Relationship Between Life Cycle Assessment and Sustainable Development Goals: Potential, Challenges and Future Directions

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Abstract. The convergence of Life Cycle Assessments (LCAs) and Sustainable Development Goals (SDGs) forms a substantial approach towards enhancing the comprehension of environmental impacts, underpinning sustainable decision-making strategies. As holistic analytical tools, LCAs critically contribute to the achievement of SDGs by assessing environmental ramifications throughout a product or service's lifecycle. This integration not only unveils synergies and trade-offs among various goals but also fortifies the monitoring and evaluation of sustainable development progress. Significant challenges impeding effective alignment, such as augmenting data quality, formulating LCA methodologies tailored for SDG appraisal, and harnessing the potential of emerging LCA methodologies, are elaborated. The paper accentuates the crucial role of robust indicators and targets in tracking progress and informing policy, thus emphasizing the need for continuous monitoring in LCA-SDG integration. Bearing significant implications for researchers, policymakers, and practitioners, future work should focus on refining LCA methodologies specific to SDG assessment, enhancing data quality, fostering interdisciplinary collaboration, conducting practical case studies, and maintaining persistent evaluation of LCA-SDG initiatives. In essence, the amalgamation of LCAs and SDGs could significantly accelerate sustainable development objectives, fostering a future that is both ecologically responsible and prosperous.

Keywords: Life cycle assessment, sustainable development goals, global environmental challenges.

1. Introduction

LCAs and SDGs represent crucial frameworks for addressing global environmental challenges and guiding sustainable development initiatives. LCAs serve as comprehensive quantitative instruments, meticulously examining the environmental implications linked with every phase of a product's lifespan, ranging from the procurement of raw materials all the way through to its ultimate disposal or recycling [1]. They provide a comprehensive perspective on the environmental implications of various choices, considering impacts on climate change, resource depletion, and ecosystem degradation [2].

On the other hand, the SDGs represent an interlinked set of 17 global objectives, instituted by the United Nations in 2015., aimed at tackling pressing social, economic, and environmental issues worldwide [3]. These goals epitomize a universal commitment to promoting a sustainable future and establishing a collaborative platform for governments, businesses, and civil society to address challenges such as poverty, inequality, and climate change [4].

The integration of LCAs and SDGs is a pivotal strategy in ensuring that environmental sustainability aspects are incorporated into the decision-making process, preventing unintended environmental consequences in our pursuit of the SDGs [5]. This amalgamation aids in identifying synergies and trade-offs between diverse objectives, fostering a more coherent approach to sustainable development [6]. Additionally, LCAs can provide critical data and evidence for tracking progress towards SDGs, informing policy and strategic decisions geared towards achieving these goals [7].

In this context, the primary purpose of this review paper is to delve into the role of LCAs in achieving SDGs, scrutinize the challenges and opportunities inherent in aligning LCAs and SDGs, and investigate the monitoring and evaluation of this integration. Through a comprehensive examination of the current state of LCA-SDG integration, this paper aspires to offer insights into potential directions for future research, policy development, and practice in this critical area.

2. The role of LCAs in achieving SDGs

2.1. Overview of LCAs and their relevance to SDGs

LCAs can substantially contribute to the realization of the SDGs by providing comprehensive and systematic approaches to evaluating the environmental impacts of products, processes, or services. The application of LCAs in the context of SDGs can help with identifying potential synergies and trade-offs among different targets, thereby promoting more informed and effective decision-making in sustainable development efforts.

LCAs can contribute to achieving SDGs in several ways. For example, LCAs can provide a solid foundation for the development of environmentally sustainable products and processes by identifying key environmental hotspots and improvement opportunities [8]. Additionally, LCAs can be applied to evaluate the environmental performances of various policy options, thereby informing policy-makers about the potential environmental implications of their decisions and supporting the development of more sustainable policies [9].

By integrating LCAs into SDG-related assessments, it becomes possible to address the environmental dimensions of sustainable development more effectively and comprehensively. In effect, this could result in the accomplishment of multiple SDG targets, encompassing areas like responsible consumption and production (SDG 12), proactive measures for climate change (SDG 13), preservation of marine life (SDG 14), and terrestrial ecosystem protection (SDG 15).

2.2. Integrating LCAs and SDGs in policy development

2.2.1 The significance of incorporating LCAs and SDGs in policy-making

The integration of LCAs and SDGs in policy-making can lead to more informed and sustainable decisions, as it allows for a better understanding of different policy options of the environment, society and economy [10]. By combining the quantitative, environmental focus of LCA with the broader, qualitative perspective of the SDGs, decision-makers can distinguish underlying synergies and trade-offs and prioritize actions that contribute to multiple SDGs simultaneously [11].

Moreover, incorporating LCAs and SDGs in policy-making can help identify and address potential rebound effects, which may occur when the environmental benefits of an intervention are offset by indirect, unintended consequences. For example, policies promoting energy efficiency may lead to increased energy consumption due to lower costs, negating the intended environmental benefits [12]. By considering the full life cycle of products and processes, and their broader social and economic context, LCA-SDG integration can help mitigate such rebound effects and ensure more sustainable outcomes.

2.2.2 Policy frameworks that integrate LCAs and SDGs

Several policy frameworks have been developed to support the integration of LCAs and SDGs. For example, the Product Environmental Footprint (PEF) methodology is an LCA-based approach for assessing the environmental performance of products and organizations, aiming at supporting the achievement of the EU's environmental and sustainability objectives [13]. The PEF methodology has been linked to several SDGs, particularly SDG 12, which calls for sustainable consumption and manufacture patterns [14].

In a parallel manner, the Social LCA (S-LCA)is a guindeline designed to evaluate the societal implications of products and processes throughout their life cycle. This approach enhances the conventional LCA by adding a social dimension to the predominantly environmental perspective [15]. S-LCA has demonstrated associations with various Sustainable Development Goals (SDGs), including but not limited to poverty alleviation (SDG 1), the advancement of gender equality (SDG 5), and the promotion of respectable work and economic growth (SDG 8) [16].

National governments have also begun to incorporate LCA and SDG considerations in their policy frameworks. For instance, the Swedish government has adopted a strategic approach to sustainable consumption and manufacture, which includes the use of LCA [17]. This approach aligns with the country's commitment to achieving the SDGs, particularly SDG 12.

2.3. LCAs in Support of SDG Implementation and Progress Tracking

LCAs can play a crucial role in implementing and tracking progress towards SDGs by providing quantitative, transparent, and comparable data on the environmental impacts. By identifying the most significant environmental hotspots and potential improvements, LCAs can help prioritize interventions and allocate resources more effectively, contributing to the achievement of multiple SDGs simultaneously [18].

Furthermore, LCAs can support the monitoring and evaluation of SDG progress by providing consistent, science-based indicators for tracking environmental performance. For example, LCA-derived indicators, such as the Global Warming Potential (GWP), can be used to track progress towards SDG 13 (climate action) by quantifying the greenhouse gas emissions associated with products, processes, and services [19].

2.4. Real-world examples demonstrating the effective use of LCAs for SDG implementation

Several case studies illustrate the effective use of LCAs for SDG implementation. One such example is the adoption of LCA methodologies in the construction sector, which has significant environmental impacts and is closely linked to multiple SDGs, including SDGs 11 (sustainable cities and communities) and 12. By incorporating LCA into building design and construction practices, stakeholders can identify opportunities for reducing resource consumption, waste generation, and greenhouse gas emissions, contributing to the achievement of these SDGs.

Another example is the application of LCA in the food and agriculture, which is associated with various environmental and social challenges, such as land degradation, biodiversity loss, and food insecurity [20]. LCA can help identify the most significant environmental hotspots in food production and consumption, as well as potential strategies for improvement, contributing to the achievement of SDGs 2 (zero hunger), 12, and 15 [21].

In summary, the integration of LCAs and SDGs can provide valuable insights for achieving more sustainable outcomes in various sectors, such as construction and food and agriculture. By identifying the most significant environmental impacts and potential improvements, LCAs can help prioritize actions and allocate resources more effectively, contributing to the achievement of multiple SDGs simultaneously.

3. Challenges and opportunities for aligning LCAs and SDGs

3.1. Identification of potential barriers in using LCAs to inform SDGs

Despite the potential benefits of integrating LCAs and SDGs, several challenges may hinder their effective alignment. One significant barrier is the data availability and quality required for conducting comprehensive LCAs [22]. Data gaps and inconsistencies can limit the applicability of LCA results, particularly in developing countries where infrastructure might be less developed. Furthermore, LCA data may be subject to uncertainties and assumptions that can affect the robustness of the results and their relevance to the SDGs [23].

3.2. The role of digitization and data in LCAs for SDGs

Digitization and advancements in data collection, management, and analysis can help address some of the challenges related to data availability and quality in LCAs. The expanding utilization of digital instruments, such as remote sensing technologies, Internet of Things (IoT) gadgets, and blockchain systems, can enhance data procurement and dissemination, thereby contributing to more secure and credible outcomes in LCAs [24]. Moreover, advancements in machine learning and artificial intelligence are instrumental in handling and scrutinizing large volumes of data, facilitating broader and more precise evaluations of the environmental repercussions of products, procedures, and services vis-à-vis the SDGs [25].

3.3. Opportunities for improving the alignment between LCAs and SDGs

Emerging trends and innovations in LCA methodologies, such as the development of consequential LCAs (cLCA), which account for the indirect and systemic impacts of products, processes, and services, can help better align LCAs and SDGs. By incorporating broader system boundaries and considering the potential trade-offs and synergies between different environmental, social, and economic impacts, cLCA can provide a more comprehensive understanding of the relationship between LCAs and SDGs.

Another avenue to enhance the synchronisation between LCAs and SDGs is by amalgamating Environmental LCA (E-LCA) and S-LCA). This combination could offer a more encompassing appraisal of the sustainability performance pertaining to products, processes, and services [15]. This unified strategy can assist in discerning potential compromises and synergies between environmental and social impacts, thereby facilitating more enlightened decision-making processes in correlation with the SDGs.

Furthermore, multi-criteria decision analysis (MCDA) can be used in conjunction with LCA to prioritize actions and policies that contribute to multiple SDGs simultaneously [26]. By incorporating stakeholder preferences and values, MCDA can help decision-makers identify and prioritize sustainable solutions that consider the complex interplay between environmental, social, and economic factors.

3.4. Implications for SDG assessment and potential areas for further research

The alignment of LCAs and SDGs has several implications for SDG assessment and presents opportunities for further research. One area for investigation is the development of new LCA methodologies and indicators that capture the systemic and interconnected nature of the SDGs. Furthermore, it would be beneficial for future investigations to delve into the fusion of LCA with other sustainability evaluation instruments like Material Flow Analysis (MFA). This integration could provide an extensive comprehension of the environmental implications of products, procedures, and services [27].

Finally, there is potential for research on the role of digital technologies in enhancing the alignment of LCAs and SDGs, including the development of digital tools for data collection, sharing, and analysis, and the utilization of artificial intelligence to support more robust and accurate LCA results [28].

4. Monitoring and evaluation of LCA-SDG integration

4.1. The importance of monitoring and evaluation (M&E) in LCA-SDG integration

M&E play a vital role in LCA-SDG integration by helping to assess the effectiveness of policies, programs, and interventions that aim to achieve the SDGs. M&E can provide valuable information on the progress, performance, and impacts of LCA-SDG integration, enabling decision-makers to make evidence-based decisions, identify areas for improvement, and ensure accountability and transparency [29]. Furthermore, M&E can support learning and adaptive management, allowing stakeholders to refine their strategies and actions in response to emerging challenges and opportunities [30].

4.2. Key elements and principles of M&E in LCA-SDG integration

M&E in LCA-SDG integration should be guided by several key elements and principles to ensure its effectiveness and credibility:

Relevance: M&E should focus on the most relevant aspects of LCA-SDG integration, such as the alignment of LCA results with SDG targets, the effectivity of stakeholder engagement, and the contribution of LCA-based interventions to SDG achievement.

Rigor: M&E should be based on robust methodologies, data, and indicators that accurately capture the progress, performance, and impacts of LCA-SDG integration.

Participation: M&E should involve a variaty of stakeholders, including government, industry, academia, and civil society, to ensure diverse perspectives, knowledge, and expertise are considered.

Adaptability: M&E should be flexible and sensitive to environmental changes, allowing for the adjustment of strategies, actions, and targets as needed [30].

4.3. Indicators for monitoring and evaluating LCA-SDG integration

Selecting appropriate indicators is a critical aspect of M&E in LCA-SDG integration. Indicators should be relevant, measurable, and sensitive to changes in the performance and impacts of LCA-SDG integration. Indicators can be quantitative (e.g., reductions in greenhouse gas emissions or resource use) or qualitative (e.g., stakeholder perceptions of the effectiveness of LCA-SDG integration). A mix of process, output, outcome, and impact indicators can be used to capture the different dimensions of LCA-SDG integration, such as the quality of LCA methodologies, the alignment of LCA results with SDG targets, and the contribution of LCA-based interventions to SDG achievement.

4.4. Data collection and analysis in M&E of LCA-SDG integration

Data collection and analysis are essential components of M&E in LCA-SDG integration. Data can be collected from various sources, such as LCA databases, government reports, and stakeholder surveys, and using a variety of methods, including secondary data analysis, interviews, and participatory approaches. Data analysis can involve descriptive, inferential, and exploratory techniques, depending on the research questions and objectives of the M&E process. Data visualization tools, such as graphs, maps, and dashboards, can help communicate M&E results to stakeholders and support decision-making.

4.5. Challenges and opportunities of LCA-SDG integration

There are several challenges and opportunities in M&E of LCA-SDG integration, including:

Data availability and quality: Acquiring available and qualified date for M&E can be challenging, especially in developing countries where data infrastructure may be limited [31]. Opportunities exist to improve data availability and quality through capacity building, investments in data infrastructure, and the use of innovative data collection methods, such as remote sensing and crowdsourcing [28].

Integration of LCA and SDG indicators: Developing integrated indicators that capture both LCA and SDG dimensions can be complex, as LCA indicators are often focused on specific environmental impacts, while SDG indicators cover a broader range of social, economic, and environmental dimensions. Opportunities exist to develop integrated indicators by combining LCA and SDG data, as well as by linking LCA results to specific SDG targets and indicators [10].

Capacity building and institutionalization of M&E: Strengthening the capacity of stakeholders to conduct M&E and integrating M&E into policy and decision-making processes are important aspects of LCA-SDG integration. Opportunities exist for capacity building through training, technical assistance, and the establishment of dedicated M&E units or centers.

5. Conclusion

The integration of LCAs and SDGs critically fortifies sustainable decision-making by elucidating environmental considerations. This review has highlighted the imperative for enhanced data quality, appropriate LCA tool development for SDG evaluation, and exploiting emerging LCA methodologies. Crucially, the importance of monitoring and evaluation in this process is underlined, requiring robust indicators and targets for informed policy development. LCAs, through this integration, aid in identifying synergies, and trade-offs, and contributing to the monitoring of progress towards the SDGs. Challenges, notably data quality improvement, LCA tool development, and alignment with LCA methodologies, need addressing for effective alignment. Implications extend to researchers, policymakers, and practitioners, with recommendations to refine LCA methodologies, incorporate LCA findings into policy-making, and encourage practitioners to adopt LCA methods. Future work should focus on refining LCA methodologies for SDG assessment, improving data quality, fostering interdisciplinary collaboration, demonstrating real-world applications, and continuous evaluation. Ultimately, LCA-SDG integration can significantly contribute to sustainable development, ensuring that environmental considerations are effectively integrated into decision-making, promoting a sustainable and prosperous future.

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