC, and RSPO had more than three studies. There is a clear need for more research on GHG emissions linked to other schemes.

Of the fifteen sectors listed, only six are represented in the evidence base, and of these only agriculture, forestry, livestock, processed food, and fish—aquaculture have more than three studies dealing with GHG emissions. There is a need for more primary research in these missing or under-reported sectors.

There is a dearth of literature in academic journals on the impact of sustainability certification schemes and labels on GHG emissions in six of the products that have historically formed a large part of the sustainability certification literature, namely cocoa, bananas, tea, coffee, cotton, and sugarcane [15].

In terms of the value chain, only the production stage is well represented; disposal and the use phase are particularly poorly represented in the evidence base. The evidence base contains few studies that report the contribution of individual GHGs, even where the individual gasses have been listed in the article. These are mainly converted to carbon dioxide equivalent measurements, and while this is not problematic if this is clearly understood, there is a danger of comparing different gasses or combinations of gasses together in a manner that may lead to errors in interpretation, for example, the impact of a certification scheme on methane emissions reduction.

The focus of studies included in the evidence base shows geographical evidence gaps for South and East Africa, Central America, India, Russia, and the Philippines.

Each certification scheme was examined within the context of the primary research question to assess what the scheme sets out to accomplish for GHG reductions, and compared those aims with the findings in the current evidence base. Studies included in the evidence base are grouped by sector and discussed under specific certification schemes and labels below. Each section begins with a brief assessment of scheme criteria or principles relating to GHG emissions and then includes a synthesis of evidence from the evidence base of impact of each certification/label.

4.2. Organic Agriculture

This section discusses articles involving the International Federation of Organic Agriculture Movements (IFOAM), VIVA, Naturland, Green Food Program (China), Label Rouge, USDA Organic, Danish Crown's sustainability certification scheme, Sweden's organic certifier (KRAV), the Environmentally Friendly Agricultural Products Certification (EFAPC) standard (Republic of Korea), and the China Organic Agricultural Product Standard. A number of studies did not specify their specific certification, or the certification status was unclear. As we cannot confidently exclude these articles, they have been included under the umbrella of "unspecified organic".

It should be noted while reading this section that (1) many sustainability certifications include organic as part of their standard, and (2) many agricultural farms hold multiple certifications (certified organic and another scheme). It is therefore difficult in reality to discern causality between what effects change, and one should be cautious about extrapolating the results listed below.

4.2.1. International Federation of Organic Agriculture Movements (IFOAM)

The International Federation of Organic Agriculture Movements (IFOAM) is a membership organization covering over 100 countries. IFOAM is dedicated to promoting the uptake of organic agriculture and associated approaches (certified and non-certified); encouraging the progression of organic operations from good practice to best practice; and increasing the number of agriculture operations that are integrating organic principles and methods [16]. It does so through a family of standards that many other certifications derive their guidelines from.

Given IFOAM's prominence in promoting organic practices, and the ambiguity expressed in many of the articles, IFOAM has been used as an umbrella term to code all papers including "organic" subjects, unless another certification scheme has been explicitly provided. Articles that have provided evidence of certification with a named organic scheme are discussed under separate headings below, while articles which have not specified the organic scheme have been discussed under "Unspecified Organic". Articles that report on 'organic' systems but do not provide any explicit evidence of a certification scheme are not further discussed [17–26], though they are coded "IFOAM" as part of the evidence mapping.

4.2.2. VIVA

The VIVA certification programme "Sustainability in viticulture in Italy" is a programme by the Italian Ministry of Environment and Energy Security, which since 2011 has been promoting the sustainability of the Italian wine sector [27]. The standard is organized around four "indicator categories": "Air", "Water", "Vineyard" and "Territory" [28]. Two papers reported on the impacts of VIVA certification on GHG emissions [29,30]. Both specifically focused on the agronomical management practices detailed under the "Vineyard" indicator category.

Borsato et al. [29] compared two vineyards at the same farm in Italy, where conventional and organic viticulture practices were practised. VIVA certification methods were used to calculate the GHG emissions factor (based on methane, nitrous oxide, and carbon dioxide estimates) for pesticides and fertilizer applications, as well as for fuel consumption. There is a high statistical difference between organic and conventional viticulture practices for the application of fertilizers and pesticides, though GHG emissions from field work operations (e.g., soil cultivation, canopy management, irrigation, and plant protection) are not statistically different between the two management practices.

Casolani et al. [30] examined the production, manufacture, and processing stages of 45 certified wines in Italy. The authors reported great variability in the results of GHG emissions and observed that there was therefore opportunity for improvement in many companies.

4.2.3. Naturland and Bioland

Naturland is a German association for organic farming created in 1982, with the mission of spreading organic certification worldwide [31]. Naturland have several standards covering 13 environmental and social areas [32]. Two papers are included in the evidence base [33,34]. The first examines the impact of Naturland's Aquaculture Standards (specific standards under which are unspecified), while the second discusses impacts where subjects certified under Naturland's Production Standards (again, unspecified) formed part of the study sample. The sample in Kiefer et al. also included organic farms that followed the guidelines of the Bioland farming association, an organic movement also active in Germany [35].

Jonell et al. [33] reported on 21 organic and 20 non-organic mangrove shrimp farms in Vietnam. The emissions of GHG per ton of shrimp produced were reported as large for both groups, and almost entirely caused by the release of carbon during mangrove land transformation. Organic farms were reported to have emitted less GHGs than the non-organic farms.

Kiefer et al. [34] reported on 81 non-representative dairy farms in southern Germany. The study reported that organic farms produced a Product Carbon Footprint (PCF) that was significantly higher than those emitted by conventional farms. PCF values for both types of farms in this study were markedly higher than the respective results of other, similar, studies. A PCF communicates the quantity of GHG emissions that are produced or consumed during the life cycle of a product.

4.2.4. Green Food Program (China)

The Green Good Certified (GFC) standard is a Chinese eco-certification scheme for food that has been active since the 1980s [36]. The Green Food Development Center provides a certification label that focuses on sustainable agricultural practices, reduced pesticide use, and environmental criteria that aim to minimize the environmental impact of food production [36]. One paper in the evidence base looks at the impact of GFC certification [37].

Wang et al. [37] used life cycle assessment to evaluate the environmental impacts (including global warming potential, measured as carbon dioxide equivalents for carbon dioxide, methane, and nitrous oxide) of GFC cucumbers cultivated under a greenhouse system in Beijing, China, relative to conventional cultivation. The environmental index of the 13 GFC cucumber farms was reported to be higher than that of the 30 non-certified farms, largely due to higher fertilizer use.

4.2.5. Label Rouge

Label Rouge is a quality-assurance packaging label created by the French Ministry of Agriculture that can be applied to food and non-food agricultural products of any geographical origin. Attainment of the label is based on sensorial perception; production conditions; the perception of product conditions; and presentation and service elements [38]. One study including Label Rouge [39] is included in the evidence base. It compares and reports GHG emissions in nine pork-based pâtés from Label Rouge, organic, conventional, and Bleu-Blanc-Cœur (a special finishing technique) systems. The study covers all stages of the products' lives, from production to disposal.

The authors report that Label Rouge pâtés cause higher emissions than conventional pâtés, despite supplying less calories and more protein. The organic pâté was between the conventional and Bleu-Blanc-Cœur systems on the calories scale and had a carbon footprint similar to Label Rouge. GHG emissions were reported to be lower for conventional pork pâtés compared to organic pork pâtés, primarily due to the indirect effect of lower productivity associated with swine feed ingredients. The authors highlighted that the study raised important methodological considerations that should be addressed in future life cycle analyses to standardize the approach and enhance comparability between studies.

4.2.6. USDA Organic

The United States Department of Agriculture (USDA) created the national standard for organic production (USDA Organic) under the Food, Agriculture, Conservation, and Trade Act of 1990. The standard covers all agricultural systems and defines organic food as that "produced without using most conventional pesticides; fertilizers made with synthetic ingredients or sewage sludge; bioengineering; or ionizing radiation" [40]. The evidence mapping includes two articles [41,42] that discuss the impacts of the USDA Organic Program.

Liang et al. [41] applied a partial life cycle assessment to estimate the impact of various feeding strategies and related crop production on GHG emissions from certified organic dairy farms in Wisconsin. The authors reported that higher levels of milk production played a significant role in reducing GHG emissions per metric tonne of energy-corrected milk (ECM). The authors also reported that increasing the proportion of soybean in cattle diet was linked to an increase in GHG emissions per metric tonne of ECM. However, including soybean in the crop rotation was reported to decrease nitrous oxide emissions due to lower applications of organically approved nitrogen fertility inputs. In addition, higher levels of soybean in the diet, which replaced corn grain, were reported to reduce enteric methane emissions per metric tonne of ECM because of a higher dietary fat content. This dietary change was found to be beneficial for lowering methane emissions. Shifting from a grain-based diet to a more pasture-based one was reported to lead to a decrease in milk production. This reduction in milk yield was found to result in substantially higher emissions per metric tonne of ECM. Therefore, a higher reliance on pasture at the expense of grain was associated with increased GHG emissions.

McGee [42] reported that the rise in the certified organic production of agricultural products in the United States is not correlated with a decline in GHG emissions, and instead a positive association between certified organic farming and overall agricultural GHG emissions are reported. The author's analysis indicates that an increase in certified organic farmland from 2000 to 2008 is positively correlated with GHG emissions from agricultural production. This suggests that organic farming practices are currently contributing to an increase in emissions of GHGs. McGee [42] also reports that organic farming may lead to more GHG emissions due to lower yields and reliance on machinery. The results also suggest that certain organic crops might produce more GHGs compared to their conventional counterparts. While the study's findings do not support a direct link between organic farming and lower GHG emissions, they acknowledge the possibility that organic agriculture could affect different types of GHG emissions in complex ways.

4.2.7. Danish Crown's Sustainability Certification Scheme

One study [43] is included in the evidence mapping that discusses organic production under the Danish Crown sustainability certification scheme. However, there is a lack of contextual information for this scheme, making it difficult to ascertain its parameters. This is important to note, as an overarching certification scheme no longer exists at Danish Crown.

Using Denmark as a case study, Olsen et al. [43] reported on the CO2 impacts of five different pig production systems (1. Standard pig production (465 herds); 2. Animal welfare (1 herd); 3. Raised without antibiotics (18 herds); 4. Free range (8 herds); 5. Organic (16 herds)) all certified as part of Danish Crown's sustainability certification scheme. Systems 1, 2, and 3 were indoor year-round, with 4 and 5 being partially outdoors. The authors reported that the organic system had the highest impact per kg, followed by free range, then the three indoor systems had the lowest impacts per kg.

4.2.8. Sweden's Organic Certifier (KRAV)

Krav is a prominent Swedish eco-label for organically produced food, established in 1985. Krav-labelled food is produced without artificial chemical pesticides and without artificial fertilizer [44]. One study [45] was found in the evidence mapping that included Krav certification.

Aggestam and Buick [45] report that certified organic milk production in Sweden leads to a reduction in emissions associated with road-related transport; however, this reduction is outweighed by the increase in emissions resulting from farmyard vehicles used for producing feed on the farm.

4.2.9. Environmentally Friendly Agricultural Products Certification (EFAPC) Standard (Republic of Korea)

The EFAPC is a certification from the government of the Republic of Korea. One article discussing the EFAPC was included in the evidence mapping [46]. In this, EFAPC-certified farms adhered to fertilizer ingredient content as recommended by the administrator of Rural Development [46].

Kim et al. [46] analyse the implications of different certification systems for rice farming, including organic, non-pesticide, and low-pesticide farming practices. They evaluated the GHG emissions of rice farms in the Republic of Korea certified by the EFAPC standard and compared these with other international rice produced to organic standards in the USA and the EU. The environmental impacts of rice farming were highest in the U.S., followed by the EU, and then by Korea's conventional, low-pesticide, non-pesticide, and organic farming practices, in descending order.

4.2.10. China Organic Agricultural Product Standard

The China Organic Standard GB/T 19630-2019 [47] enables organically produced raw agricultural products to be commercialized as organic in mainland China and Hong Kong [48]. There is one paper in the evidence mapping that discusses the standard [49].

Zhen et al. [49] compared the GHG emissions of organic rice–fish co-culture (certified under the China Organic Agricultural Product Standard) and conventional rice value chains, encompassing cultivation, processing, transportation, cooking, and waste disposal. The study found that organic rice had the highest carbon input, output, and net GHG emissions within the farming system. Methane accounted for over 60% of total GHG emissions across the three rice farming systems. Post-harvest activities, such as processing, waste disposal, and transportation, contributed minimally to the overall GHG emissions of the three rice value chains. The higher GHG emissions associated with organic rice compared to rice–fish co-culture and conventional rice were mainly attributed to increased organic material inputs in the farming process.

4.2.11. Unspecified Organic

Eight papers included reference to certification but did not specify which or did not include enough information about the certification of the subjects to exclude them. They have been included here under the umbrella of "unspecified organic" [50–57].

Cordes et al. [50] reported nitrous oxide emissions (from organic nitrogen fertilizers) in the production and processing of five blueberry orchards in Chile. The analysis of the carbon footprint included agricultural factors such as fertilizers, pesticides, fossil fuels, electricity, materials, machinery, and direct land-use change. The authors emphasized that the variability in the results indicates that production practices significantly influence the carbon footprint and highlighted the importance of separately reporting GHG emissions from land-use change.

Vaglia et al. [51] reported GHG emissions from 10 farms certified as part of the Organic Rice Network in Italy. Environmental impact values vary widely based on farmers' choices, such as water management, weed control strategies, and nutrient and organic-matter management plans. Notably, the impact categories influenced by energy and fossil fuel consumption in organic rice farming are reported to have a positive effect, reducing the relative contribution of fertilizers to the overall environmental impact.

Baydar et al. [52] assessed environmental impacts (including global warming) of Eco T-shirts produced in Turkey. The Eco T-shirts are made from organically grown cotton and processed with a green dye. These were then compared with the environmental impacts of conventional T-shirts using a life cycle assessment (LCA) methodology. The authors concluded that Eco T-shirts have lower impact potentials across all assessed categories. However, the global warming potential remains the largest environmental impact for both conventional and Eco T-shirts, with the main contribution arising from the use phase, followed by the cultivation and harvesting stages, and the fabric processing phase.

Biermann et al. [53] also used an LCA methodology to compare the environmental impacts of conventional and organic common carp certified under European Commission Regulation No 710/2009 raised in traditional pond aquaculture in Germany. The authors note that the "environmental superiority of one production method over the other depends on the impact category analyzed" and there is, therefore, no clear impact of organic certification in isolation.

Kontopoulou et al. [54] studied the impacts of organic vs. conventional farming practices on nitrous oxide emissions in a field experiment in west Greece. The authors reported that organic farming resulted in insignificantly lower emissions than conventional farming in terms of the overall global warming potential of the farming treatments.

Using highbush blueberry as the target crop, Montalba et al. [55] analysed the environmental impacts of three different management systems in south-central Chile: conventional orchards, organic orchards based on input substitution, and organic orchards following agroecological principles. Four orchards were assessed for each management type. The study found that GHG emissions from conventional orchards were higher than those from both organic management systems. Most GHG emissions in conventional orchards were attributed to external inputs used for soil management and pest control. No differences in GHG emissions were observed across the management regimes concerning machinery use and irrigation practices.

Qin et al. [56] reported on the impacts of different irrigation methods and cropping systems on GHG emissions in rice paddies, particularly comparing organic and conventional approaches. The study demonstrates that the choice of irrigation method and cropping system significantly affects GHG emissions and their potential impact on radiative forcing in rice paddies. The impact of organic versus conventional systems depends on the specific water regime used and the balance between methane and nitrous oxide emissions.

Bandanaa et al. [57] compared 398 cocoa farmers in Ghana, of which 71 were organic and 327 conventional. The authors reported that the organic farming system was better in terms of GHG emission reduction and improvement in air quality compared with non-organic farms. Some subjects were noted as Rainforest Alliance-certified as a prerequisite for entry into their specific farming groups, however the analysis does not attempt to attribute specific benefits to the Rainforest Alliance certification itself.

4.3. Palm Oil

The evidence mapping captured articles discussing the impact of the Roundtable on Sustainable Palm Oil (RSPO) and the Malaysia Sustainable Palm Oil (MSPO) standard.

4.3.1. The Roundtable on Sustainable Palm Oil (RSPO)

The RSPO was founded in 2004 to address the global call for sustainably produced palm oil. Their certification incorporates a set of environmental and social criteria that help minimize the negative impact of palm oil production on the local environment, wildlife and communities [58]. Three papers were included in the evidence mapping that involve RSPO certification [59–61].

Evidence from two of the three articles that examine the impact of RSPO certification on GHG emissions (carbon dioxide, methane, and nitrous oxide expressed as CO_2 equivalent) indicated that two certified plantations in Indonesia produced less GHG emissions than non-certified palm oil plantations across Indonesia and Malaysia (non-certified data averaged across palm oil produced across Indonesia and Malaysia) [59,60]. The datasets for certified and non-certified palm oil in both of these papers are the same. All GHG emission results from these papers are modelled from selected key performance indicators for oil palm cultivation (e.g., planted area, soil type, and application of nutrients and fertilizers).

In both papers, the authors report that RSPO certification has a positive impact on reducing GHG emissions in palm oil production, primarily through better land-use practices, use of a peat soil-free supply base, and improved management of various stages of the production process.

Schmidt and De Rosa [59] report a 35% reduction in GHG emissions for certified palm oil compared to non-certified palm oil, attributing this reduction primarily to higher yields achieved per unit of land. De Rosa et al. [60] report a reduction in GHG emissions of 49–58% for certified palm oil from the Hanau and Sungai Rungau facilities (Indonesia) compared against the average for non-certified palm oil across Indonesia and Malaysia.

During the crop cultivation stage, De Rosa et al. [60] suggest that avoiding the use of tropical peatlands is a crucial factor in reducing GHG emissions [60], and, during the manufacturing stage, further reported lower contributions of GHG emissions for one RSPO-certified oil palm production plant (due to biogas capture facilities, compared with average certified production). However, higher than average methane production is reported for the other RSPO-certified palm oil production plant due to the absence of biogas capture facilities. The use of residues from the palm oil process is also indicated to be useful in the production of electricity, which, when combined with a biogas capture facility, avoids further GHG emissions from the palm oil creation process. Schmidt and De Rosa [59] further suggest, through modelling, that the by-products of palm oil cultivation and production reduce GHGs through use as animal feed, while De Rosa et al. [60] model a reduction when used in the production of biodiesel. No difference was detected between certified and non-certified palm oil refining [59].

In contrast to the results from Schmidt and De Rosa [59] and De Rosa et al. [60], Hilmi and Utami [61] reported that RSPO certification had no significant effect on the amount of CO_2 emissions produced when compared against non-certified palm oil production.

The results reported from these three articles highlight the fact that studies use the differences in methods and variables used to model GHG emissions for the production of palm oil as well as the range of effect variables that are considered in different models.

4.3.2. MSPO

The Malaysian Sustainable Palm Oil (MSPO) certification scheme is the national certification framework in Malaysia for oil palm plantations, independent and organized smallholdings, and palm oil processing facilities, to ensure compliance with the MSPO standards [62]. One study conducted an environmental life cycle assessment and life cycle costing analysis of uncertified and MSPO-certified fresh fruit bunches (FFB) production among independent smallholders to evaluate the environmental and economic impacts of MSPO implementation [63]. They report lower environmental impact with certified smallholders. The reduction in GHG emissions is attributed to fertilizer production and diesel consumption (processing) in machinery in Malaysia. The incorporation of organic fertilizers emerges as an effective strategy for mitigating the overall environmental footprint associated with the cultivation practices of fresh fruit bunches.

4.4. Forestry

Where forestry was concerned, the evidence base captured five articles discussing the Forest Stewardship Council (FSC) certification scheme. The FSC's certification system verifies sustainable sourcing of forest products and ecosystem services at every step of the value chain, from forest to consumer. It is underpinned by the FSC's sustainable forestry standards [64].

Five papers presented data for GHG emissions in FSC-certified forests or forest tracts compared with non-certified forests. Of these, three reported no impact of certification on GHG emissions [65–67] and two reported a positive impact for some forestry operations associated with FSC certification [68,69].

Umunay et al. [65] evaluated the effectiveness of reduced-impact logging for carbon emissions reduction (RIL-C) in twenty-three commercial forest concessions across the Congo Basin, comprising nine concessions in Gabon, eight in the Democratic Republic of the Congo, and six in the Republic of the Congo. The selected concessions represented a diverse range of management practices, logging techniques, and pre-logging biomass carbon stocks. Their study compared carbon dioxide emissions from six FSC-certified concessions to seventeen non-certified concessions, which included concessions with registered management plans and those operating under temporary logging permits. Logging emissions were primarily attributed to damage caused by hauling and felling. Although carbon emissions per cubic metre of timber harvested differed between countries, they did not differ significantly between FSC-certified and non-certified concessions. The authors highlighted the ease of monitoring logging roads via remote sensing and FSC field audits but noted that felling-related emissions—such as those from abandoned logs and poor bucking practices—were more difficult to track without employing the RIL-C methodology. They recommended incorporating elements of this methodology into national standards to improve the accuracy of logging emissions assessments.

Ellis et al. [66] similarly found no significant differences in carbon emissions between FSC-certified and non-certified concessions practising selective logging in community forests on the Yucatan Peninsula, Mexico. However, they emphasized that the widespread adoption of RIL-C practices across all community-managed forests in the region could significantly enhance the forest sector's contributions to climate change mitigation efforts in Mexico.

Goodman et al. [67] examined carbon emissions from felling, skidding, and hauling operations in Peruvian forest concessions, comparing five FSC-certified concessions where workers received RIL training to four non-certified concessions without RIL-trained workers. Their findings supported earlier studies, showing that concessions employing RIL operated at lower logging intensities and, as a result, produced lower emissions per hectare. However, once logging intensity was accounted for, there were no differences in carbon emissions between certified and non-certified concessions.

Griscom et al. [68] compared carbon emissions from logging activities in three FSC-certified concessions and six non-certified concessions in East Kalimantan, Indonesia. While they did not observe lower overall carbon dioxide emissions in certified concessions, they noted reduced emissions specifically from skidding operations. The authors pointed out that FSC certification standards and associated RIL practices were not explicitly designed to reduce overall emissions. They suggested that to effectively link forest certification with carbon emissions reductions, certification criteria must explicitly mandate RIL-C practices.

Armenta-Montero et al. [69] reported on selective logging operations in two forestry communities, one of which was FSC-certified and incorporated RIL, in the Yucatan Peninsula, Mexico. There were lower emissions and damage from felling and skidding in the FSC-certified concession.

4.5. Cattle Production

This section includes one article that discusses sustainable cattle production under the Sustainable Agriculture Network (SAN) and Rainforest Alliance. The Standard for Sustainable Cattle Production Systems, developed by the Sustainable Agriculture Network (SAN) and Rainforest Alliance, only applies to farms where cattle have access to pasture. It includes the following principles: integrated management systems, sustainable pasture management, animal welfare, and carbon-footprint reduction. One study related to the standard was included in the evidence mapping [70].

Bogaerts et al. [70] compared GHG emissions from beef farms certified by the SAN standard for sustainable cattle production systems against emissions from farms operating under one of four different programmes (Novo Campo Project (Instituto Centro de Vida), Rondonia Intensification Program (Imaflora, Vida Verde, Marfrig Global Foods), Silvipastoral Program (Instituto de Conservaçao e Desenvolvimento Sustentavel do Amazonas), and Pecuaria Verde Program (Sindicato Rural de Produtores Rurais de Paragomina). In the study, 19 farmers were participating in a sustainability or certification programme, and 21 farmers were not. The single SAN-certified farm had a per-kilogram GHG emission output substantially lower than the averages of other groups of farms, although the authors note that there were individual farms which had lower emissions. As noted above, the Rainforest Alliance administers the SAN scheme, but the data do not support an assessment of the effects of the Rainforest Alliance on GHG emissions.

4.6. Aquaculture

Similarly to forestry and cattle production, aquaculture is only represented by one certification: the Aquaculture Stewardship Council (ASC) certification. The Aquaculture Stewardship Council (ASC) was launched in 2010 with the goal of making aquaculture more sustainable. The ASC certification validates seafood and farms' adherence to their strict underpinning standards [71]. One study discussed ASC certification [72].

Nhu et al. [72] reported that GHG emissions for an ASC-certified farm in Vietnam were generally lower than a non-certified farm. This was attributed to the fact that Pangasius feed (consisting of fishmeal and fish oil) is generally restricted in ASC-certified Pangasius farming.

5. Conclusions

Overall, there is insufficient evidence to determine with any certainty whether sustainability certification schemes and labels, used in the bioeconomy, reduce greenhouse gas emissions. However, assembling the evidence base with a systematic approach has meant that evidence gaps are apparent, and this will focus attention on priorities for future research and publication of evidence that is currently held within organizations and not made available in the academic literature.

There are large differences in the volumes of evidence across different sectors and products within the bioeconomy. Agriculture, as a sector, has the most evidence available; however, even within this sector there are too few studies that report the same variables to enable comparisons to be made of the impact of sustainability certification schemes and labels on GHG emissions at the production stage. Additionally, the evidence base is largely concentrated in Southeast Asia and parts of Europe, which limits the generalizability of these results to other regions and countries.

Most phases of the value chain are under-represented, with the production stage overwhelmingly dominating the evidence base. Therefore, generalizing findings from the production stage to other phases of the value chain should be approached with caution. The geographic limitations mentioned earlier are equally relevant when considering the various stages of the value chain.

The evidence base shows significant knowledge gaps in terms of specific certification schemes and labels, most sectors and products, and most parts of the life cycle, including the six products that have historically formed a large part of the sustainability certification literature, namely cocoa, bananas, tea, coffee, cotton, and sugarcane. Notwithstanding the explicit exclusion of biofuels, these evidence gaps represent a research opportunity to advance not only knowledge of the impacts of certification on GHG emissions, but also to address deficiencies in the certification schemes and labels themselves, particularly in respect of measuring and monitoring.

Ultimately, determining whether sustainability certification schemes and labels in the bioeconomy effectively reduce GHG emissions is a complex and context-specific question. The current evidence base lacks the robustness across value chains, sectors, and geographic regions.

Finally, it is unclear how specifically many schemes target GHG reduction as an outcome of interest, though many do focus on important enabling conditions. Similarly, many schemes have GHG calculators (RSPO; MSPO; Bonsucro) that they require certified entities to use to track and manage emissions. This suggests that emissions are being incorporated as a key concern for some schemes and labels; however, schemes could work to better clarify their causal pathways of change on GHG emissions and links to their standards.

Nonetheless, determining whether sustainability certification schemes and labels used in the bioeconomy reduce GHG emissions is a complex and context-dependent question. There is insufficient robust evidence across the value chain, sectors and geographic regions to provide a definitive answer. Therefore, further primary research is necessary to address these gaps and enhance our understanding.

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