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Social sustainability assessments of industrial level solar energy: A systematic review

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ABSTRACT

This study discusses the application of Social Life Cycle Assessment on existing Solar Thermal Energy and similar energy systems used in industrial supply chains. Practitioners assessing STE supply chains using the current assessment framework appraised social issues such as fair payment and employee health and safety by collecting quantitative data on employee salary and social risk. Qualitative assessment methods were also deployed through community questionnaires to measure social acceptance and audits to evaluate health and safety policy compliance. The resulting data was processed using Type 1 protocol, a model which measures social performance to assess the magnitude of a company's social impact on its stakeholders. This parameter was found to take regional and universal social standards as neutral criteria to grade the level of policy compliance, regarding fairness of employee pay and client relationships. Qualitative feedback from social audits and interview dialogue was also compared to these standards, to determine the level of a company's compliance with social policy. Our literature review revealed that current practitioners provided limited elaborative commentary on an organisation's social performance within a given case study, limiting managerial insight into observed gaps in social performance. This was found to be rooted in the lack of comprehensive and empirically driven methodology adopted by most practitioners. Our research aims to develop a framework that will provide more critical insight for managerial decision-making in order to improve the social sustainability of newly developed STE and related renewable energy systems.

1. Introduction

According to the Bruntland report, three fundamental constituents of the concept of sustainability [1]. The first two major constituents of sustainability; environmental and economic, have been very well investigated in the literature. With every technological innovation in the drive for more energy and emission-efficient industrial supply chains, scientific work to assess the attributable level of sustainability within the first two constituents is published in high volumes according to the best of the author's knowledge. Such novel and emerging energy-generating technologies include Solar Thermal Energy (STE) systems, crucial to European Union's 2050 carbon-reducing strategies, aiming to reduce greenhouse gas emissions by 80 % [2]. Guillen-Burrieza & Konigshofer reported that the influx of advanced technological development of solar thermal systems as a form of renewable energy source for industrial processes, known as Solar Heat for Industrial Processes (SHIP) developments, has dramatically increased to fulfil the intense heating demands of medium to high-temperature processes of 200-400 °C [2].

A particular development referred to in the report calls for current and future scenarios of SHIP's social sustainability, the third constituent of sustainability. These scenarios should be designed to determine the social feasibility of integrating SHIP systems into the EU energy sector [2]. The report highlights the novelty and ingenuity of the information that will be demonstrated by these scenarios, adding significant value towards the feasibility consideration of SHIP integration. Indeed, the review of Dantas & Soares [3] demonstrated that social issues affecting supply chain stakeholders of solar energy have been given little consideration and appraisal as compared to environmental and economic aspects. Thus, performing such an appraisal will provide an explanation as to how these technologies will socially impact the different human resources and supply chain beneficiaries, a crucial step towards achieving social acceptance of SHIP technologies. The exploration of the social acceptance of these novel and emerging technologies have only begun to gain interest by as described by Cousse [4]. Their review highlighted how public interest in the rapid expansion and

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Abbreviations

H&S	Health and Safety
LCA	Life Cycle Assessment
PV	Photovoltaic
R&D	Research and Development
SEM	Structured Equation Modelling
SHIP	Solar Heat for Industrial Process
SHDB	Social Hotspots Database
SLCA	Social Life Cycle Assessment
SP	Social Performance
STE	Solar Thermal Energy

implementation of solar energy systems is unclear and indeterminate, evidencing the limited evidence published in the scientific literature concerning this topic. Hai [5] further expanded stating that emerging solar technologies suffer from weak market penetration due to the uncertainty faced by policymakers regarding the unknown social consequences that may emerge as a result of STE integration. Cousse [4] described these consequences as the likelihood of resistance and public disapproval that STE might face during implementation, evidence of which is still ambiguous. Therefore, it is imperative to establish social scenarios of SHIP development and evidence both positive and negative social impacts experienced by the wider community. This will increasing public understanding of the social sustainability of STE systems, acquitting governing bodies with more certainty and enhancing the plausibility of social acceptance.

One particular framework already adopted by practitioners which holds invaluable potential to map out both current and future social scenarios of SHIP systems is the Social Life Cycle Assessment (SLCA). This tool has been adapted from its well established environmental counterpart by Benoît et al. [6], who has established a comprehensive framework regarding SLCA that draws on guidelines from the same governing LCA standards, ISO14044 [7]. This splits the SLCA scope into two subsections as follows: (i) the definition of three distinctive supply chain stakeholders that include employees, value chain actors, and the local community, (ii) the identification of all relevant social issues that impact and affect each of the three stakeholders. The framework of assesses the social impact on stakeholder at each life cycle stage of the product or system in discussion, and the results are characterised such that areas of positive and negative system performance can be easily identified at each life cycle stage. Recognising the invaluable potential that SLCA holds for the SHIP strategy, this paper aims to evaluate the applicability of current SLCA methodologies in the literature, applied to upcoming engineering and energy technologies, for SHIP systems. Methodological components of SLCA, including the social issues covered, data collection and characterisation models will all be appraised.

However, a known persisting challenge inhibits application of SLCA for SHIP systems, described by Bonilla-Alicea & Fu [8] as rooted in the lack of a comprehensive social assessment methodology available for practitioners. Kühnen & Hahn [9] elaborated that such comprehensive methods require stronger integration within the current literature to provide more evaluative and critical insight on the social impact of emerging technologies. Sureau et al. [10] described that research being conducted to develop those types of approaches which classify social data in preparation for deep critical evaluation is still in its infancy for sustainability assessments. As a result of this research gap, a lack of understanding emerges in this novel field which inhibits the ability of policymakers and management boards to efficiently allocate resources and improve the social performance of novel renewable technologies. This notion is consistent with the review of Dantas & Soares [3], who described the far extent that these knowledge gaps persist in the field of renewable technological development, a reality which concerns the progression of SHIP development. Corona & Miguel [11] further argued on this point by putting it into the context of STE systems, emphasising the need to develop and adapt social sustainability assessment methods to for those applications.

Therefore, this paper builds on the arguments presented in these literature works and investigates to what extent these knowledge gaps persist within SLCA applied to novel engineered technologies, and what implications do they have on the current state of social policymaking. The findings produced by such a review will be used to create a roadmap detailing how SLCA can be improved, particularly for the application of emerging STE systems scaled for industrial integration. Commentary will guide the development of novel approaches to SLCA which are more critical rather than descriptive, transforming it into a powerful management tool and enabling policymakers to improve the social performance of SHIP technology. Moreover, the study will provide guidance on what unexplored social issues should be considered for appraisal particularly relevant to an R&D environment, due to how R&D activities are key drivers of SHIP development. Such social issues have received limited prior coverage and are exploitable areas for more novel findings. Hanger et al. [5] affirmed that acquitting policymakers and governing bodies with such comprehensive knowledge of social benefit and risk generation as a result of integrating STE technologies in the industry will lead to an up rise in public interest. This will enhance their social acceptability and attract investors towards SHIP development, opening up new markets and accelerating the deployment of the technology, thereby propelling progress towards carbon-reducing goals.

2. Methods: Systematic review

A systematic review was deployed to consider SLCA application to solar energy systems and similar engineering systems and products in other industrial settings. While individual social assessments have been conducted providing detailed results on select processes focusing on a single social issue for solar energy systems such as Health and Safety (H&S) and employee job satisfaction in R&D environments [12,13], the scope this study's literature review considers social assessments that deploy a more holistic, all-encompassing considering multiple life cycle stages, hence the focus on SLCA.

Two major databases were selected for screening; Scopus and ScienceDirect. The inclusion criteria encompassed original research articles and case studies published between 2017 and 2023, with particular focus on the latest developments in SLCA given its novelty. All other types of publications including reviews, book chapters, and conference proceedings were excluded. The search terms "social life cycle", "social life-cycle" OR "SLCA", "S-LCA", and "social sustainability assessment" were used interchangeably used to extract all related literature. These search terms were only extracted from either the title, abstract, and keywords from each articles to ensure that review only included SLCA studies. Combining it with Boolean operators, the search term; "social life cycle", OR "SLCA" OR "S-LCA" OR "social sustainability assessment" yielded n = 647 publications, filtered down to n = 395 research articles and case studies. To further reduce the search size, only studies with an exclusive focus on SLCA or social impact analysis were considered, excluding any hybrid studies with environmental and economic. While these terms may be included in an abstract of completely relevant articles, this exclusion criteria applied to the article's title only by introducing the search terms; "social" AND NOT ("environmental" OR "economic"). This filtered the publications for review down to n = 190.

The next step was to include another key component of the inclusion criteria; only SLCA applied to upcoming renewable energy producing products or systems were reviewed in this study. The previous search term was then combined with an AND operator to search for energy systems in the article's title, abstract, and keywords. The search terms encompassed all mainstream renewable technologies; solar, wind, hydropower, hydrogen fuel cells, and all bio-based fuels. The new Boolean combined search term was; ("social life cycle", OR "SLCA" OR "S-LCA" OR "social sustainability assessment") AND ("solar" OR "wind" OR "hydropower" OR "bioelectricity" OR "biodiesel" OR "biofuel" OR "hydrogen" OR "energy"), which filtered the number of publications down to n = 46. A final screen for the quality and relevance of the paper was conducted, ruling out 17 more publications and arriving at a final batch of n = 29.

3. Results

From the 29 selected articles and case studies, the number of times that different types of mainstream energy products were addressed in each of the reviewed SLCAs are presented in Fig. 1.

An observation from Fig. 1 demonstrates that SLCA studies favoured biofuel production with 8 total studies published in the last 7 years, notably covered by Costa & Oliveira [14] for feedstock sourcing in Brazil. Studies related to biomass for electrical generation also came under this category, performed by Gamboa et al. [15] for a case study in the Portuguese electrical grid. Studies related to clean, renewable energy systems included 2 publications on social impact and acceptance of wind farms [16], 2 on hydropower dam projects [17,18], and 3 for solar energy systems. 2 of these were solar thermal driven CSP electrical plants; one located in Spain as documented in the works of Corona et al. [19] and the other published by Terrapon-Pfaff et al. [20] in Morocco.

3.1. Stakeholders categories and related social issues addressed

To apply SLCA methodology to each of these renewable energy systems, the first step performed by practitioners was to identify the associated project stakeholders involved in their production and development. This was then proceeded by attributing a number of social issues that are of sincere concern and/or interest to the project stakeholders during their engagement with supply chain activities. Each of these social issues were then observed to have been assigned with a number of quantifiable social indicators which measure the magnitude of social impact on the affected stakeholder. The mean number of indicators assigned to a stakeholder group by each reviewed publication is shown in Fig. 2.

Fig. 2 displays three categories of project stakeholders that were addressed in SLCA literature. These were employees, value chain actors, and the local community. Starting off with employees, Tavakoli and Barkdoll [21] had presented the most comprehensive breakdown of employee occupations deployed at all life cycle phases. They considered technical employees such as operators of the industrial machinery at the manufacturing site, R&D specialists, the full engineering team, and project managers. The mean number of quantifiable indicators assigned to this stakeholder category was observed to be the highest at 5.5 indicators per publication. These indicators represent social issues affecting employees on an STE development project, as evidence in the works of Corona et al. [19], who investigated the social issue of fair pay using measurable indicators such as annual salaries and mean wages for part-time and full time workers. Josa & Garfí [22] developed further on the use of this indicator by measuring difference between the national expected level of pay for each occupation type in order to measure the fairness of pay. Costa & Oliveira [14] had use similar methods to measure another social issue; fair employee working hours were managed in their feedstock production line. Their social indicator graded social performance based on how many employees had working hours exceeding the legal maximum stipulated working hours. Another key social issue concerning employees was their Health and Safety at work, covered by Cooper et al. [23]. They compared the rate of worker injuries per unit energy of natural gas produced against other energy producing technologies, such as solar and wind, to deduce the relative safety of employees working in their supply chain. Given the technical nature of solar thermal energy systems, these methods can easily be adapted due to the intensity of material production and risks that high temperatures pose on workers within the energy sector. Such technical employee classifications and breakdowns are of significant importance to the solar renewable energy sector.

The value chain actors were defined by Corona et al. [19] to be all organisations and firm participating in the supply chain of the STE system, adding value to the STE product being developed by the core engineering company. They identified these to be the material and part suppliers where the core engineering procures STE system components from. The number of social issues affecting firms down the value chain were far fewer than those affecting the employee category, assigned with an average of only 1.4 social indicators per reviewed publication. One social investigated by Wei et al. [24] was the upkeep of relationships between the material suppliers and core company, an issue defined by how the partner material suppliers were affected as a result of purchasing decisions made by the core company. Terrapon-Pfaff et al. [20] used an indicator of economic development due to the increased involvement of value chain firms in material procurement to measure the impact induced by STE integration on other involved value chain firms in Morocco, reporting a positive results.

The local community stakeholder group was addressed more frequently in publications, with an average assigned number of social indicators of 3.8. The main social issue that was brought under discussion by authors was the collection of public perception, as documented by Buchmayr et al. [16] in their article of social sustainably of wind technological. They used survey polls designed to collect public opinion across 200 participants and investigated whether communities either accepted or rejected the instalment of wind farms. The social acceptance for solar energy systems was measured by Terrapon-Pfaff et al. [20] for a CSP plant in Morocco by intaking public perception on the future sustainability of the technology. Bonilla-Alicea & Fu [25] for domestic Photovoltaic (PV) solar panel production in the United States measured similar qualitative aspects by using questionnaires to gauge public engagement with carbon-reducing goals. The former asset of authors

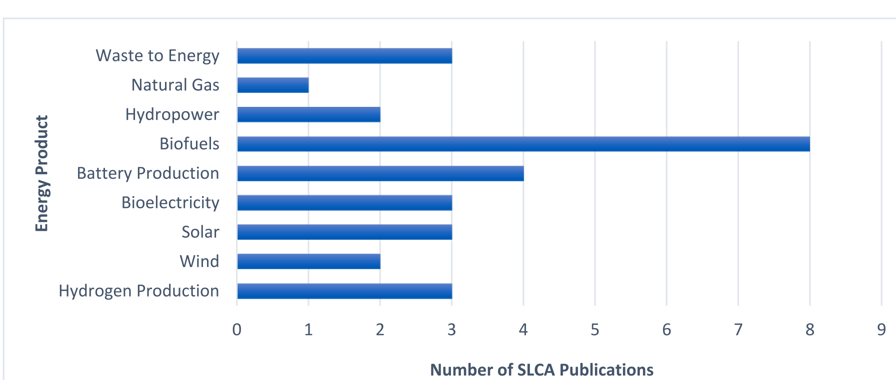

Fig. 1. Number of SLCA publications addressing each mainstream energy product.

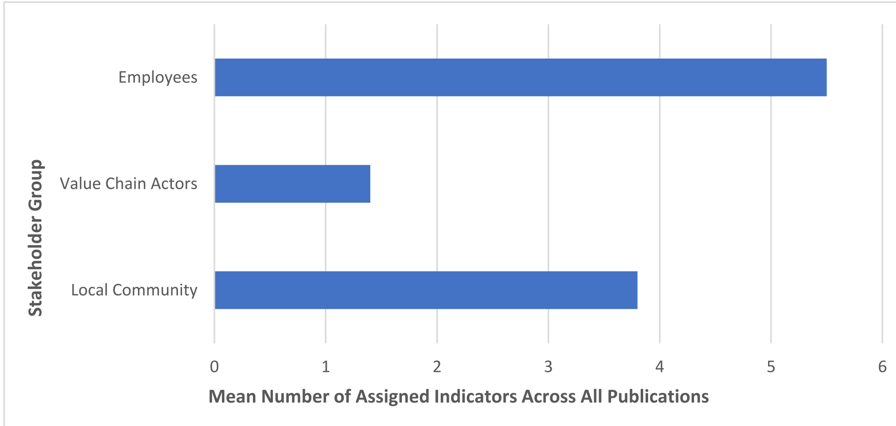

Fig. 2. Mean number of indicators per stakeholder group.

quoted environmental benefits of using solar technologies to further gain recognition of the technology's sustainability and increase the public's awareness on the importance of reducing emissions. Gaining the acceptance of the public was seen as a key component in their article to strengthen their case for integrating solar technology.

3.2. Data collection methods used

Building upon the inclusion of social issues and assignment of indicators, the next step taken by SLCA practitioners was to employ methods for data collection and assessment. Fig. 3 examines presents the types of quantitative and qualitative data collection methods and the frequency at which practitioners applied them for each of their real-life case study.

Fig. 3 shows that the most popular data collection method in reviewed SLCA was the use of Social Hotspot Database (SHDB). Two common SHDB platforms were found in the literature, one as documented by Norris & Norris [26] was added as extension to PRé Sustainability's SimaPro, originating from Amersfoot, Netherlands. The other one was described Tragnone et al. [27] as the Product Social Impact Life Cycle Assessment (PSILCA) database developed by GreenDelta in Berlin, Germany. Norris & Norris [26] established a guide on the former platform, describing it as a software which intakes quantitative material flows and information the country of origin of any given engineering product, relates the flows to the material's monetary value, then outputs the social risks to supply chain employee per working hour. Shi et al. [28] maintains that these risks portray the impact on labour within that region by describing the fairness of pay, working conditions, and health and safety implications on downstream employees. Koese et al. [29] performed these techniques for their SLCA on lithium ion batteries, extracting significantly higher social risk in China-based production as compared to supply chain activities occurring in Germany. Werker et al. [30] applied PSILCA to assess social risk to workers for an energy related application; hydrogen production. Their results agreed with the previously mentioned authors, who found high risk of violation of labour rights in China's process chains. As far as the review is concerned, Corona et al. [19] is the only practitioner to have utilised SHDB techniques for an STE system, who conducted such an SLCA to identify high levels of H&S related social risks within metal manufacturing industries in China and African countries. Their results hold significant value to SHIP systems due to the risk analysis conducted for crucial STE components, such as CSP collectors and energy storage systems.

Other methods quantitative data collection noted in Fig. 3 mainly comprised of dissecting HR records, scanning company reports and using national and/or governmental databases. Company reports were widely to extract financial data on employee pay and salary [14,19], while H&S records were used to determine the recorded annual accident rate in a production setting [23]. Qualitative techniques were noted to be used less frequently by SLCA practitioners. A frequently used one were surveys and questionnaires, administered to gain a subjective insight directly from the affected stakeholders regarding their satisfaction and/or agreement on numerous social issues. Such techniques were deployed by Sawaengsak et al. [31], who assessed satisfaction amongst employees on their biofuel production line regarding social issues such as their pay, working hours, training, and their H&S at work. Similar questionnaires were administered to local communities [16,20,25] to gauge the social acceptance of solar technologies, as explained in section 3.1.

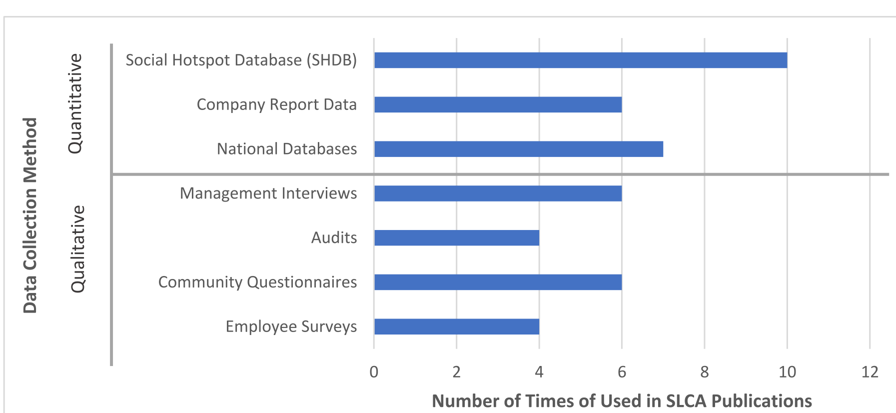

Fig. 3. Data collection types and frequency used in the literature.

Evaluative audits were also adapted as another qualitative technique to measure the compliance of company practice to enforced regional policy. An example was documented about the examination of Health and Safety policy, in the case studies related to High-Density Polyethylene (HDPE) production done by Hannouf and Assefa [32], and by Singh & Gupta [33] for a steel mill. In both case studies H&S labour policy was examined using indicators that grade the level of the chemical safety using qualitative observations. It was found by Hannouf & Assefa [32] that exposure to hazardous substances among workers on the shop floor and among the local community was high due to the ineffective management practices within their HDPE production facility. Using audit reports, they found that only 10 % of the chemical company's sites are certified to governing ISO standards ISO14001. Given that similar H&S standards are imposed for solar thermal energy production, the use of auditing can be implemented to cover a breath of social issues that could be qualitatively assessed.

3.3. Data processing and assessment methods used

To process the collected data, SLCA practitioners first employed a method which consisted of assigning hierarchal weightings. Sawaengsak et al. [31] maintained that these were subjective value-based coefficients which weigh the relative importance of social issues addressed in section 3.1, derived from expert opinion from company officials. For example, Bouillass et al. [34] gave H&S higher importance in comparison to employee working hours, as decided by interviewing and collaborating with a panel of experts. They described how this issue holds slightly less but credible importance as compared to the former due to its indirect effect on human health. Fattahi et al. [35] elaborated on prioritising social risks based on value-based decision making, in their case study of sustainability planning for biomass-based power generation in Iran. The value-based decisions were aided by a panel of experts in bioenergy supply chain management, holding valuable knowledge on what stakeholders are at most risk along the supply chain. They recommended job creation and annual turnover as critical socio-economic indicators to be given importance when considering the impacts of implementing the new power generating technologies for their stakeholders. These data processing techniques should indeed be adapted to SHIP systems to enhance the accuracy of the SLCA results.

Proceeding the processing and collection of data, two distinctive characterisation models were identified as appropriate methodologies to assess raw data in SCLA studies; Type I and Type II methodology. Parent et al. [36] defines that a Type 1 approach is a model that aims to quantify social impact based on the measured data collected by all social indicators described in section 3.1, assessed for each stakeholder in Fig. 1. It is a model that puts these supply chain stakeholders as the core scope of the analysis making it crucial for EU socio-economic sustainability objectives described in the report of Gullien-Burrieza et al. [2]. Benoît et al. [6] also adds that this is a vital step in the SLCA methodology, used to compare weighted data across all lifecycle stages of the product for final evaluation.

The defining parameter which drives Type 1 assessment protocol is known as Social Performance (SP). Parent et al. [36] explains that the numerical data that SP comprises of is generated based of a grading scheming using points known as Performance Reference points (PRP). Such a grading scheme was adopted by Costa & Oliveira [14], who used it to numerate SP based off on how well a company is complying to objective standards of social acceptability, such as binding regional social policy. Corona et al. [19] expanded by stating that performance points calculate the magnitude of deviation of indicator data from those objective social norms acting as neutral criterion, which fit within the range of -2 to $+2$. The negative numbers demonstrate negative SP of specific social indicator, and vice versa for positive numbers. Josa & Garfí [22] had proposed to use the regional averages of each social indicator, which were sourced through national databases are government statistics. A frequently sited statistic in this paper was the national average salaries per occupation, which would be matched with collected employee salaries from the engineering firm. Based on the industrial average within the regional, their study showed to what extent employees were being paid fairly for a given job title by calculating the percent deviation. Such methodology can be adopted for audit based studies, as was in the case of Wang et al. [37]. Their SLCA methodology used the national labour regulations to measure the company's treatment of their employees. Deviation from minimum or maximum allowances would be the magnitude of social impact on the appropriate stakeholders. The measure of how effectively the company is implementing imposing laws was emphasised by the author as a direct reflection on labour practices. Muthu [38] agreed with setting labour laws at cut off thresholds, using the minimum wage law to determine whether workers are paid sufficiently. This was used to highlight underpaid workers as negatively impacted, while workers above the minimum threshold are being positively impacted.

In stark contrast, Type II methodology is rarely used in SLCA methodology and according to our review, is still well in its infancy with a vast amount of research still required to be undertaken to develop the model for SLCA framework. A handful of studies have addressed the Type II model, which was described by Sureau et al. [10] as a protocol to establish impact pathways. These pathways are cause-effect relationships between the same social variables and indicators explained in section 3.1, for example employee pay on job satisfaction or training on technological development. Rather than simply reporting the magnitude of social impact on stakeholders in the form of SP as performed under Type I protocol, Type II aims to find the key drivers and root causes of negative social impact. Wu et al. [39] further commented that multiple variables could be creating negative social impact, all with different levels of correlation. In such cases, they advised that social data could be processed by multi-variable numerical techniques to calculate the correlation coefficient of each mediating variable, such as regression analysis. The significance of these numerical techniques and the overall consideration of Type II SLCA will be elaborated upon in the discussion of existing knowledge gaps present in Type I SLCA studies in section 4.0.

4. Discussion

The main knowledge gap that was present throughout this review was observed to be a lack of elaborative commentary and evaluation of measured SP. Evaluative discussions within the concluding sections of most SLCA case studies consistently fall short in providing in-depth and comprehensive insight of compliance to existing social policy. Studies using SHDB platform [19,28–30] had covered the areas of high social risk within their supply chains, but could have gone into more depth as to why risk was generated in those areas. While speculative insights were given referencing social policy and current conditions within high risk regions, further insight provided by additional studies with the supply of reliable numerical data would be needed to provide a stronger case. Such knowledge gaps were addressed by Kühnen & Hahn [9], but still persistent in studies published after theirs. Other studies which considered quantitative data from national databases [14,23] also exhibited similar knowledge gaps, given how they simply had compared their company data with national averages without critically discussing why differences exist. This holds true for the audit oriented SLCA study of Hannouf & Assefa [32], whose recommendations on improving H&S standards around hazardous chemicals were briefly explained in the discussion. The authors could have explored the drivers which were generating the observed negative social externalities and non-compliance to social policy, backing up with more numerical statistical support.

The implications of the research gaps in current SLCA approaches clearly impedes policymakers' ability to make well-informed decisions on managerial intervention in order to improve the SP of STE supply chains. While areas of high social risk and negative impact can be highlighted, Kühnen & Hahn [9] undermined that robust managerial decision-making for efficient resource allocation requires a deeper understanding into the key drivers and root causes of social risk. Sureau et al. [10] highlighted the importance of identifying these key drivers towards developing SLCA into a robust tool better suited for decision making. Such information can be used by policymakers to develop more targeted strategies for resource allocation and mitigate adverse social impacts associated with those drivers, improving the outcomes for various stakeholders.

Taking examples of social issues which require more attention, the key drivers of organisational gaps in compliance with labour laws should be better understood to facilitate interventions and enhance employee pay and job satisfaction. Similarly, training gaps should be correlated with employee qualification mismatches and poor job performance, so that policymakers can develop initiatives that focus on skills development programs to enhance employee productivity. In another example, by correlating training gaps with high accident rates and health and safety (H&S) risks on the shop floor, policymakers can prioritise occupational safety measures and design targeted training programs to mitigate risks and improve workplace safety. These insights can lead to the implementation of robust policies and guidelines to ensure a safe working environment for employees. It is important to note that these knowledge gaps have persisted even in studies related to sustainable technology and energy (STE) systems, as highlighted in the study of Corona et al. [19]. This persistence emphasises the urgency of addressing these gaps and the need to advance the development of Social Life Cycle Assessment (SLCA) as an effective managerial tool for STE and similar renewable energy systems.

An arising proposition evidenced by Chen et al. [41] considers the combination of standard Type I protocol with Type II methodology, coupling traditional SLCA studies with additional quantitative techniques which allows decision-makers to make informed choices based on solid empirical evidence and rigorous analysis. The numerical techniques that they recommended could indeed revolutionise SLCA; Structured Equation Modelling (SEM). They described that this technique could be integrated into Type II SCLA framework, as it helps uncover interconnected direct and indirect relationships between social variables. They add that numerical coefficients can be derived to understand what variables strongly or weakly contribute to a hypothesised relationship in the social data, revealing previously unknown correlations and trends. Another numerical approach mentioned in section 3.3 deployed by Samman & Abdelnasser [40] in their study of the drivers of job satisfaction was the multi-variable regression analysis, which enables the identification of all key social variables that significantly influence specific impacts. The findings and information generated form this numerical techniques helps managers prioritise interventions and implement targeted measures to mitigate negative social impacts. They are of significance to SLCA framework due to how they provide a more in-depth insight into the root-cause of non-compliance, enabling the identification of where resources should be allocated for improved social policy and better compliance.

4.1. Secondary knowledge gap: Examination of all addressable social issues

The review had picked up on a second knowledge gap within current SCLA literature. This builds upon the finding made by Bouillass et al. [34], who had demonstrated a varied focus when undertaking the selection of social issues that need addressing in their studies. They stated that the way SLCA practitioners considered both internal and external stakeholders was uneven, giving different levels of considerations to each individual stakeholder perception. Indeed, the results from Fig. 1 shows that the overwhelming number of studies focus on employee stakeholders with the mean number of related indicators of 5.5 as compared to 1.4 indicators to the value chain actor group. Bonilla-Alicea & Fu [8] also found this inclination towards the worker stakeholder in their review, commentating the limited scope on the external actors in the supply chain. The focus on the local community and supply chain actors is crucial to understanding the full comprehensive social impact within the external supply chain. This could have been more evident within the literature survey, particularly in the field of solar and renewable energy. For example, Corona et al. [19] explained how fair competition was being upheld by the main operators of their CSP Solar Plant. However, analysis of how the entire supply chain is assembled and socially engaged with the core engineering company could have been added to back up their argument. Interaction between the firms, material suppliers, and technological end users could have been explored in their study. Commentary on the benefit of solar energy on the increase in productivity of supply chain firms as a result of STE integration is very briefly described in the works of Terrapon-Pfaff et al. [20]. More critical analysis and appraisal in to issues affecting this stakeholder group could have been conducted through methods such as management interviews measure client satisfaction.

Kühnen and Hahn [9] in their review has elaborated by further dwelling in the underlying causes of this varied scope. They stated that there is a need of application of empirical knowledge when deciding and justifying the inclusion of quantifiable social indicators, which represent the selection of what social issues are to be addressed. Bonilla-Alicea & Fu [8] agreed with this notion and pointed that there needs to be a stronger consideration of what social issues are of practical importance to analyse in a case study. According to the findings of the review documented in this article, such consideration must be given to assessing the upkeep of relations with technological end users in the case of STE systems due to the involvement of industrial partners in SHIP integration. Another set of issues that should be introduced in the SLCA framework of STE systems include employee training, professional development and the impact on Research and Development (R&D). These three issues are highly relevant to a novel solar thermal energy project being developed in an R&D environment as they directly contribute to the positive social impact experienced by project employees. Such issues have yet to be covered by SLCA literature according to the findings of this analyses, and bringing issues into SLCA and conducting appropriate appraisal through the use of impact pathway numerical techniques mentioned in section 4.0 would be invaluable towards the tool's development. The evaluation of R&D activities in particular is crucial for finding ways to boost innovation, technological advancement, and employee engagement within the STE project. The demonstration of the net positive impact on employees and end user will attract public interest in acceptance of STE systems, proving itself as a highly feasible and sustainable alternative source of energy. This will attract more demand and investments leading to increased market size and thus contributing towards carbon-reducing goals.

4.2. Limitations of the review

The main limitation of this analysis was the omission of established, mainstream social assessments available in the literature, such as explorations into the driver's job satisfaction documented by Munir & Rahman [42] in their study of human resource management in private hospitals. These authors conducted a quantitative factor analysis, which serves a crucial role in the processing and analysing the root causes of negative social impact experienced by employee stakeholder in a similar fashion to the SEM and multi-variable numerical techniques mention in section 4.0. Other types of qualitative social assessments such as audits conducted by Subramanian & Yung [43] for an application on desktop computers and another application in the construction industry conducted Alshihre et al. [44] were performed with more thorough critical insight than similar method types documented in SLCA studies. Subramanian & Yung [43] had established in-depth guidelines as how neutral criteria of optimal social performance should be set and used to grade fairness of employee and detect non-conformance to labour policy. Alshihre et al. [44] utilised a methodology unused in previous studies altogether; thematic content analysis. This form of analysis was employed to gain insight into the satisfaction of project clients by systematically extracting feedback from the interview transcripts provided by their management panels, techniques which could crucially be employed to similarly asses the satisfaction of STE's technological end users. Such techniques could have been incorporated in the search terms, broadening the scope of the review beyond SCLA. It could also be seen from the applications in Refs. [42–44] that limiting the review scope publications only relating energy-related settings played a role in the limited types of methodological developments detected by review in this article. Indeed, opportunities to delve deeper into the underlying structure of these methodologies were missed had they been included and appraised in the review for their suitability to SLCA. Taking hold of these opportunities are vital to advancing SLCA for STE systems as emphasised in section 4.0, leading to the proceeding benefits of increased social acceptance and expansion of STE integration as explained at the end of section 1.0. Follow up publications should look into both the latest developments in social assessment and well-established theory, considering all types of engineering applications, to gain the most comprehensive insight into available methodology.

5. Conclusion

In conclusion, the survey of the literature has presented SLCA has a potentially powerful tool for effective management of resource allocation, particularly for addressing and rectifying all social issues across the supply chains of STE and similar energy producing systems affecting three key project stakeholders. The results of the review showed that these social issues comprised of fairness of employee pay, working hours, upheld of labour rights, and the quality of H&S. Issues relating to the public acceptance of STE systems by local communities are gaining interest in the literature, and the engagement of downstream and upstream value chain actors has scarcely been addressed. Various quantitative and qualitative data collection methods have been employed by SLCA practitioners, ranging from the popular SHDB platforms to community questionnaires and evaluative audits. The application of Type 1 protocol was the main characterisation model adopted by SLCA practitioners, used to process raw data into numerated SP of the energy system. The use of numerated PRP was key to providing insight into areas of negative SP and identifying areas for improvement. However, it was recommended that Type II protocol should be integrated into future SLCA framework in order to provide more elaboration when discussing SP and to be able to derive concise conclusions that hold more value to management panels. It was determined that correlation numerical methods should be adopted into future SLCA framework to improve the robustness and depth of analysis. Additionally, the scope of social issues in SLCA methodology needs to be widened to include all affected stakeholders. The selection of social issues in each case study should also be more relevant to the engineering product being addressed. Such advancements in SLCA scope and data analysis would greatly benefit policy makers tasked to find sustainable solutions to improve the SP of SHIP technology and other emerging renewable systems, which would increase their social acceptance, hence expanding their presence in international markets and paving the way for cleaner energy sources for the industry.

Declaration of competing interest

The authors declare that there are no conflict of interest related to this paper.

Data availability

No data was used for the research described in the article.

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