

Social sustainability assessment of energy systems: research status and opportunities

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Abstract— In pursuit of sustainable development, the energy sector must consider the three basic pillars of sustainability: economic, environmental, and social. However, research on the social sustainability pillar has been lagging relative to the two other pillars. This paper explores the status and opportunities in the field of social sustainability assessment of energy systems through a systematic literature review of 122 peer-reviewed articles. The paper primarily highlights the common research gaps identified in existing literature, the definition of social sustainability as defined by previous research, and the tools used to measure social sustainability. The findings of this paper can guide researchers and other stakeholders about future research directions and serve as a knowledge base in the field of social sustainability assessment of energy systems.

Keywords— *energy systems, social sustainability, sustainability assessment*

I. INTRODUCTION

Ensuring sustainability has become imperative over the last century due to the degradation of the environment and depletion of earth's resources. This is especially important to the energy industry since it is the backbone of progress and modern society, but simultaneously is the sector with the greatest emissions of greenhouse gases and other pollutants. Additionally, energy systems play a major role in economic progress and greatly impact society. Thus, ensuring sustainability in energy systems encompasses the three fundamental pillars of sustainable development: economic, environmental, and social.

Over the last decades, a growing number of research on sustainability assessment has been conducted. Among the three pillars, the social aspect has received lesser attention due to various reasons, such as lack of a common definition of the concept and the absence of mature quantitative and qualitative tools to measure social sustainability, among others [1]–[3]. An overview of previous literature on energy system sustainability assessment, with a focus on the social pillar, is therefore necessary to investigate this field further.

Previous literature on general sustainability assessment of energy systems include the works of [4]–[10]. Meanwhile, a number of review articles particularly focused on social sustainability. The work of [1], presented an exhaustive list of 101 social impacts of energy systems. A second [11], compared social impact assessment (SIA), socio-economic impact

assessment (SEIA), and social life cycle analysis (SLCA). A more recent work in social sustainability assessment of energy systems is [12], which developed a sustainability assessment framework for energy systems based on previous studies, focused not only on energy but also other sectors, such as manufacturing, supply chain, and construction. Additionally, [12] identified three gaps in literature: no standard definition of social sustainability, lack of studies about social sustainability aspects, and absence of comprehensive review of social sustainability indicators applied in the energy sector. However, their work highly focused on the third research gap and partially covered the second one.

Overall, four major gaps are identified in previous literature. First, existing literature reviews [4]–[10] focused on general sustainability and have only discussed social sustainability to a certain extent. Another limitation is the limited number of reviewed articles, such as in [1], [10]. This could potentially limit the information relevant to the field of social sustainability assessment. On the other hand, although [12] reviewed over 100 articles, not all articles are within the energy sector context.

Meanwhile, some review articles covered only specific tools. Reference [4] focused on multi-criteria decision analysis (MCDA), [5] focused on combining MCDA with life cycle analysis (LCA) approach, and [11] focused on only SIA, SEIA, and SLCA. Additionally, the work of [8] focused on evaluating only the negative impacts of energy systems. Although [5] and [9] focused on general methodologies, they recommend to further investigate and analyze social sustainability assessment tools. Finally, some articles focused only on a particular energy type; the literature reviews of [6], [7], [11] focused on bioenergy while [8] focused on solar energy.

Recognizing the observed gaps in the present literature, this work aims to present the research status and opportunities in the field of social sustainability assessment of energy systems by reviewing the most-relevant 122 scientific papers. The main contributions of this work are the summary and analysis of the following: geographic origin of the articles and case studies; how previous literature has defined social sustainability in the context of sustainability assessments of energy systems; research gaps and aims of previous studies; common energy types considered for assessment; and common methodologies used for social sustainability assessment.

II. METHODS

This study performed a literature review to investigate the status of social sustainability research in the context of energy systems. Fig. 1 shows the steps conducted in this study while the remaining parts of this section detail each step.

The study commenced with a literature search with the Scopus database using “social sustainability” and “energy systems” as the main keywords. Only original research articles and review articles were included in the search. Time period was not restricted to allow earlier articles to be included in the review. The search resulted in 3,162 articles.

To consider only relevant studies to be included in the review, two levels of screening were performed. The first level involved reading the title and abstract of the articles. An article was considered relevant if the article’s title and/or abstract implies that (1) the article focuses on energy generating systems and (2) the article includes an assessment of the system’s social sustainability. No restriction on energy type and tool of assessment was imposed. A total of 282 articles passed the first level of screening.

Afterwards, the full texts of the remaining articles were examined at the second level of screening. This was done to confirm if the remaining articles adhere to the main criteria mentioned in the first screening. Additionally, an article was also excluded for the following reasons, among others: the article solely focused on either the positive or negative social impacts; the article merely refers to previous literature when discussing social sustainability – in other words, the article does not perform its own assessment; or the article does not clearly discuss its methods to measure social sustainability. Some of the review articles discussed in the introduction section were also excluded to avoid redundancy and overlap. Furthermore, 17 articles were also excluded because the authors were not able to access a full copy of the research during the time of the study. A total of 122 articles have passed the second screening and were included in the literature review.

Finally, various information was extracted from the pool of articles included in the review. This included: (A) geographic information about the article’s origins and the location of case studies; (B) research gaps and aims of the article; (C) definitions of social sustainability; (D) energy types considered in the assessments; and (E) methods to perform sustainability assessment.

This research used Microsoft Excel and Covidence, a browser-based tool, to collate and analyze information collected from the relevant articles.

III. RESULTS AND DISCUSSION

A total of 122 articles, comprising 114 original research articles and eight review articles, were covered in the detailed analysis component of this review. Fig. 2 shows the yearly number of articles included in the literature review. It can be observed that more research has been done in the recent years and is line with the general trend of sustainability research in the recent years.

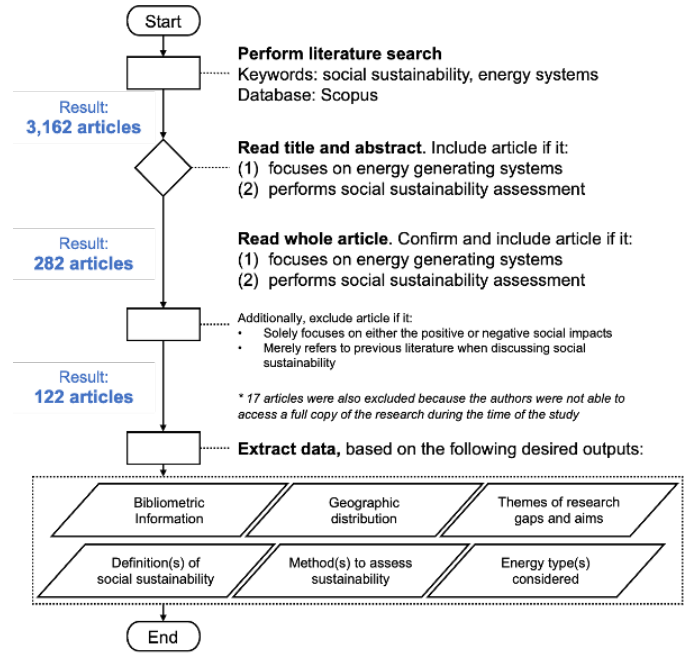


Fig. 1. Literature review methodology.

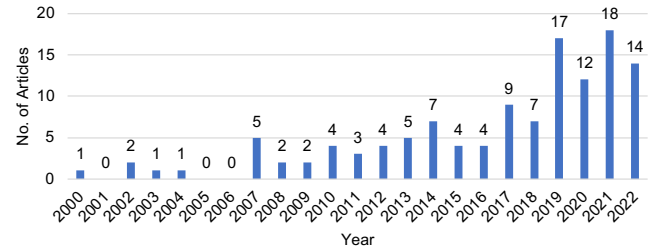


Fig. 2. Number of articles included in the literature review per year.

A. Geographic Distribution of Articles and Case Studies

Out of the 122 articles covered in this review, more than half originate from Europe and Asia. Shown on Table I is the article count per region where articles originate from.

In terms of case study application, 100 articles conducted a case study. Similar with article location, case studies were usually conducted in the Asia and Europe. The remaining 22 articles either did not perform a case study or did not explicitly specify the location. Table II shows the article count per region where case studies were conducted.

TABLE I. REGIONS WHERE ARTICLES ORIGINATE FROM

Region	Article Count	Percentage
Europe	59	48%
Asia	36	30%
North America	9	7%
Africa	9	7%
South America	5	4%
Oceania	4	3%

TABLE II. REGIONS WHERE CASE STUDIES WERE CONDUCTED

Region	Article Count	Percentage
Asia	38	31%
Europe	32	26%
Africa	16	13%
South America	8	7%
North America	4	3%
Oceania	2	2%

B. Research Gaps and Aims

The overarching research gap and aim that previous research has tried to address is the universal need to evaluate the sustainability of energy systems. Aside from this, four other research gaps and aims have been observed. These are not mutually exclusive; an article can have multiple research gaps/aims.

Several studies have attempted to try a new approach/method for sustainability assessment. For example, [13] and [14] explored the application of data envelopment analysis in sustainability assessment. Other studies sought to improve MCDA by exploring combinations of weighting and aggregation techniques [15]–[17]. While the works of [18], [19] incorporated life cycle approach to sustainability assessment.

Meanwhile, other articles tried to address the lack of sustainability assessment studies in a specific country or region. Presented in Table III are the locations where previous studies were contextualized.

Rather than specific locations, the work of [13], [16], [54] shifted their focus to developing countries. While [55]–[57] situated their research in the European context. References [58], [59] focused on remote communities. The work of [60] involved countries along the Belt and Road, while [61] focused on countries in the Arctic region.

Aside from location-related research gaps, other studies sought to focus on an energy type, particularly renewable energy, as shown in Table IV.

Finally, fewer articles, 28 out of 122, have specifically focused on addressing the lack of studies in the social aspect of sustainability assessments. Eight of those studies solely or heavily focused on social sustainability [14], [20], [40], [56], [68], [75], [78], [86]. The remaining articles performed a general sustainability assessment encompassing different sustainability pillars, but also emphasized the role of the social pillar [21], [22], [36], [47], [58], [67], [69], [70], [73], [83], [87]–[96].

C. Definition of Social Sustainability

More than half of the studies (74 studies) covered in the review did not explicitly provide a definition of social sustainability. They either immediately proceeded to enumerating the indicators or methods they used to measure social sustainability, or just referred to a broad statement concerning “social impacts” or “influences of the energy system to society”, without defining what those impacts or influences are.

TABLE III. LOCATIONS THAT PREVIOUS STUDIES FOCUSED ON

Region	Article Count
Asia-Pacific	Australia [20], Bangladesh [21], [22], China [23]–[25], Greece [26], India [19], [27], [28], Indonesia [29], [30], and Iran [31]–[33], Malaysia [34], Pakistan [35], Sri Lanka [36], Turkey [37]
Europe	Lithuania [38], Portugal [39], [40], Serbia [41], United Kingdom [42]–[44]
Africa	Algeria [45], [46]–[48], Niger [49], Nigeria [50], South Africa [17], Zambia [51]
South America	Chile [52], Peru [53]

TABLE IV. ENERGY TYPES THAT PREVIOUS STUDIES FOCUSED ON

Region	References
Biomass	[31], [40], [48], [62]–[77]
Solar	[20], [42], [49], [52], [78]–[80]
Hydropower	[30], [60], [81]
Nuclear	[33], [44], [82]
Wind	[83]–[85]

As the concept of social sustainability differs based on authors’ perceptions, it can be implied that social sustainability in these studies is reflected by the indicators chosen by their authors.

Meanwhile, the remaining 48 studies gave a brief and simple definition of social sustainability before listing the indicators or methods they use to evaluate social sustainability. These definitions were broadly categorized according to six main themes, as presented in Table V.

Aside from the six main themes, other minor themes were also observed. These include improving education levels [24], [53], [59], [69], [75], [96], [104], [105], [113], bridging the gender gap [104], [105], [113], ensuring human rights [68], [114], and strengthening governance and public involvement [46], [48], [53], [68], [97], [113].

D. Energy Types Considered

More than half of the articles covered in this literature review have included solar energy systems in their assessments. This is followed by biomass and wind energy technologies. Generally, more studies have focused on the sustainability assessment of renewable energy technologies. Fig. 3 shows the frequency of articles that have considered each energy type.

When energy type is analyzed together with the identified research gaps and aims found in previous literature, the general observation is that there is an opportunity to explore social sustainability further in the context of some renewable energy technology (hydropower, geothermal, ocean/tidal) and most non-renewable energy technologies. The percentage of studies that tried to address the research gaps while considering different energy types are shown in Fig. 4.

Meanwhile, Fig. 5 shows the percentage of studies that considered various energy types vis-à-vis the social sustainability themes found in previous literature. Overall, it is

TABLE V. MAIN THEMES OF SOCIAL SUSTAINABILITY DEFINITION FOUND IN LITERATURE

Social Sustainability Theme	Article Count	References
<i>Social development/well-being and quality of life</i> : sustainable energy systems enrich the well-being of the communities and people's quality of life.	25	[14], [25], [33], [51], [56]–[59], [69], [75], [81], [86], [92], [94], [96]–[106]
<i>Socio-economic benefits</i> : sustainable energy systems improve the livelihood of society by providing jobs and contributing to local/regional development.	24	[13], [14], [26], [33], [48], [59], [68], [69], [75], [77], [78], [94]–[96], [99], [100], [103], [104], [106]–[111]
<i>Health and safety</i> : sustainable energy systems improve human health and ensure safety across its life cycle stages	14	[33], [48], [53], [59], [68], [75], [77], [92], [99], [104], [105], [107], [112], [113]
<i>Energy access, quality, and reliability</i> : sustainable energy systems are accessible and reliably provide the demand of the users.	13	[13], [20], [26], [27], [68], [69], [96], [97], [100], [102], [108], [114], [115]
<i>Social acceptance</i> : sustainable energy systems and technologies are socially acceptable to the community or the public	11	[13], [20], [37], [69], [75], [81], [86], [94], [99], [113], [114]
<i>Social equity</i> : sustainable energy systems help close disparities in terms of socio-economic status, energy access, and resources, among others	10	[14], [26], [33], [52], [53], [77], [92], [98], [105], [113]

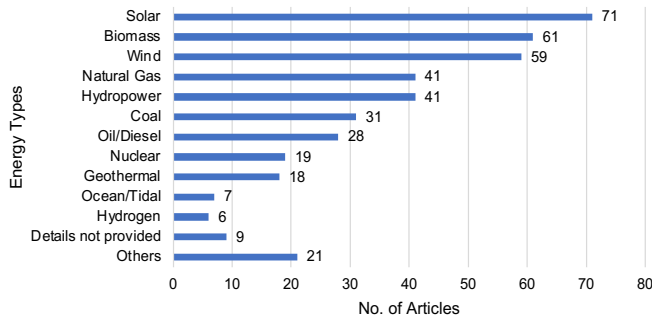


Fig. 3. Number of articles showing energy types considered in sustainability assessments.

	n	RESEARCH GAPS / AIMS			
		To try a new approach/method for sustainability assessment	To address lack of studies in a specific country or region	To address lack of studies for a specific energy technology	To address the lack of studies in the social aspect of sustainability assessments
ENERGY TYPE	n	68	48	48	28
	Solar	62%	60%	33%	61%
	Biomass	48%	40%	56%	61%
	Wind	48%	50%	29%	50%
	Hydropower	34%	42%	25%	18%
	Natural Gas	31%	40%	17%	32%
	Coal	21%	31%	15%	21%
	Oil/Diesel	24%	31%	8%	21%
	Nuclear	10%	23%	13%	18%
	Geothermal	17%	13%	10%	7%
	Ocean/Tidal	7%	6%	0%	4%
	Hydrogen	3%	2%	8%	7%
	Details not provided	10%	10%	2%	0%
	Others	21%	23%	8%	11%

Fig. 4. Percentage of studies considering different energy types and research gaps/aims.

		SOCIAL SUSTAINABILITY THEMES									
		Social development/well-being, quality of life	Socio-economic benefits & employment	Health & Safety	Energy Access & Reliability	Social Acceptance	Social Equity	Education	Involvement and Governance	Gender	Human Rights
n		25	24	14	13	11	10	9	6	3	2
ENERGY TYPE	Solar	64%	63%	50%	69%	55%	60%	56%	50%	67%	50%
	Biomass	64%	58%	71%	62%	55%	60%	56%	67%	67%	100%
	Wind	52%	46%	36%	62%	36%	30%	44%	50%	33%	50%
	Hydropower	48%	25%	50%	31%	36%	40%	56%	50%	67%	50%
	Natural Gas	28%	25%	21%	15%	27%	30%	11%	17%	0%	50%
	Coal	24%	21%	14%	15%	18%	20%	11%	17%	0%	50%
	Oil/Diesel	24%	17%	7%	23%	18%	20%	11%	33%	0%	50%
	Nuclear	20%	13%	14%	15%	18%	20%	11%	0%	0%	50%
	Geothermal	16%	17%	29%	15%	36%	20%	11%	0%	33%	50%
	Ocean/Tidal	16%	13%	21%	0%	0%	10%	22%	0%	33%	0%
	Hydrogen	0%	0%	7%	0%	0%	0%	0%	0%	0%	0%
	Details not provided	8%	8%	7%	8%	9%	20%	11%	17%	33%	0%
	Others	16%	17%	14%	15%	9%	10%	0%	0%	0%	0%

Fig. 5. Percentage of studies considering different energy types and social sustainability themes.

observed that most themes have been considered in studies that included solar, biomass, and wind energy types in their assessment. The minor themes (education, involvement and governance, gender, and human rights) can be further explored in non-renewable energy technologies and other renewable energy technologies.

E. Methods to Perform Sustainability Assessment

Various methods exist to conduct sustainability assessments. To allow a more streamlined discussion about the methods used by the articles included in this literature review, three major categories of assessments are used, which is based on the categorization of [116]. The three categories are:

- Indicators/indices are simple, usually qualitative measures that reflect economic, social, and/or environmental state of the system. Indicators/indices can be integrated (where different sustainability dimensions are aggregated) or non-integrated (where different sustainability dimensions are mutually exclusive)
- Product-related assessments comprise methods that focus on flows and processes across the system analyzes. A common example of this type is the life cycle analysis or a similar method; as such, this type usually caters the environmental aspect. However, life cycle tools for economic (life cycle costing) and social aspects (social life cycle assessment) have also emerged.
- Integrated assessments usually tend to policy or project decision-making and often evaluate different scenarios or alternatives. This type generally performs systems analysis approaches to incorporate all sustainability dimensions. Common examples of this type of assessment are multi-criteria decision analysis, conceptual modelling, system dynamics, risk and uncertainty analyses, vulnerability analysis, cost-benefit analysis, and impact assessments.

Table VI summarizes all the studies covered in this review according to the three categories. Hybrid methodologies were also observed, such as the mix of integrated assessment with non-integrated indicators or with product-related assessment concepts.

TABLE VI. SUMMARY OF METHODS USED FOR SUSTAINABILITY ASSESSMENT

Category	Tool Details	References
Indicators and Indices	Integrated indices	[27], [57], [98], [104], [117]
	Non-integrated indicators	[20], [22], [30], [31], [33], [44], [46], [52], [53], [61], [68], [76], [78], [83], [96], [103], [113], [118]
Product-related assessments	Cumulative social effects assessment framework	[75]
	LCA and input-output analysis	[90]
	LCA, LCC, and SLCA	[89]
	SLCA	[40], [80]
Integrated Assessments	MCDA	[15]–[17], [21], [23], [25], [26], [29], [32], [34]–[36], [38], [45], [47]–[50], [54], [55], [58]–[60], [62]–[65], [71], [72], [74], [81], [82], [85], [87], [88], [94], [95], [99], [100], [102], [106]–[108], [112], [119]–[131]
	DEA	[14]
	DEA and MCDA	[13]
	Fuzzy logic and other techniques	[66]
	Fuzzy logic and MCDA	[84], [97]
	Impact assessment	[105]
	MCDA and grey relational analysis	[111], [114]
	MCDA and interviews	[43], [77]
	SD	[73]
	SD and MCDA	[51]
	Multi-objective optimization	[37], [67], [92], [109], [115], [132]–[134]
	SWOT and MCDA	[24]
Hybrid: Integrated assessment and non-integrated indicators	SWOT analysis and non-integrated indicators	[69]
	Simulations and non-integrated indicators	[93]
	Interviews and non-integrated indicators	[28], [56], [86]
	Fuzzy logic and integrated index	[91]
Hybrid: Integrated assessment and product-related assessment	MCDA and life cycle approaches	[18], [19], [70], [79], [135]
	MCDA, life cycle approaches, and multi-regional input output modeling	[110]
	Multi-objective optimization and life cycle approaches	[136]
Hybrid: Product-related assessment and non-integrated indicators	LCA and non-integrated indicators	[39], [42], [101]

Notes: DEA – data envelopment analysis; LCA – life cycle analysis; LCC – life cycle costing; MCDA – multi-criteria decision analysis; SD – system dynamics; SLCA – social life cycle analysis; SWOT – strengths, weaknesses, opportunities, threats

Overall, most of the articles have employed MCDA as its main tool to perform sustainability assessment. Some common MCDA approaches are analytic hierarchy process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), ViseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and fuzzy MCDA, among others. To measure social sustainability, some articles have combined MCDA with other tools, such as strengths-weaknesses-opportunities-threats analysis [24], fuzzy logic [84], and system dynamics [51]. Readers interested in using MCDA as a sustainability assessment tool are directed to the work of [4]; the authors provide detailed background about the general MCDA steps and the different weighting, aggregation, and ranking techniques.

F. Simplified Framework for Social Sustainability Assessment

On the basis of the review to this point, a simplified framework for social sustainability assessment was developed as shown in Fig. 6. This framework can be used as a quick guide by stakeholders who will conduct social sustainability assessments of energy systems.

First, it is fundamental to have a clear definition of social sustainability. This work summarizes the six main themes that reflect the definition that has been used in previous literature: social well-being and quality of life, socio-economic benefits, health and safety, energy access and reliability, social acceptance, and social equity.

Aside from defining social sustainability, it is essential to select an appropriate tool to evaluate social sustainability. This work presents a list of various tools that previous literature has used. The scope, advantages, and disadvantages of the most common tools have been presented in previous literature [4], [11], [116]. The definition of social sustainability as well as the chosen assessment method(s) will eventually help develop the sub-criteria and the indicators that are needed to perform the assessment.

The social sustainability assessment is influenced by research gap or motivation that will guide the formulation of study objectives. Based on literature, there is a wide range of reasons why social sustainability assessment of energy systems is performed, such as improving or trying a new assessment method, contextualizing the assessment in a particular country or region, investigating a specific energy technology, and/or deepening the knowledge on social sustainability assessment, among others.

Other matters influence the overall assessment. For example, stakeholder interests influence the goal and direction of the assessment activity. Selection and development of criteria as well as available data source also affect which indicators to be used eventually. These aspects, which are currently considered in future work, are crucial to develop a more comprehensive and holistic framework.

IV. CONCLUSIONS

Sustainable development is marked by its three pillars: economic, environmental, and social. Recognizing the lack of detailed studies that focus on the social aspect of energy systems, this paper presents a literature review comprised of 122

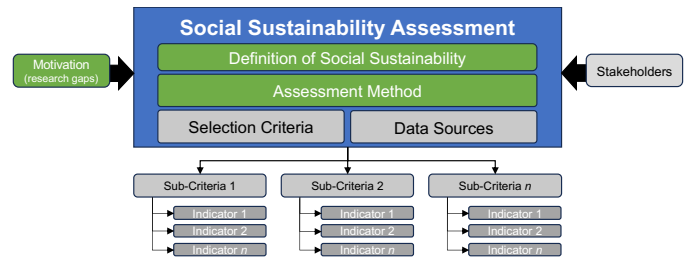


Fig. 6. Simple conceptual framework for social sustainability assessment of energy systems.

research articles. The following are the highlights of the findings:

- Asia and Europe are the main sources of articles in this field. Likewise, majority of the case study applications have also been performed in these regions.
- Previous studies try to address one or more of the main themes: to explore a new approach for assessment, to address lack of studies in a specific country or region, to address lack of studies on a specific energy technology, and/or to address the lack of studies in the social sustainability aspect.
- Even though more than half of the articles covered do not comprehensively define social sustainability, several themes — social well-being and quality of life, socio-economic benefits, health and safety, energy access and reliability, social acceptance, and social equity — have been observed from articles that were able to provide a definition.
- Solar, biomass, and wind energy technologies were the main types involved in the reviewed studies.
- Integrated assessments are the most used assessment method, with MCDA leading this category. Various indicators and indices as well as product-related assessments have also been used, which can also be used simultaneously with MCDA.

Although the concept of green energy systems has been highly attributed to the environmental aspect, it is hoped that these findings serve as a knowledge base for researchers and stakeholders to perform more a well-rounded energy system sustainability assessment. In particular, the findings provide the main themes surrounding social sustainability and identify the overall tools to measure social sustainability. Additionally, research gaps — reflected in the intersection between themes and energy types, for example — provide researchers opportunities to conduct future studies.

The field of social sustainability assessment of energy systems is still evolving. As such, an extension of this research is being conducted to focus on indicators along with the tools to qualify and quantify social sustainability in this context.

ACKNOWLEDGMENT

A.L.G.L. thanks the Japanese Government for the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) Scholarship for funding his doctoral studies.

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