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ORIGINAL RESEARCH

Uncovering the role of sustainable value chain and life cycle management toward sustainable operations in electricity production technologies

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Abstract
Sustainable value chain management (SVCM) incorporates the social, economic, and environmental aspects (known as the triple-bottom-line) of production systems, offering significant potential for sustainable operations. By broadening system boundaries and including triple-bottom-line sustainability indicators, SVCM can improve the existing literature on sustainable operations management. Life cycle sustainability assessment (LCSA) identifies sustainability hotspots within value chains but is often underutilized in the practical design of sustainable operations. This paper presents a three-phase framework that combines SVCM and LCSA to enhance sustainable operations, using electricity production as a case study due to its substantial carbon footprint. The authors reviewed 443 articles from an initial 1649 documents on electricity production technologies, emphasizing the use of life cycle assessment (LCA) models to achieve responsible operations in the energy sector. The study highlights the benefits of the proposed integrated framework in achieving sustainable operations through sustainability reporting, stakeholder engagement, transparent procurement, global value chain management, corporate social responsibility, integrated decision-making, circular economy, and carbon footprint management. Future research should focus on developing circular production systems, integrating socioeconomic indicators, and aligning sustainable development goals with value chain hotspots.

Keywords Sustainable value chain management · Sustainable operations management · Life cycle sustainability assessment · Electricity production technologies · Sustainable development

Abbreviations

3BL	triple-bottom-line
BEPC	building energy performance certification
CBAM	The Carbon Border Adjustment Mechanism
CED	Cumulative energy demand
CLCD	Chinese Life Cycle Dataset
CSR	Corporate social responsibility
ESG	Environmental, Social, and Governance (ESG) reporting
FCA	Financial Conduct Authority
GHG	Green House Gas
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Technologies model
GRI	Global Report Initiative
GWP	Global warming potential
HLCA	Hybrid Life cycle assessment
ILCD	International Reference Life Cycle Data System
IO-LCA	Input-Output Life cycle assessment
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
LCC	life cycle costing
LCI	Life cycle inventory
LCOE	Levelized Cost of Energy
LCSA	life cycle sustainability assessment
MCDA	Multi-criteria decision-making
MRIO	Multi-Regional Input Output
ODP	Ozone depletion potential
PED	Primary energy demand
P-LCA	process-based Life cycle assessment

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PMF	Particulate matter formation
PSIA	Product Social Impact Life Cycle Assessment
PV	photovoltaic
SDGs	sustainable development goals
SEC	Securities and Exchange Commission
SHDP	Social Hotspot Database
SVCM	Sustainable value chain management
TCFD	Task Force for Climate-Related Financial Disclosure
TRACI	Tool for the Reduction and Assessment of Chemical and other environmental Impacts
UNGC	United Nations Global Compact
WAT	Water consumption

1 Introduction

Adopting sustainable practices has become an essential requirement, rather than an option, for ensuring the sustainability of our common future. The expansion of the global economy has surpassed the Earth's environmental limits, as evidenced by Whiteman et al. (2013), highlighting the critical need for comprehensive sustainability strategies. This endeavor, although complex, presents novel opportunities for the evolution of operations management beyond its conventional boundaries. According to Lee and Tang (2018), traditional domains of operations management, such as inventory control, scheduling, and supply chain management, have approached their research saturation, necessitating a transition toward the development of environmentally and socially sustainable value chains to address the escalating global sustainability issues.

The movement towards sustainable operations management embodies a holistic approach that encompasses the social, economic, and environmental impacts of value chains, thereby fostering a more inclusive and sustainable economic model. This approach not only bridges the gap between different stakeholders such as suppliers, manufacturers, distributors, retailers, and consumers but also enriches the operations management field with interdisciplinary insights. Moreover, the embrace of sustainability within operations management spanning areas like sustainable manufacturing, carbon footprint reduction, and the development of sustainable supply chains (Mithas et al. 2022; Sharma et al. 2023) reflects a significant theoretical evolution. It marks a shift from traditional management theories towards frameworks that integrate environmental stewardship, social responsibility, and economic viability, underscoring the importance of sustainability in driving innovation and ensuring long-term business success (Feng et al. 2023; Jauhar et al. 2023; Le et al. 2023).

The sustainability and extended supply chain framework discussed by Kleinderfor et al. (2005) describes the advantage of creating shared value within the entire value chain with the relationship between the economy, society, and the environment. Porter and Kramer (2011) define shared value as "corporate policies and practices that enhance the competitiveness of a company while simultaneously advancing social and economic conditions in the communities in which it operates." Creating a shared value provides companies or organizations with the opportunity to address socioeconomic and environmental pillars of sustainability throughout their entire value chain. With the increasing significance of socioeconomic and environmental challenges, regionally and globally, the shared value concept has become an important subject, which mainly focuses on the socioeconomic conditions of society and, therefore, considers how 'value' is created within the interconnected value chains (Porter et al. 2011).

Sustainable value chain management expands the traditional supply chain management (Tang and Zhou 2012) and it considers social, economic, and environmental (termed as triple-bottom-line, 3BL) impacts of production that consider the use of products and end-of-life management (Fearne et al. 2012). It employs a full life cycle style of thinking and facilitates a detailed mapping of value chain activities from cradle-to-grave or cradle-to-cradle perspectives (Eisenreich et al. 2022). While the cradle-to-grave value chain mainly follows a linear economy structure that takes a 'take-make-dispose' approach, the cradle-to-cradle value chain structure follows circular economy principles with a 'take-make-reuse' approach. Fig. 1 visualizes these concepts and differentiates between supply chain management and value chain management, as well as linear versus circular value chains, including several 3BL sustainability indicators.

As discussed by Lee and Tang (2018), sustainable operations management needs to enlarge its scope and explore new directions. The researchers discussed the importance of socially and environmentally responsible value chains that can add new dimensions to conventional operations management research, which has reached saturation over the last period. Some studies pointed out new research directions for the field, such as the inclusion of emerging and developing economies, incorporating the role of economic, environmental, and social pillars of sustainable development goals into operations management, and contemplating the role of diverse stakeholders within the value chain (Van Wassenhove 2019; Lee and Tang 2018; Lee and Rammohan 2017; Tang 2018).

To expand existing sustainable operations management literature with holistic and socially responsible, economically viable, and socially acceptable value chains, life cycle assessment (LCA) acts as a systematic method that considers the entire value chains of production

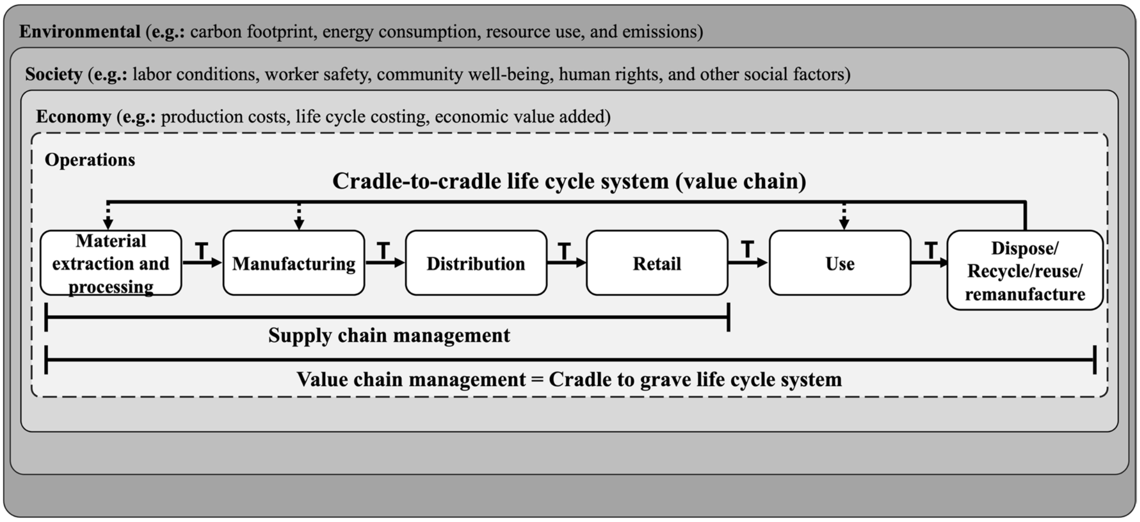

Fig. 1 The system boundary of sustainable value chain management (**T**: Transportation)

systems. LCA appears a systematic method used to analyze the environmental impacts of various life cycle phases of production systems (Blanco 2021). The LCA method plays a critical role in managing the value chain-wide environmental impacts of production. However, with the increasing importance of socioeconomic concerns in value chains (e.g., child labor issues, health, and risk, fair salary, and compensation) (Gamarra et al. 2023), a traditional LCA has evolved into a life cycle sustainability assessment (LCSA) framework. It expands the scope to include social and economic dimensions, making it a comprehensive approach that evaluates 3BL sustainability implications (Guinée 2016; Visentin et al. 2020). It consists of three independent methods, such as environmental LCA (e.g., carbon footprint, energy consumption, resource use, and emissions), social LCA (e.g., employment, worker safety, community health and well-being, human rights, and other social factors), and economic assessment (e.g., production costs, life cycle costing, economic added value) (Visentin et al. 2020).

The importance of social, economic, and environmental life cycle analysis is discussed in operations management literature and this method is also mentioned by past studies towards shifting paradigms and discovering new opportunities in sustainable operations and value chain management (Atasu et al. 2020; Kleinderfor et al. 2005). LCSA identifies sustainability hotspots within value chains but is underutilized in designing sustainable operations in the field. To this end, this research designed a novel framework on how sustainable value chain management can foster sustainable operations and bridge the gap between disciplines such as engineering, environmental sciences, social sciences, engineering, and operations management.

In this paper, the authors first highlighted LCSA as a tool to build sustainable value chains for production systems, referring to the life cycle-focused value chain definitions provided by WBCSD (2011) and GHG (2011). As described by the World Business Council for Sustainable Development (WBCSD 2011), *"A value chain refers to the full life-cycle of a product or process, including material sourcing, production, consumption, and disposal/recycling processes and reveals opportunities for companies to make more sustainable decisions about their operations"*. GHG protocol (2011) also defines a value chain as *"all of the upstream and downstream activities associated with the operations, including the use of sold products by consumers and the end-of-life treatment of sold products after use"*.

Our framework starts with the integration of three LCA methods: Social LCA, Environmental LCA, and Life Cycle Economic Analysis. Furthermore, we conducted a comprehensive systematic review of the LCA studies in 443 articles screened from an initial review of 1,649 documents on electricity production technologies. After finalizing their review, the authors identified major applications. The authors' framework merges LCA with sustainable value chain management and aims to empower sustainable operations in the electricity production value chains. The research framework has four major objectives:

1) To show the connection between LCA methods and sustainable value chain management for achieving socially and environmentally responsible sustainable operations.
2) To design a theoretical and practical interdisciplinary framework on how sustainable value chain management combined with LCA can catalyze sustainable operations in electricity production value chains.

3) To identify the current LCA applications in sustainable electricity production and how the interdisciplinary research framework can enable the energy sector to achieve 3BL sustainable operations, and
4) To point out the importance of interdisciplinary research and bridge the gap between various disciplines for expanding sustainable operations management research in the energy sector.

The rest of the paper is organized as follows. Section 2 presents the significance of sustainable operations in the electricity production sector. Section 3 details the comprehensive research framework and structured review method. Section 4 discusses how the proposed framework can foster sustainable operations in electricity production. Finally, Section 5 summarizes the research with future remarks on the required interdisciplinary research connections.

2 Why does sustainable electricity production matter?

The most substantial rise in emissions within specific sectors during 2022 was observed in the domain of electricity generation, with emissions surging by 1.8%, equivalent to 261 million metric tons. Notably, global emissions stemming from coal-fired electricity production showed a considerable increase of 2.1%, equivalent to 224 million metric tons, primarily driven by emerging economies worldwide (IEA 2022). The world is already transitioning towards sustainable energy production, with renewable energy presently providing at least 27% of the world's electricity generation (Bogdanov et al. 2021).

Several nations consider sustainable energy production to be a strategic move to achieve long-term carbon mitigation targets to support sustainable production. In response, these countries make renewable energy production part of their national policies and laws (Li et al. 2022a, b). Additionally, global energy companies are setting science-based targets toward reducing their direct and value chain-inducted, indirect emissions through energy-efficient operations, green supplier selection, and further investment in renewable technologies. The aim is to reach net zero emission goals, which were initially discussed at the United Nations Climate Change Conference (COP 21) in 2015, also known as the 'Paris Agreement'. For example, the UK's Electricity Northwest company is committed to reducing absolute direct and energy consumption-related indirect greenhouse gas (GHG) emissions by 63% by 2035 from a 2020 base year. The company also undertakes a commitment to reduce scope 3 carbon emissions originating from its value chain, encompassing the procurement of goods and services, energy-related endeavors, fuel consumption, corporate travel, and employee commuting. Additionally, the company aims that, by 2026, 41% of its suppliers, who are involved in emissions associated with acquired goods, services, and capital goods, establish science-based carbon emission reduction targets.

In a recent report, UN SDG Compass (2015), various LCA methods, including process-based LCA and environmentally extended input-output LCA (discussed in Section 3.2) are given among the suggested methods for measuring, managing, and reporting environmental footprints within the company value chains, which can improve the sustainability of operations through the selection of sustainable suppliers, the identification of carbon and resource-intense operations, the mapping of upstream and downstream value chain contributions to the net environmental footprints, and the reporting of indirect carbon footprints in company operations.

Governments in the U.S., China, the UK, Denmark, and Germany, have a set of policies, including energy-efficient standards, feed-in-tariffs, and "building energy performance certification (BEPC) schemes, which help regulate and ensure sustainable energy production" (Lu et al. 2020). Investing in research on sustainable energy value chains is essential because it provides critical insights on how best to transition toward clean energy. Energy remains recognized as an essential element of UN SDGs. SDG-7 is dedicated to sustainable energy; it seeks to "ensure access to affordable and sustainable" power for all (Gebara and Laurent 2023). To this end, the authors focused on the electricity production technologies for the implementation of their framework and conducted an extensive structured review, followed by discussions of applications and knowledge gaps for advancing sustainable operations in the electricity sector.

3 Methods

3.1 Research framework

Fig. 2 visualizes the authors' research framework, which comprises three integrated stages. At stage 1, we propose to connect three independent LCA methods. A combination of these methods forms the foundation of sustainable value chain management in product systems. At stage 2, the authors conducted a comprehensive structured review of the LCA applications for electricity production technologies, used to map their value chain impacts from a holistic life cycle perspective (see section 3.2). Their structured review investigates the six groups of applications: technology, LCA methods, databases, indicators, decision-making methods, and mapping using the Sustainable Development Goals (SDGs). At stage 3, the authors discussed several

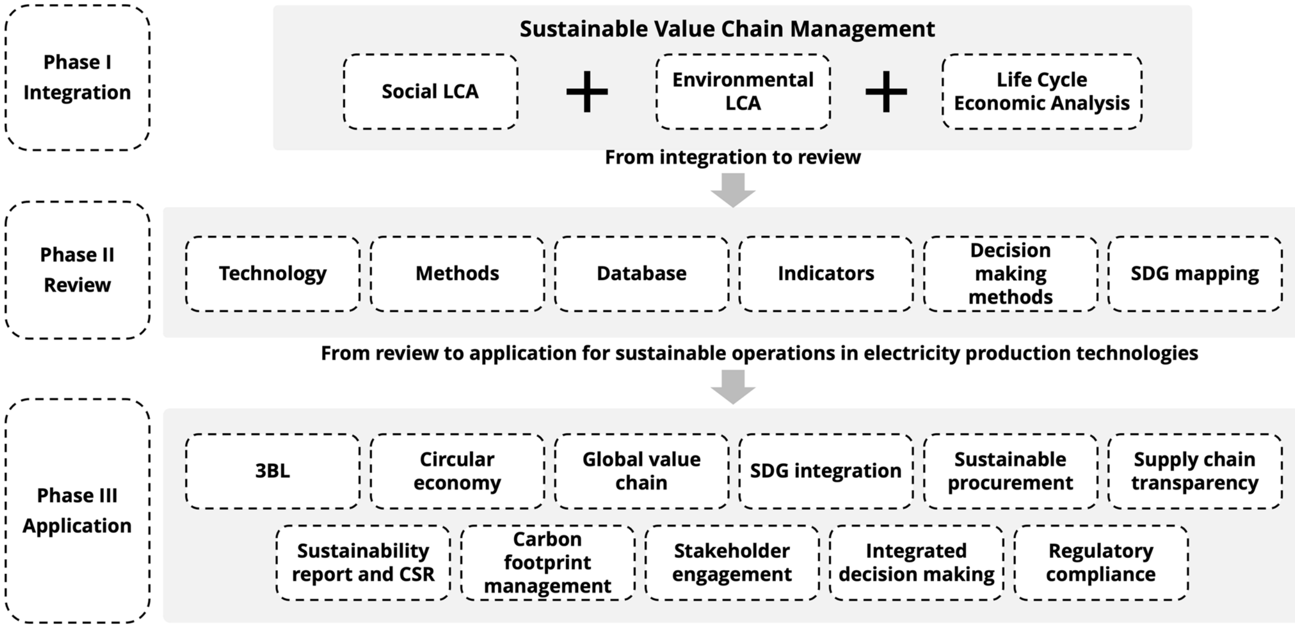

Fig. 2 Research framework

key aspects of life cycle methods advancing sustainable operations in electricity production for emerging research areas in the sustainable operations management literature grouped under the extensive list of supporting information (SI), including (1) sustainability reporting and stakeholder engagement; (2) sustainable procurement and supply chain transparency; (3) global value chain management; (4) corporate social responsibility; (5) integrated decision making; (6) circular economy and closed-loop supply chains; (7) carbon footprint management and regulatory compliance; and (8) mapping using sustainable development goals (see Fig. 2). The categories were selected after a meticulous review of the papers, identifying the key areas of focus within each. For the analysis in this paper, the most used categories were chosen to ensure relevance and coherence.

3.2 Structured review

The review of the literature occurred in three phases as Fig. 3. During the first phase, a literature search was performed using the Scopus database. The protocol used in this review considered the search terms in the abstract, keywords, and title. At this stage, the keywords used in the search included “life cycle assessment” and “electricity generation” or “electricity production.” The review search spanned 10 years, between 2014 and 2023, and only considered articles published in English. The decision to focus on 10 years for this review was influenced by the noticeable surge in momentum within the field over the last decade, as clearly illustrated by Fig. 4. Additionally, this timeframe allows us to provide an updated perspective spanning the recent 10 years. The review focused on relevant studies and peer-reviewed journals published in 2014 to ensure the articles obtained were up to date and would include advances in sustainability within the electricity sector. This initial search yielded 1,649 documents.

Following these results, it was necessary to filter and reduce the number of documents to ensure only relevant, good-quality articles were used. Hence, the next stage involved further filtering to identify articles for exclusion. During the second phase, the identified documents were filtered based on the two inclusion criteria. The first inclusion criterion required that all the papers were articles, so other types of reports and documents were excluded. The second required that the documents were journal publications, so any papers that were not journal publications were excluded. The search filtration and narrowing resulted in 983 documents. These sources met the inclusion criteria due to the quality of the information in the peer-reviewed journal articles. Using journal articles in research is essential as these documents contain accurate, well-analyzed, and thoroughly reviewed information to ensure quality and trustworthiness.

During the third phase of the search, the authors examined all 983 articles to select only those directly related to the study topic, which is the LCA of electricity production technologies. Because no more filters could be applied in the database search, all 983 articles were skimmed. Of these, only 443 directly addressed the scope of the study and were evaluated for review and analysis. The remaining 542 articles

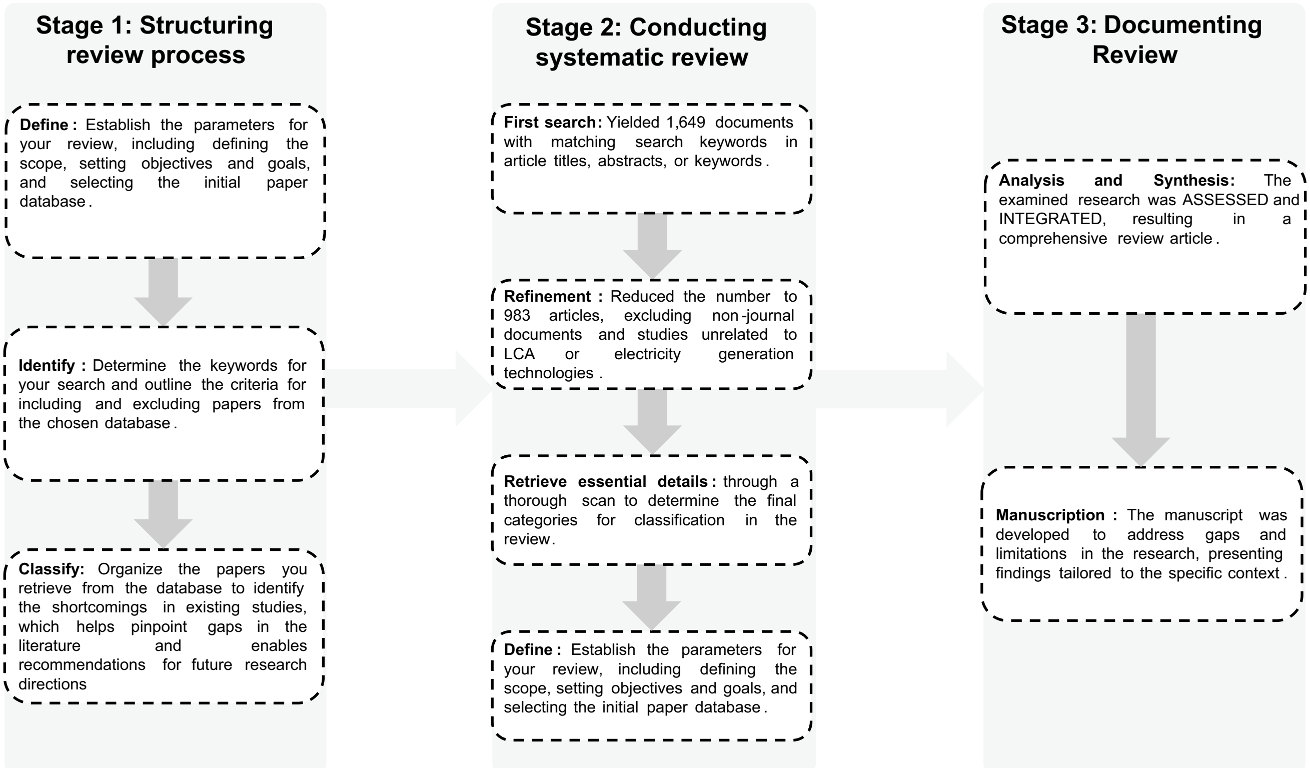

Fig. 3 Stages of structured review

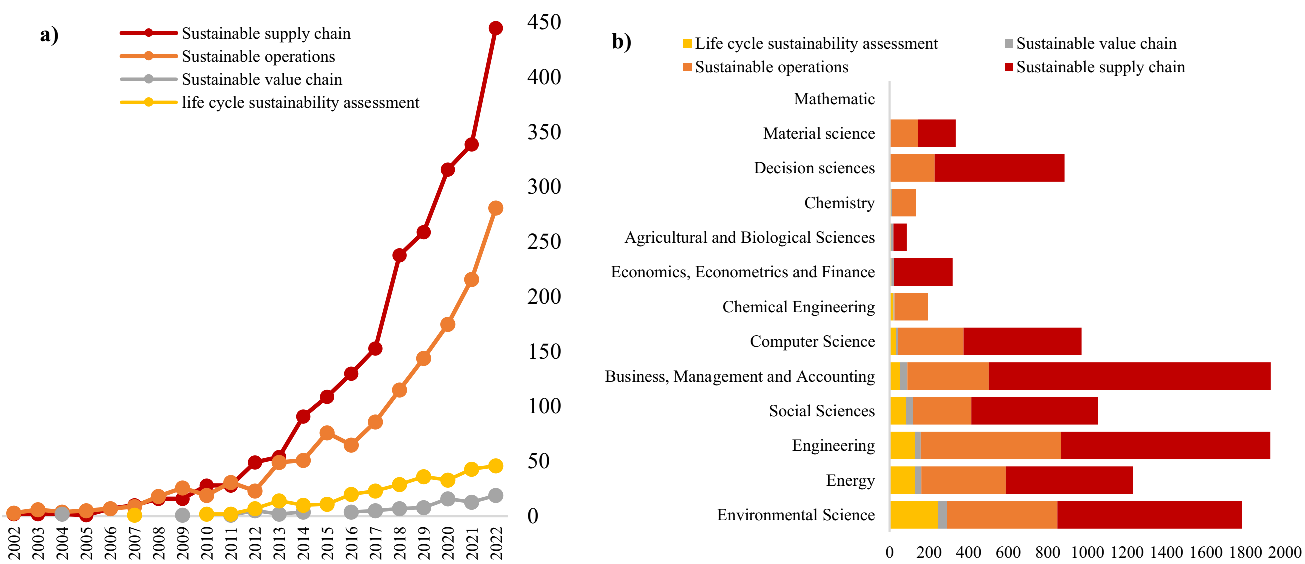

Fig. 4 Number of studies obtained from the Scopus database search: **a**) by year; **b**) by subject area

either did not directly address the scope or focused on the sub-processes within the electricity generation cycle. The reason for excluding these articles was to ensure that only documents that detailed the topic became part of the review. Following phase three, 443 articles were critically reviewed and analyzed in detail. The data extraction process occurred qualitatively for all the considered articles. The authors synthesized the data by classifying the identified articles based on their design and themes. Data were then extracted from each of the articles based on the shared themes. Primarily, the themes that formed part of the articles' analysis included life-cycle sustainability assessment and electricity production. In addition to the classification based on methodological design, the articles were categorized according to factors such as technology, study period, LCA method, impact assessment method, operations research methods, environmental and socioeconomic sustainability indicators, SDGs, and use of different databases.

For comparison, we conducted a parallel search in the Web of Science database using the same conditions as in Scopus. The search criteria were:

- Search the topic (abstract, title, and keywords) for "life cycle assessment" AND ("electricity generation" OR "electricity production").
- Cover the years 2014 to 2023 for both databases.
- Include only final-stage articles.
- Limit to articles published in English.

This search resulted in 978 articles from the Web of Science, like the 983 articles found in Scopus. This similarity supports our confidence in the thoroughness and reliability of our literature search. It shows a significant overlap in the coverage of articles relevant to our review topic across both databases. The following subsections summarize the detailed codebook entries

3.2.1 Database Used (DU)

- **Code**: DU
- **Values**:

1 = Scopus
2 = Web of Science

3.2.2 Search Terms (ST)

- Code: ST
- Values:

1 = "life cycle assessment" AND "electricity generation"
1 = "life cycle assessment" AND "electricity generation"

3.2.3 Time Frame (TF)

- **Code**: TF
- Values:

2014-2023

3.2.4 Language (LANG)

Code: LANG
Values:
1 = English

3.2.5 Document Type (DT)

- Code: DT
- Values:

1 = Journal article

3.2.6 Inclusion Criteria (IC)

- Code: IC
- Values:

1 = Journal Article (exclude reports and other documents)
2 = Journal publication

3.2.7 Themes

Life-Cycle Sustainability Assessment (LCSA)
Code: LCSA
Sub-codes:
1 = Use of different database
2 = Impact assessment methods
3 = Environmental indicators
4 = Socioeconomic indicators
5 = Mapping with Sustainable Development Goals (SDGs)
Electricity Production (EP)
Code: EP
Sub-codes:
1 = Technologies used
Methodological Design (MD)
Code: MD
Sub-codes:
1 = LCA methods
2 = Operations research methods

4 Results and discussions

4.1 The current state of research efforts

Fig 4. presents a comprehensive overview of the number of studies published by year and the articles by subject area. This search was performed through the Scopus database using four keywords (sustainable supply chain; sustainable operations; sustainable value chain; and life cycle sustainability assessment) to search for abstracts, titles, and keywords. To access more studies, the authors limited their search to the abovementioned keywords without adding 'management,' such as sustainable supply chain management, sustainable operations management, and sustainable value chain management. The initial search indicated that sustainable operations followed the largest number of studies related to sustainable supply chains. Sustainable value chain research generated the lowest number of results. When the authors compared the number of articles published on sustainable operations and supply chain management, there was a significant discrepancy between the areas. Similarly, LCSA studies were still limited, following a similar trend to the sustainable value chain. This also proves significant research needs in the management field considering the 3BL indicators combined with extended value chains. Earlier studies published in management science and operations management journals also discussed this research need. For example, Lee and Tang (2018) discussed the need for expanding operations management in new research areas, and environmentally and socially responsible value chains are highlighted as a future direction. Tang and Zhou (2012) and Atasu et al. (2020) underscored the potential of operations management research in fostering the advancement and influence of environmentally and socially conscientious operations. These scholars advocate for the integration of the interdisciplinary domain of industrial ecology, particularly emphasizing life cycle modeling to enhance the robustness and effectiveness of this research pursuit.

A lack of attention has been paid to industrial ecology literature and interdisciplinary research connecting management with engineering, and natural and social sciences. The analysis of articles by subject area also revealed important insights about the current state of interdisciplinary research in the field. Expectedly, business, management, and accounting are the leading subject areas for articles published in the fields of sustainable operations and supply chain. Although it is suggested as a systemic method for analyzing the social, economic, and environmental implications of value chains, studies using LCA emerge mainly from environmental sciences, energy, and engineering with limited contributions from social sciences and business, management, and accounting. This suggests that there is still a lack of integration between business and other disciplines, such as engineering, energy, and environmental sciences for the given subject (see Fig. 4). Kleinderfor et al. (2005) emphasized the importance of multidisciplinary research and life cycle thinking toward bridging the gap between original links between sustainable operations management and engineering, industrial ecology, and other disciplines, including natural sciences.

4.2 Electricity production technologies and publication venues

This section analyzes the technologies discussed in the reviewed articles. One energy source addressed in the literature is solar, which is emerging as a valuable source of clean power. Solar photovoltaic (PV) technologies were the most discussed, accounting for 30% of all the analyzed articles shown in Fig. 5a. This is an important finding, indicating that solar PV technologies are gaining attention and are presently being applied by many countries to cut carbon emissions. Biomass, wind, and coal-related technologies were discussed in 23%, 22%, and 21% of the articles, respectively. This indicates that, in addition to solar PVs, researchers emphasize the significance of biomass, wind, and coal technologies in moving toward sustainable electricity. The fact that many researchers are shifting their focus to biomass-related technologies suggests that these methods produce cheap energy while reducing carbon emissions, thus demonstrating environmental, economic, and social benefits (Wang and Yang 2022). Specifically, 23% of the articles discussed biomass focused on gasification technologies, which have been proven to significantly cut greenhouse gas emissions.

Wind-based technologies for electricity generation were recorded in 22% of the reviewed articles, further revealing the expanding role and potential of wind as a source of sustainable power generation. As a source of clean energy, wind technologies, such as wind turbines and floating offshore wind farms are widely used to cut carbon emissions worldwide. Poujol et al. (2020) found that wind turbines produce at least 25% of global renewable energy sources, due to their efficiency and low carbon emissions. This statistic explains why a more significant percentage (22%) of the reviewed articles examined this area. In the future, wind turbines and other related technologies will drive the global transition toward sustainable energy production.

Based on the findings, 21% of articles examined coal-related technologies and their environmental impacts. This outcome indicates that more scholars are paying attention to coal and related technologies as a source that can drive sustainable energy production (Leme et al. 2021). The rise of coal-fired plants in many parts of the world means that coal is still a crucial source of electricity and can be tapped to produce clean energy (Vilén et al. 2022). Hydropower was discussed in 20% of the reviewed articles, which shows that hydropower technologies are also gaining popularity amongst researchers, thus becoming important in sustainable power production. For example, Lazo Vásquez et al. (2022) noted that hydropower represents 15% of the global electricity supply, making it one of the future sources of clean power. Therefore, researchers are increasingly exploring how hydropower-related technologies can help achieve SDG-7, which focuses on access to clean energy for all. A

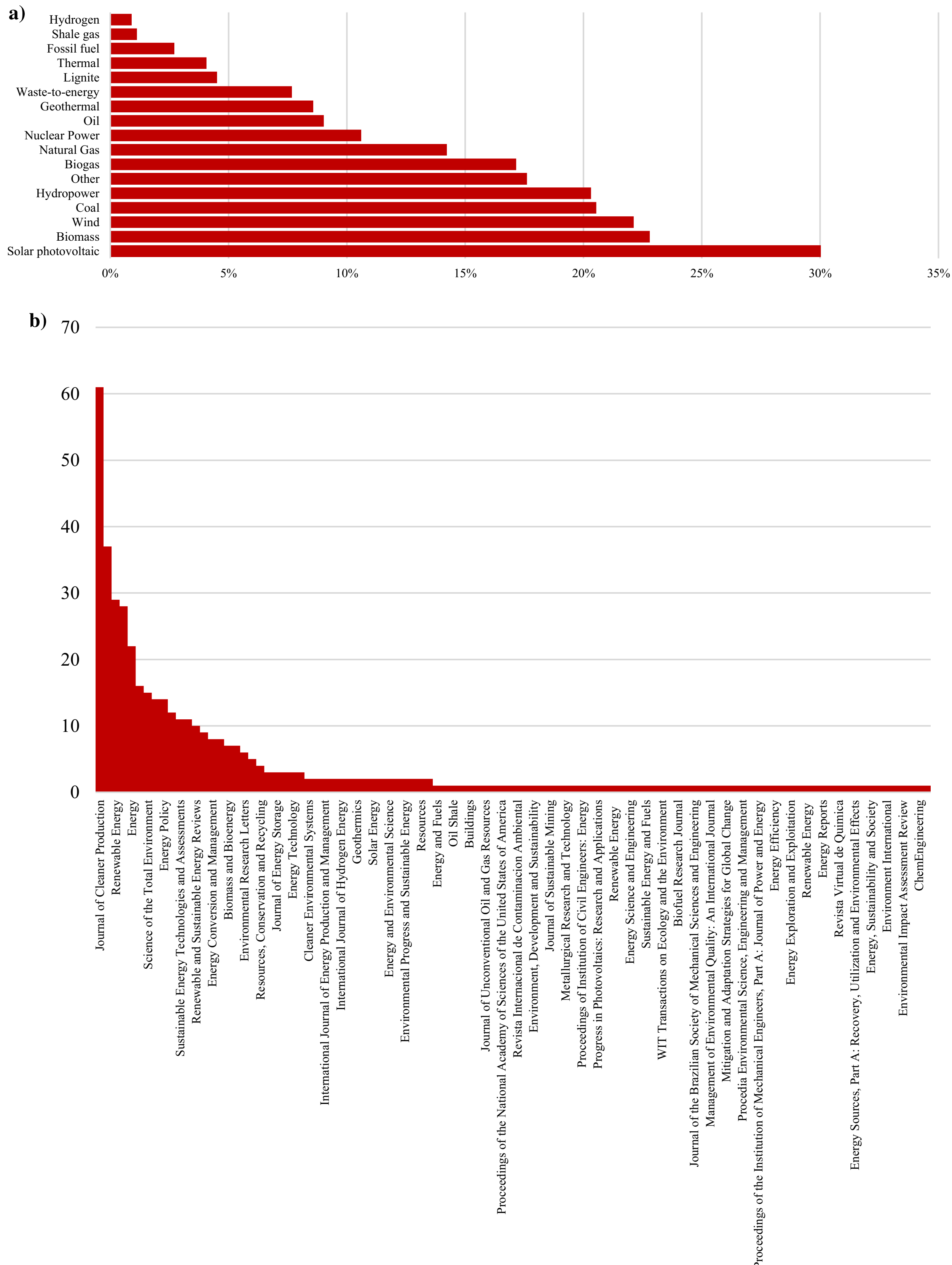

Fig. 5 **a** Coverage of electricity generation technologies (%); **b**) number of papers published by the journal

similar outcome was evident in biogas, discussed in 17% of the reviewed articles. As the world shifts towards sustainable energy, biogas-related technologies will be critical in cutting emissions (Miranda and Kulay 2023). Interestingly, the least-discussed technologies included emerging hydrogen and shale gas technologies, each representing only 1% of all the articles reviewed. This outcome means that hydrogen and shale gas technologies remain overlooked in the literature, despite their potential to decarbonize electricity generation. The literature review revealed that scholars rarely explore these technologies and their role in harnessing sustainability, thus creating a gap in the literature. It should be highlighted that the total percentage of discussed technologies in Fig. 5a does not total 100% as some of the articles addressed more than one technology. A significant percentage (73%) discussed single technologies, while only 27% considered a wide range of technical abilities. These results indicate that most researchers consider a specific technology for sustainable electricity production rather than examining a range of technologies.

As shown in Fig. 5b, renewable energy production technologies, such as solar, biomass, and wind received more attention from researchers, followed by coal-based electricity production. When the researcher examined the journal types, it was evident that the environmental sciences, engineering, and energy-related journals, such as the Journal of Cleaner Production, Renewable Energy, Energy Policy, and Science of Total Environment place more focus on the life cycle assessment of electricity production (see Fig. 5b). This fact supports the discussion in the introduction. It also indicates that when combined with life cycle sustainability, sustainable value chain management research is mostly studied by researchers from the engineering and environmental sciences. There is still little joint research effort between management and those disciplines, which creates silos in the academic literature for such an interdisciplinary energy topic.

4.3 LCA methods

This section critically analyses and discusses the findings of the reviewed articles using various LCA methods to support insights about LCA in electricity production. The process-based LCA (P-LCA) was the most widely used method (89.39%), followed by the hybrid LCA (2.03%). The author also observed that the input-output LCA (1.58%) and the multi-regional input-output LCA (0.23%) had little application in the sustainability assessment of electricity production technologies and their value chains. Fig. 6a indicates that many studies adopted the P-LCA and found that renewable energy sources, such as solar-based products and plant-based biomass sources presented a lower carbon footprint and better environmental impacts on land use, water consumption, and global warming. Adopting the P-LCA decision-making approach allowed the authors to collect actual primary data on all processes involved in production value chains and scientifically analyze the actual processes adopted in electricity generation using different energy sources (Pomponi and Hart 2021).

IO LCA constitutes a valuable method for comprehending the ecological implications associated with electricity generation with an expanded scope that encompasses national and regional scales. This approach harmoniously combines the principles of LCA and Input-Output (IO) Analysis (Lindner et al. 2013). As shown in Fig. 6a, a few studies adopted the input-output LCA analysis method and found that energy sources, such as wind turbines, presented a lower carbon footprint and had better environmental and financial impacts. Moreover, these studies helped establish which input-output processes, products, and operations were adopted while generating electricity using renewable sources presented higher adverse environmental impacts. This method is well suited for the high-level analyses of economic systems and their environmental impacts on energy value chains at the national or regional level (Kumar et al. 2016).

Input-Output LCA (IO LCA) can be extended to include data from multiple regions or countries, providing a more comprehensive view of the global value chain and international trade environmental and socioeconomic implications. Multi-Regional Input-Output LCA (MRIO LCA) models go beyond national or regional boundaries and typically include multiple regions or countries and consider global value chains (Zafrilla et al. 2014). It accounts for both the direct and indirect environmental and socioeconomic impacts associated with the production of electricity across different regions. The MRIO LCA method was the least used among the other reviewed articles (see Fig. 6a). One article adopted the MRIO LCA method and found that solar power and biomass energy sources resulted in reduced GHG emissions. Like MRIO and IO LCA methodologies, the hybrid LCA was not commonly applied among the reviewed articles. An advantage of using the hybrid LCA method is that it combines the strengths of two important methods, such as P LCA and IO LCA, and presents more holistic and credible results (Pomponi and Hart 2021).

While P LCA focuses on collecting micro-level, actual data from diverse input units, focusing on the physical process flow of inputs and outputs of energy use, generation, and environmental impact, IO and MRIO LCA collect data at the macro-level from a country's national-level economic sector and focus on the monetary value flow of inputs and outputs of energy use, generation, and environmental impact. The HLCA utilizes both methods to compare the social, environmental, and economic

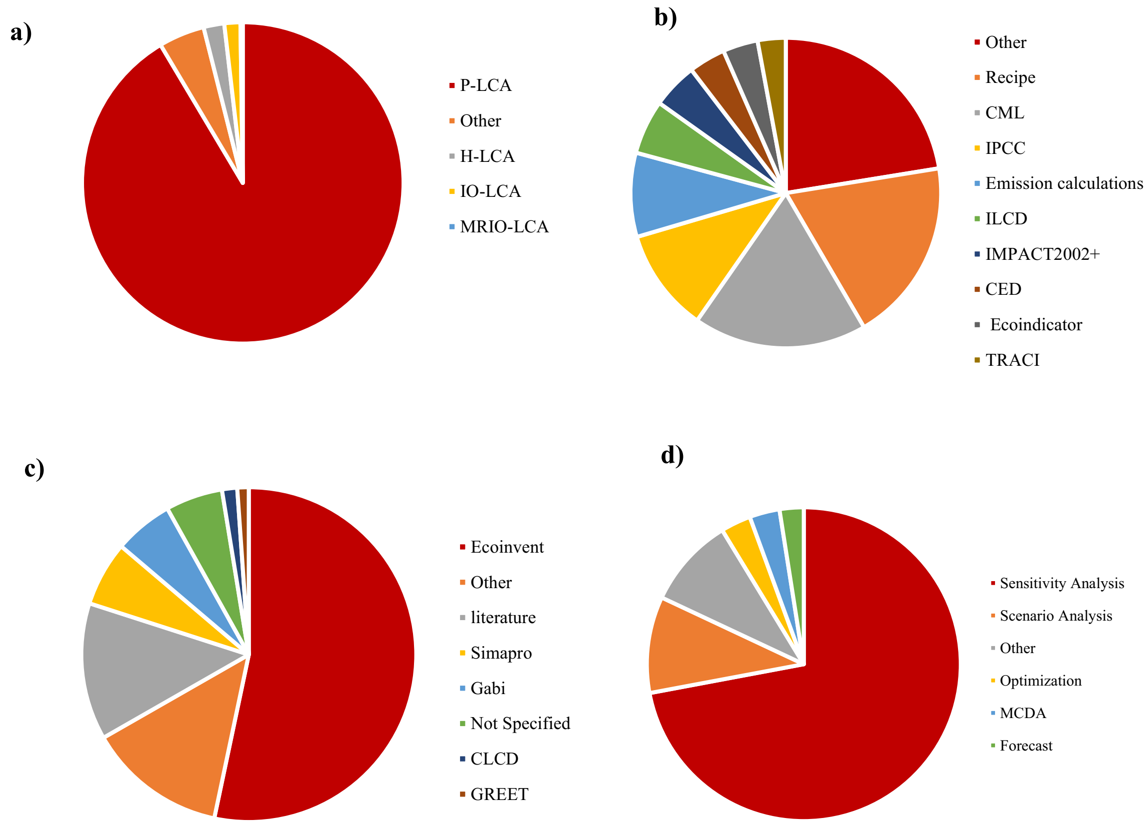

Fig. 6 Percentages of studies by **a**) LCA methods; **b**) impact assessment methods; **c**) databases; **d**) decision-making methods

impacts of various energy sources in electricity production, combining the strengths of each methodology, such as detailed process analysis and capturing indirect impacts in first, second, third, and even higher-order supply chains (Wiedmann et al. 2011).

4.4 Impact assessment methods and databases

The gathered articles in the review of the related literature adopted several methodologies in assessing the LCA of electricity generation. Most of them utilize LCA methods, which assess the environmental effects of various technologies throughout their life cycles, which is one popular strategy. Various approaches can facilitate an LCA impact assessment, which will be discussed in this section. Several articles used multiple and combined methodologies in assessing the life cycle of energy generation. Fig. 6b shows the number of used assessment methods per article in the literature. Recipe, CML, and the Intergovernmental Panel on Climate Change (IPCC) were widely used to evaluate the possible harm to human health, ecosystems, and natural resources.

Additionally, as illustrated in Fig. 6c, the analysis of the 443 articles on sustainability in electricity generation revealed that Ecoinvent was the most frequently used database, with 65% of the articles using that method. The second most-used source of data was that from the available literature, accounting for 16%. Simapro was the third-most frequently used database, appearing in 8% of the reviewed articles. Gabi and the Chinese Life Cycle Dataset (CLCD) were used in 7% and 2% of the articles, respectively. GREET was used in only 1% of the pieces, and 7% of the articles did not specify the database used. A range of databases were used in 16% of the articles. The database selection depends on the study scope and required coverage and will also directly rely on the availability of information required to conduct the LCA.

4.5 Operations research methods

There were 443 reviewed articles on the decision-making methods researchers adopt to support the conclusions regarding life cycle assessment and electricity generation. Fig. 6d summarizes the LCA decision-making methods and the percentage of use in the reviewed literature. Among the articles, 36% used decision-making methods, while 64% did not. This review indicates minimal utilization of system-based decision-making techniques (36%) when making conclusive findings on the environmental impact of electricity generation. This review determined that researchers made heavy use of sensitivity analysis (72.05%). However, scenario analysis (9.94%), optimization (3.11%), forecast (2.48%), and multi-criteria decision-making (MCDA) (3.11%) were applied less in LCA research.

Adopting this decision-making approach provided benefits, such as identifying the hot points or possible areas that drive the highest risks within LCA and adverse environmental impact. Many studies adopted sensitivity analysis to support their findings. One benefit of the sensitivity analysis technique is its ability to establish variances in electricity production processes, indicating how different decision-making techniques present varying computations and quantifications of reduced carbon emissions, carbon footprint, and intensity.

The review of these studies indicates that sensitivity analysis helps to outline exact processes with historical data that affect a model's reaction only within electricity generation that should be avoided, and alternative materials could be considered. It involves assessing how various factors affect a model; for example, how different life cycle stages (manufacturing, transportation, maintenance, and end of life) and materials (renewable and non-renewable energy sources) affect carbon intensity and carbon footprint within electricity generation. Sensitivity analysis allows for a cost-benefit analysis, which helps the authors determine the effects caused by performing, or not performing, the processes and provides informed recommendations for a better lifecycle assessment and improved sustainable electricity generation practices and patterns (Rigamonti and Brivio 2022). Like the studies that adopted sensitivity analysis, these studies provide consistent findings in that various lifecycle stages of electricity generation present adverse environmental impacts; nonetheless, electricity can be generated using more sustainable and renewable energy sources than fossil fuels.

Scenario analysis helped the authors identify how various stages within the mid and endpoints of electricity generation showed varying impacts, depending on different scenarios, including the materials and plants that were used. A benefit of conducting scenario analysis was its ability to provide a comparative analysis of the variances in carbon emissions and global warming potential, depending on the region. Compared with sensitivity analysis, a scenario analysis is effective in providing a comparative analysis of the life cycle impacts on electricity generation in the broader context. Scenario analysis provides the authors with informed decisions and operational information to fully understand a specific situation, establishing which areas and factors are the highest contributors to the adverse impacts of electricity production, providing operational information to make a comparative analysis with various alternatives (inter and intra-regions) and making informed decisions to address the problem.

4.6 Sustainability indicators

This section provides a critical discussion on the environmental and socioeconomic impacts of electricity generation, justifying the obtained results supported by the literature. Based on the reviewed articles, 80% focused their analysis on a single pillar of sustainability (environment, economy, or society), while 16% chose two different pillars (environment-economy, environment-society, or economy-society). Only 4% of the reviewed articles considered the 3BL of electricity production technologies. Fig. 7a summarizes the dominant environmental impacts resulting from electricity generation processes, with the most extensive impact being the contribution to the global warming potential, in other words, carbon footprints, accounting for 85.78%. Other environmentally related impacts are related to mid-point impact categories including acidification and eutrophication potential. Similarly, Fig. 7b summarizes the most prevalent socioeconomic impacts of electricity generation, which include life cycle and energy costs and impacts on tax systems, employment, and human health, among others. The analysis showed that life cycle costing (LCC) is studied mostly among the socioeconomic indicators.

4.7 Mapping with SDGs

A small number of studies linked the results to the SDGs in the reviewed literature (see Fig. 8). The SDGs mostly linked to the findings on sustainable energy were SDG-7 and SDG-13. SDG-7 seeks to enhance access to clean and sustainable energy, thus directly linking it to the findings related to sustainability in energy production. SDG-13 also appears frequently due to the close link between energy production and climatic change. SDG-13 seeks to reduce climatic actions, including global warming, a major element of energy production.

Other SDGs, such as SDG-6, are also widely discussed because of the direct relationship between energy production, water, and sanitation. Fig. 8 illustrates the percentage of each discussed SDG category in the literature. It was interesting to see that 98% of the researchers did not link their analysis or findings to the SDGs. This creates a huge gap in the literature because the available information does not provide information about the required policy and decision-making areas to enhance the energy sector's sustainable operations on a global scale. One key area that remains overlooked by researchers, who failed to tie SDGs to the study findings, is that these goals are closely interlinked, and the achievement of one affects

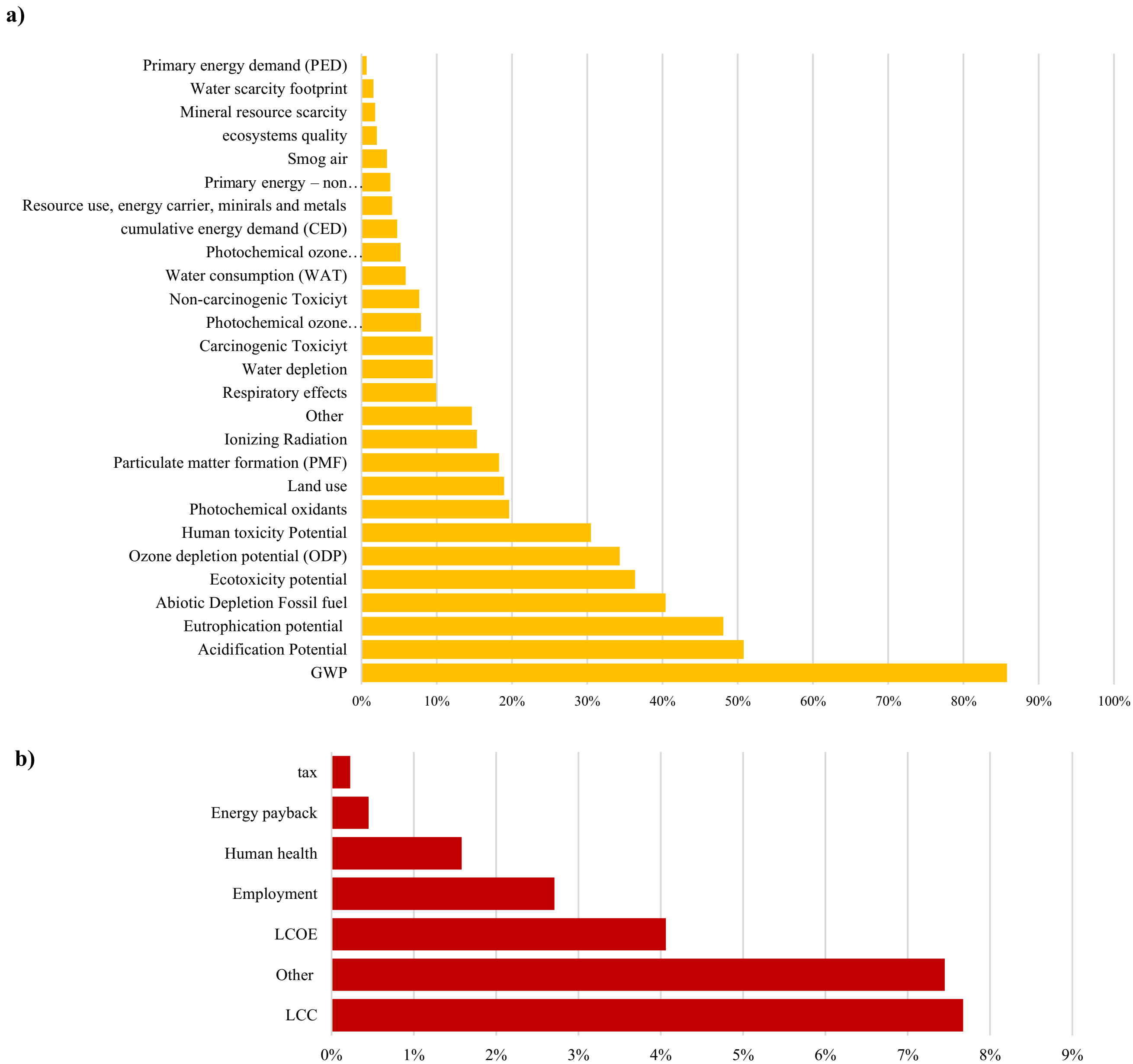

Fig. 7 Percentage of life cycle indicators **a**) environmental; **b**) socioeconomic

the fulfillment of the other. 'SDG-7' and 'SDG-13' remain closely linked and are impacted by electricity production. Due to this interconnectedness, there is a need to connect the research on sustainable electricity production and its value chains to SDGs as this impacts policy formation and the realization of several goals set by the United Nations. Hence, more studies are needed to bridge the identified literature gaps with interdisciplinary research between management, energy, natural science, social sciences, and public policy.

5 Empowering sustainable operations through sustainable value chain and life cycle thinking

The literature survey underscores the significance and prospective research directions for sustainable operations, underlining the utility of an integrated framework that merges sustainable value chain management with life cycle assessment to boost sustainability in electricity production and the broader energy sector.

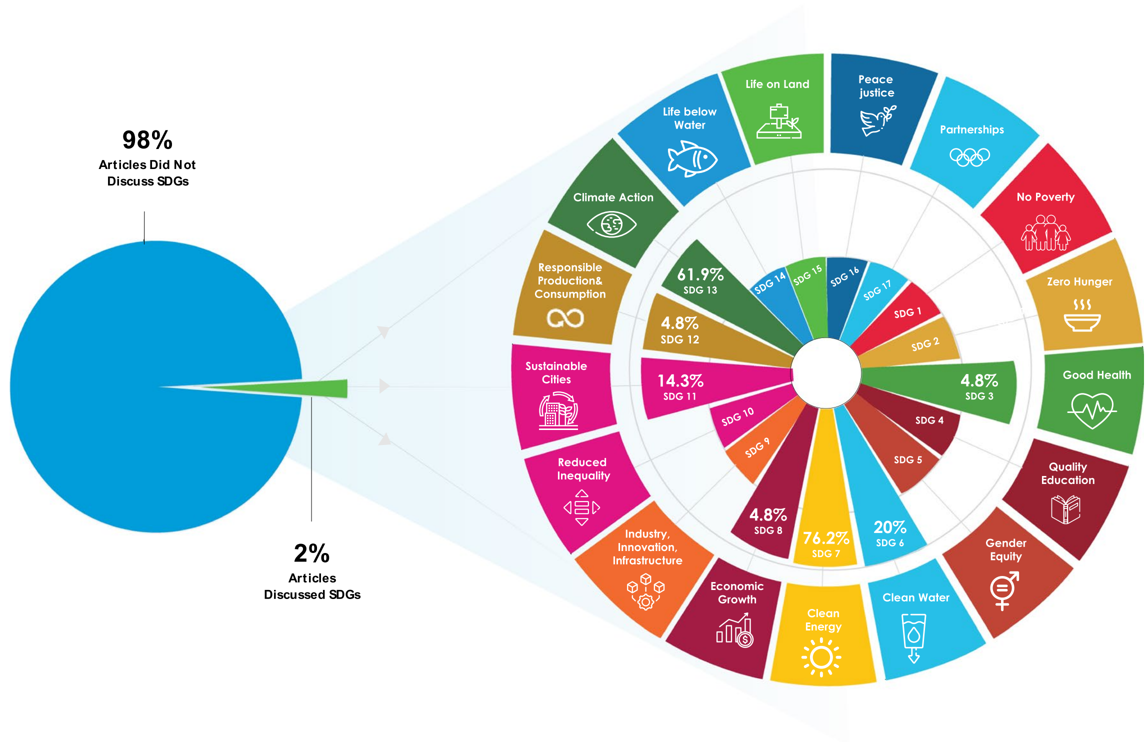

Fig. 8 SDG integration

5.1 Sustainability reporting and stakeholder engagement

As presented in Fig. 7a, most of the reviewed studies focused on environmental aspects, and a small portion analyzed the socioeconomic indicators for electricity production technologies (see Fig. 7b). Over 85% of articles investigated the carbon footprint of these technologies; however, only a handful of articles investigated important socioeconomic indicators, such as human health, employment, and cost. It is worth mentioning that P LCA and IO LCA methods are suggested by the Global Reporting Initiative (GRI) globally accepted sustainability reporting standards for the energy sector (Talbot and Boiral 2018), including electricity production and oil and gas. These methods can play a crucial role in enhancing Environmental, Social, and Governance (ESG) reporting of companies in the energy sector (Behl et al. 2022) by providing comprehensive and data-driven insights into the 3BL aspects of sustainable operations.

With the development of social impact databases such as the Social Hotspot Database (SHDP), Product Social Impact Life Cycle Assessment (PSIA), and United Nations Global Compact (UNGC), social LCA can help the energy production sectors to understand and report on the social aspects of their value chains, contributing to the rising 'S' in ESG reporting (United Nations Environmental Program 2020). This data-driven approach enhances transparency in the value chain operations of the energy sector and helps set and track social and governance-related ESG targets. Transparency in the value chain provides an immense opportunity to communicate the indicators related to society and governance (Chakraborty et al. 2023). This transparency builds trust and fosters communication between stakeholders, including customers, suppliers, producers, and regulators, who contribute to the development of sustainable operations in the energy sector. However, integrating social aspects into sustainable operations is highly limited and requires integrating interdisciplinary methods and disciplines to achieve socially responsible energy operations.

5.2 Sustainable procurement and supply chain transparency

Life cycle modeling aids sustainable procurement by offering extensive environmental and social data for electricity value chains, which consume considerable resources. Research by Wilhelm and Villena (2021) indicates that firms focusing on the 3BL of sustainability or engaging with vital stakeholders in their value chains are more inclined towards sustainable procurement practices. Hence, sustainable procurement bolsters sustainable operations through ethical product selection, risk reduction, setting sustainable procurement benchmarks, and engaging suppliers. Incorporating LCA in sustainable procurement strategies leads to environmentally conscious procurement decisions within the sustainable energy production sector, supporting sustainability goals and encouraging ethical business practices across the value chain.

Fig. 6b presents applied impact assessment methods in the environmental analysis of electricity production, such as CML, IPCC, Recipe, GREET, TRACI, and IMPACT2002+. These methods can provide a significant capability for operation managers to analyze the mid- and end-point environmental impacts of procurement decisions. This also enhances supply chain transparency in several ways, such as identifying impact hotspots and assessing associated supply chain risks. For instance, using the LCA impact assessment methods, it is possible to reveal vulnerabilities and risks within the energy value chain related to environmental issues (Feng et al. 2014) and help identify dependencies on resource-intensive materials, locations with higher environmental risks for material procurement, or suppliers with poor environmental and social performance. This information allows electricity production to assess and mitigate potential regional and global supply chain risks. The recently developed LCA impact assessment database and software shown in Fig. 6c (e.g., Ecoinvent, GABI, US LCI Database, and GREET) has considerable coverage of sector and region-specific data that can support the understanding of the region-specific environmental impacts of suppliers of electricity production.

5.3 Global value chain management

As presented in Fig. 6a, many papers used the P LCA, and a few articles applied IO LCA, hybrid LCA, and MRIO LCA models for electricity production, capturing their impacts throughout the value chains. As discussed earlier, adopting multiregional and hybrid life cycle models can enlarge the system boundary of value chains to a global scale. This enlarged system boundary will allow for a more holistic exploration of the interconnected global economy and various electricity production technologies' intricate socioeconomic and environmental impacts. These holistic LCA modeling techniques extend the analytical scope beyond local considerations, enabling a deeper understanding of the complex nature of energy's regional and global value chains (Wolfram and Wiedmann 2017). This, in turn, will provide invaluable insights into the widespread consequences of electricity production on both local communities and the broader global stage, assisting in formulating informed decisions and promoting sustainable energy operations and their management aligned with long-term socioeconomic and environmental objectives. Emerging global MRIO databases, including EXIOBASE (Budzinski et al. 2023), WIOD (Dietzenbacher et al. 2020), Eora (He et al. 2022), OECD Inter-Country Input-Output (ICIO) and GTAP (Owen et al. 2017), make it possible to map the global value chains of the energy sector. They are valuable resources for various applications, such as understanding the impacts of global operations in material purchasing, electricity transmission and distribution, and assessing associated global environmental footprints.

Although the P LCA models remain essential in providing detailed information about the life cycle processes involved in electricity production, they may not provide complete information about the economy-wide and value-chain-based global and regional impacts. Hence, addressing the macro-level issues and developing energy technology-specific policies to support global targets remain a vital application gap. Many reviewed studies did not use such holistic methods and databases (see Fig. 6a). For this reason, there is an opportunity for researchers in the operations management field to blend the life cycle models with the abovementioned multiregional databases for the upstream and downstream global sustainable operations of the energy sector.

5.4 SDG mapping

As shown in Fig. 8, only 2% of the reviewed articles linked their findings directly or indirectly to SDGs. These results hold great importance as they shed light on the tendency of researchers to underestimate the importance of linking the value chain of the sustainable electricity sector with SDGs. Research in sustainable energy production plays a significant role in shaping the policymaking agenda at the United Nations level. It also shapes decision-making in other areas of SDGs, including health, economic growth, climatic change, and education. The literature review on sustainable energy production revealed that some scholars link their findings to the SDGs while others do not. This creates a gap in how the results could help make sound policy decisions at the UN assembly on realizing the 17 goals. The United Nations SDGs can be directly linked to sustainable electricity generation (United Nations 2022). Many SDGs are directly influenced by the processes within the life cycle of electricity generation, such as clean energy (SDG-7), climate action (SDG-13), clean water (SDG-6), sustainable cities (SDG-11), economic growth (SDG-8), good health (SDG-3) and responsible production and consumption (SDG-12). Based on the findings from the review of the literature, 98% of the articles did not link their results to SDGs. These findings are critical since they reveal how researchers overlook the significance of connecting "sustainable energy" production to the SDGs. As Van Wassenhove (2019) discussed, integrating SDGs with sustainable operations management research can foster responsible, sustainable operations, and regulation-driven operations in the energy sector. Addressing social and environmental issues in line with the SDGs can help mitigate risks associated with legal issues or resource scarcity in operations. As presented in the UN Sustainable Development Compass (2015), by incorporating these goals into value chain management, the energy sector can reduce risks and improve the sustainability of its operations by guiding a sustainable energy strategy, promoting innovation in renewable energy, and aligning with global sustainability priorities.

5.5 Environmentally and socially responsible operations

Fig. 7b indicates that the integration of socioeconomic factors with emerging electricity generation technologies is still missing; however, it is essential to understand the shared-value aspect (discussed by Porter and Kramer 2011) of electricity generation strategies. As more attention shifts toward carbon footprints and climate change-related research, socioeconomic factors such as health and well-being, job creation, improved living standards, and income development remain a critical part of sustainable operations and creating a shared value through the consideration of the unwavering role of society (Kumar 2020). Corporate social responsibility (CSR) and sustainable operations are interrelated concepts that reflect the commitment to addressing social and environmental issues. As Lee and Tang (2018) discussed, environmentally and socially responsible value chains are critical for sustainable operations. However, most reviewed studies were oriented toward environmental impact analysis, which created a socioeconomic assessment gap in the literature. To ensure CSR applications in the electricity production sector, critical socioeconomic indicators such as human health, employment, and income should form part of the extension of LCA studies, indicating the need for researchers to examine social and economic elements and environmental issues. Therefore, making socioeconomic indicators part of value chain sustainability, social LCA provides a better comparative analysis of different sources of electricity generation technologies based on their social performances (Laureti et al. 2019). The UN's 'Environment Development Program's Life Cycle Initiative offers comprehensive procedures for the social LCA of production systems, which applies to the social sustainability of electricity generation technologies (Fortier et al. 2019). Research efforts in this area are minimal. Addressing this gap will increase knowledge of health and safety, employment, and the economy, which could be crucial to achieving socially responsible sustainable operations in the energy sector.

5.6 Integrated decision making

A vital gap in the literature relates to the integrated decision-making approaches and macro-level decision support. Most of the studies did not utilize integrated modeling. This appears when overlooking the integration of the model to decision-making techniques and the type of database used, which can only offer life cycle results for a portion of the value chain components. As presented in Fig. 6d, only 36% of the papers expanded the 3BL data with support techniques, such as forecasting, MCMD, and sensitivity analysis. Despite this omission, applying modeling approaches remains helpful in interpreting, clarifying, and articulating a unified objectives system. These techniques are, in turn, essential to the critical stakeholders in informing policy decisions around electricity production technologies and the realization of SDGs. The LCA maps the environmental and socioeconomic impact hotspots within the production value chains. At the same time, operations research can develop decision models that incorporate 3BL data and utilize it alongside operations research methods, such as multi-objective optimization, linear programming, nonlinear programming, supply chain optimization, simulation, and decision analysis. Environmental, social, and economic data can be merged with these techniques to support the decision-making of sustainable operations. Tang and Zhou (2012) also highlight the importance of applying Operations Research/Management Science techniques to balance the economy, the environment, and society in environmentally and socially sustainable operations. In a recent study, Tang (2024) discussed the importance of social issues in value chains and pointed out the importance of socially responsible operations for decision science researchers.

From a business perspective, data analytics and visualizations are essential. For example, Microsoft (2023) built a software called 'Sustainability Manager,' which is used for carbon footprint and ESG reporting. IBM (2023) also launched a new software called 'Envizi,' which is integrated with artificial intelligence and used to manage and report carbon footprints and ESG performance within the company's value chains. Both tools used the LCA and IO LCA methods and several databases such as Ecoinvent, Recipe, OpenLCA, and U.S. EPA life cycle inventory (see Fig. 6c) to estimate the value chain-wide sustainability impacts to improve the responsible operations in companies, including energy. This shows that more LCA models and databases will be used to build sustainable value chains. However, as shown in Fig. 6d, a lack of integrated decision-making in electricity production appears to be another critical research gap for the management society that can be addressed by interdisciplinary research between sustainability, decision sciences, operations research, and management sciences.

5.7 Circular economy and closed-loop supply chains

Given the escalating global reliance on materials within the electricity sector, the adoption of sustainable value chain management, which employs life cycle modeling, emerges as an indispensable instrument for the formulation and execution of closed-loop supply chain systems and the promotion of circular economy strategies. These measures hold the potential to curtail waste generation and mitigate the environmental footprint associated with energy production along the energy value chains. This includes determining the best recycling, remanufacturing, or disposal methods to minimize environmental impact and support the transition towards circular economy practices in electricity production technologies. A circular economy becomes vital for sustainable energy transition; however, transitioning to these technologies results in a massive demand for critical materials, such as lithium, cobalt, and rare earths. Waste problems related to solar power plants (Xu et al. 2018) and wind turbines (Jensen and Skelton 2018) are growing, and designing closed-loop supply chains by implementing strategies to reuse and recycle solar panels and components at the end of their life cycle becomes critical.

Another example of a closed-loop supply chain is the Kalundborg Industrial Symbiosis Project, located in Denmark, an example of industrial ecology and circular economy principles put into practice in the sustainable operations of various interconnected industries (Jacobsen 2006). It is a unique example of how industrial symbiosis and circular economy principles can create sustainable operations for industries. For example, excess heat from electric power plants is used to heat homes and industrial processes. Overall, circular economy practices through the reuse of waste and heat, the recycling of critical materials embodied in renewable energy technologies, and the use of low-carbon materials will be inevitable for achieving sustainable operations in the energy sector. Yang et al. (2023) emphasized that the LCA is required to build circular flows of critical materials; however, Fig. 6a indicates that less than 5% of reviewed studies investigated resource, metals, and minerals use, which remains another research gap.

5.8 Carbon footprint accounting and regulatory compliance

The review findings demonstrate that using LCA makes it feasible to map carbon footprints in the value chains of electricity production, aiding in identifying climate risks that could jeopardize its operations' long-term financial and environmental sustainability. As shown in Fig. 7a, most studies focused on global warming potential, directly linked to carbon emissions, and explored the value chain-sourced carbon footprints of electricity production. Scope 3 emissions, as outlined by the corporate value chain (scope 3) standards (GHG 2011), encompass all indirect emissions occurring in the production system's value chain. LCA is employed to analyze scope three emissions within the value chains and applied to electricity production technologies (Hertwich and Wood 2018), with governments and regulatory bodies increasingly requiring the electricity production sector to measure and mitigate value chain carbon footprints.

LCA aids the energy sector in adhering to mandatory regulations. For instance, as part of the European Green Deal, by the end of 2024, the Carbon Border Adjustment Mechanism (CBAM 2023) introduced by the European Union acts as a crucial tool for establishing fair carbon pricing for emissions from carbon-intensive sectors, including electricity, imported into the EU. This mechanism aims to encourage cleaner energy generation in non-EU countries. California's State Senate (2023) passed a bill mandating large energy companies to report their scope 1, 2, and 3 emissions, increasing pressure to decarbonize their value chains. The legislation addresses a vital issue in climate regulation by requiring companies to measure and report scope three emissions. The U.S. Securities and Exchange Commission (SEC 2022) is preparing regulations to standardize climate-related information disclosure. If a corporation has established targets for mitigating scope three sourced carbon footprints, it must disclose carbon footprints from upstream and downstream value chain activities. Notably, new regulations by the UK Financial Conduct Authority (FCA 2022), the EU's Taxonomy Regulation and Green Deal (European Commission 2020), and the U.S. SEC (SEC 2022) will enforce mandatory climate risk disclosure by 2025, aligning with the guidelines set by the Task Force for Climate-Related Financial Disclosure (TCFD 2021).

In summary, LCA, IO LCA, and MRIO LCA are suggested by the Global Report Initiative (GRI) Sustainability Reporting Standard (Ismail et al. 2021) and the UN's Sustainable Development Compass (2015) as globally accepted methods for accounting and managing scope three emissions within the electricity sector, responsible for nearly 30% of global GHG emissions. These methods are suggested by international standards and international organizations as systemic tools to identify, measure, and reduce the indirect emissions associated with electricity value chains, contributing to reduced financial risks and responsible and carbon-neutral sustainable operations at regional and global scales.

6 Conclusions and future remarks

This study introduces an innovative framework that marries sustainable value chain management with the Life Cycle Sustainability Assessment (LCSA) to foster sustainable operations within the realm of electricity production technologies. By crafting a tri-phased framework that weaves together three distinct life cycle methodologies, this paper not only undertakes a thorough review but also showcases practical applications of this interdisciplinary approach. The essence of this framework lies in its practical implications, particularly in enhancing sustainable operations in electricity production. This is achieved through strategic initiatives such as enhancing sustainability reporting and engaging stakeholders more effectively, promoting transparency in sustainable procurement and supply chains, managing global value chains with a focus on sustainability, embedding corporate social responsibility into operations, facilitating integrated decision-making, advancing the circular economy and closed-loop supply chains, managing carbon footprints alongside regulatory compliance, and aligning operations with Sustainable Development Goals (SDGs).

The practical significance of this research is manifold, offering a pathway for the integration of socioeconomic factors alongside environmental considerations, thereby enriching the discourse on sustainable operations management within the energy sector. It calls for the development of circular production systems, underscoring the critical role of closed-loop supply chain design, and highlights the necessity of mapping SDGs to value chain activities as pivotal areas for future inquiry. The findings from this research are poised to provide researchers and practitioners alike with profound insights into the current landscape of LCA and sustainable value chain management within electricity production, encompassing emerging energy technologies. This endeavor to broaden the scope of sustainable operations management research to include Triple Bottom Line (3BL) sustainable value chains and life cycle thinking promises to foster interdisciplinary collaboration across fields such as engineering, the social and natural sciences, and policymaking. Echoing the sentiments of Kleinderfor et al. (2005), this paper emphasizes the need for sustainable operations to converge with disciplines like industrial ecology, leveraging the strengths of the Operations Management Society to address this imperative.

Furthermore, the expansion into sustainable value chain management and life cycle thinking addresses a critical skills gap identified within the industry. A survey by Microsoft and Boston Consulting Group highlights the pressing need for expertise in carbon accounting, sustainable value chain management, and climate-specific digital tools (Microsoft 2022), underlining the potential of this research to bridge the gap between academic research and the skills demanded by the energy industry for sustainability. In conclusion, the Operations Management Society possesses the requisite theories, methodologies, tools, and scholarly excellence to spearhead interdisciplinary research endeavors that promote sustainable operations. Given the ongoing challenges posed by global energy demands, environmental degradation, and geopolitical tensions, management scholars must re-evaluate the environmental and social pillars of sustainability. By more closely integrating with engineering, social, and natural sciences, the community can lay the groundwork for a sustainable energy future, thereby responding to the urgent call for sustainability in operations management.

Declarations

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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