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Measure of Primary Data as A Quality Indicator in Life Cycle Assessments

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Introduction

Life Cycle Assessment (LCA) is a comprehensive methodology used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle, from raw material extraction to disposal. It is a crucial tool for understanding the environmental trade-offs and impacts associated with different stages of a product's life cycle, enabling informed decision-making for sustainability. LCA is widely used across various industries to assess and optimize environmental performance, contributing to the transition towards a circular economy and sustainable development goals. Key components of an LCA include - Goal and Scope Definition: This initial step involves defining the purpose of the LCA, the system boundaries, and the functional unit of analysis. It sets the framework for the entire assessment and determines the level of detail required (Ramakrishna & Brindha, 2024)

Life Cycle Inventory (LCI) Analysis: This phase involves collecting data on all inputs and outputs associated with the product system, including raw materials, energy consumption, emissions, and waste. The accuracy and comprehensiveness of the LCI are critical for the subsequent impact assessment (Meskers et al., 2024)

(Ramakrishna & Brindha, 2024)

Life Cycle Impact Assessment (LCIA): In this stage, the inventory data is analyzed to evaluate the potential environmental impacts, such as climate change, ozone depletion, and resource depletion. This step helps in understanding the trade-offs between different environmental impacts (Aviso, 2024)

(Wattier et al., 2023)

Interpretation: The final step involves analyzing the results to draw conclusions and make recommendations. It includes identifying significant issues, evaluating the robustness of the results, and suggesting improvements or alternatives (Ramakrishna & Brindha, 2024)

To perform an LCA properly there are a lot of data requirements. Comprehensive data on material and energy flows throughout the product's life cycle is essential. This includes data on raw material extraction, manufacturing processes, transportation, usage, and end-of-life disposal or recycling (Aviso, 2024)

(Wewer, 2023)

Effective management of metadata is crucial for ensuring data quality and interoperability across different LCA tools and frameworks. Ontologies and AI-aware data management can enhance data integration and utilization (Malek et al., 2024)

The data should cover the relevant timeframes, geographical locations, and technological contexts to ensure the LCA results are applicable and accurate (Ramakrishna & Brindha, 2024)

(Douziech et al., 2023)

For complex systems, parameterized life cycle inventories and simulation models can capture nonlinear interactions and provide flexibility in assessing different scenarios (Meskers et al., 2024)

(Douziech et al., 2023)
While LCA is a powerful tool for assessing environmental impacts, it is not without challenges. The accuracy of an LCA heavily depends on the quality and availability of data, which can vary significantly across different industries and regions.
This paper suggests using the percentage of primary data share in the LCA as an indicator of the quality and specificity of the LCA.

Differences between primary and secondary data

Primary Data

Primary data is the information that is directly measured or collected, reflecting the activities at a particular facility or group of facilities. This type of data is specific and precise, originating from primary sources. Primary data in the context of life cycle assessment (LCA) refers to site-specific, directly collected data that is used to evaluate the environmental impacts of a product or process throughout its life cycle. This data is crucial for creating accurate life cycle inventories (LCIs) and conducting reliable LCAs, as it reflects the actual conditions and processes at specific sites, rather than relying on generalized or secondary data from databases.
Primary data encompasses various categories, including site-specific process data, information obtained from suppliers and distributors, and data related to the usage phase of a product, which details how consumers interact with the product. For example, emissions directly linked to a specific manufacturing process, the exact quantities of raw materials purchased and utilized, energy consumption, and waste management practices all represent primary data. This information can be gathered through various means, such as invoices, metered readings, site visits, and surveys. A significant portion of this data is often available from suppliers or distributors.
Primary data provides a more accurate representation of the environmental impacts associated with specific processes. For instance, in the cement industry, primary data collected from different plants in India allows for a detailed assessment of carbon emissions and energy consumption, which are critical for sustainability assessments and process improvements (Basavaraj & Gettu, 2024)
Primary data offers insights into the specific conditions and technologies used at a site, which can significantly influence the environmental impacts. While primary data is invaluable for accurate LCAs, its collection can be resource-intensive and challenging, especially in regions lacking established databases. Additionally, the variability in data quality and availability can affect the consistency of LCA results. In some cases, secondary data from established databases like Ecoinvent is used to supplement primary data, especially when local data is unavailable (Deng & Kendall, 2019)
However, reliance on secondary data can introduce uncertainties, underscoring the need for comprehensive primary data collection efforts.

Secondary data

Secondary data in the context of Life Cycle Assessment (LCA) refers to data that has been previously collected by other researchers or organizations for purposes other than the current LCA study. This data is then repurposed to support the assessment of environmental impacts associated with the life cycle of a product or process. The use of secondary data in LCA is prevalent due to its cost-effectiveness and the time savings it offers compared to primary data collection. However, the quality and relevance of secondary data can vary, necessitating careful evaluation and adaptation to ensure its suitability for specific LCA applications.

Secondary data is not collected specifically for the current LCA study but is sourced from existing databases, surveys, or reports. This data is often available in public repositories, libraries, or archives, and can be accessed through online platforms and APIs (Yeole, 2023)
(Secondary Data, 2023)
Utilizing secondary data can significantly reduce the time and financial resources required for data collection, making it an attractive option for LCA practitioners (Mulhern, 2010)
The appropriateness of secondary data for LCA depends on its accuracy, relevance, and the level of detail it provides. It is crucial to evaluate these aspects to ensure the data aligns with the specific needs of the LCA study (Mulhern, 2010)
Techniques such as context-based filtering and sanitization can enhance the quality of secondary data by resolving data selection issues and incorporating confidential business information, thereby increasing the representativeness of the data (Meyer et al., 2021)
Critical appraisal of secondary data sources is necessary to identify gaps and improve the richness of available databases, ensuring they provide comprehensive and reliable data for LCA (Teixeira, 2015)
While secondary data offers significant advantages in terms of cost and accessibility, its use in LCA is not without challenges. The variability in data quality and relevance necessitates careful evaluation and adaptation to ensure it meets the specific requirements of the LCA study.

Importance of primary data

The use of primary data in life cycle assessments (LCAs) is crucial for obtaining accurate and reliable results, which are essential for evaluating the environmental impacts of various production processes. Secondary data offers greater accessibility, enabling quicker LCAs without the complexities associated with obtaining primary data from suppliers. This type of data can provide a preliminary understanding of significant impact areas, which can help identify where further sustainability research and enhancements are necessary. However, reliance on secondary data may not yield precise or authentic information from suppliers, rendering the LCA somewhat generic and potentially susceptible to scrutiny, including accusations of greenwashing. Consequently, it is essential to incorporate primary data from suppliers whenever feasible. Doing so enhances the credibility of the LCA by providing accurate data tailored to the specific study, rather than depending on generalized averages. Primary data ensures that the LCA reflects the specific conditions of the production process, leading to more accurate assessments. For example, in the cement industry, primary data from six different plants in India was used to assess the carbon footprint and energy consumption, providing a detailed understanding of the environmental impacts and enabling process modifications to reduce emissions (Basavaraj & Gettu, 2024)
In the Italian electricity sector, primary data from thermoelectric power plants revealed significant differences in LCA outcomes compared to using generic database information, highlighting the importance of site-specific data for robust results (Monache et al., 2024)
Primary data allows for the consideration of local conditions and practices, which can significantly influence environmental impacts. For example, the LCA of hot mix asphalt production in Italy used primary data to identify critical environmental burdens and potential improvements in production processes (Sollazzo et al., 2020)
(Franzitta et al., 2020)
In the production of heavy rare earth oxides in China, primary data provided insights into the specific environmental impacts associated with local mining practices, which differ from those in other regions

(Deng & Kendall, 2019)
By providing detailed and specific information, primary data supports better decision-making in the design and improvement of production processes. In the construction sector, focusing on foreground processes with primary data collection can significantly enhance the reliability of LCA-based decisions, particularly in regions lacking comprehensive local databases (Silva et al., 2020)
The use of primary data in the Aluminum industry has enabled the identification of key environmental impacts, such as those from electricity and thermal energy use, facilitating targeted strategies for impact reduction (Nunez & Jones, 2016)
While primary data is invaluable for accurate LCAs, it is often challenging to collect due to resource constraints and the complexity of production processes.

Challenges with primary data collection
The collection of primary data in LCA presents several challenges that can significantly impact the accuracy and reliability of the assessment results. These challenges stem from the complexity of data collection processes, the variability in data quality, and the inherent difficulties in capturing comprehensive and representative data across different stages of a product's life cycle. One of the primary challenges is the lack of available data, which often necessitates the use of approximations and assumptions. This can introduce significant uncertainty into LCA results, as seen in the case of estimating CO_2 emissions from coal-fired power plants where regression models were used to fill data gaps (Steinmann et al., 2014)
The quality of data is crucial for reliable LCA outcomes. Issues such as precision, completeness, and representativeness of data can vary significantly, affecting the reliability of the assessment. Different methods of Life Cycle Inventory (LCI) documentation can yield varying levels of data quality, making it challenging to select the most appropriate method (Saxcé et al., 2012)
Collecting primary data is often a time-intensive process, requiring significant effort to gather site-specific information. This is particularly evident in industries like road construction, where detailed data collection is necessary to assess environmental impacts accurately (Sollazzo et al., 2020)
The need for skilled personnel to collect and analyze data can be a limiting factor. The use of skilled interviewers and the need for precise data capture methods further complicate the process (Bradley, 2013)
Integrating data from various sources and ensuring compatibility with existing systems is another significant challenge. This requires careful consideration of data formats and the development of information systems that can support diverse stakeholders throughout the product life cycle (Carlson et al., 2005)
Ensuring consistency and reproducibility of data across different assessments is essential for compliance with standards like ISO 14044. This involves addressing issues related to geographic and technology coverage, as well as managing data uncertainty (Cooper & Kahn, 2012)
While these challenges highlight the complexities involved in obtaining primary data for LCA, they also underscore the importance of developing robust methodologies and frameworks to address these issues.
Primary data share as an indicator of quality and specificity
The measure of primary data share as a quality indicator in LCAs is proposed as it is crucial for ensuring the accuracy and reliability of environmental impact evaluations. The use of primary data in LCAs can significantly influence the outcomes and interpretations of environmental assessments, as it enhances the specificity and relevance of the data used. Primary data offers a detailed and accurate depiction of the

processes under study, which is essential for precise environmental impact assessments. For instance, in the Italian electricity generation mix, primary data from thermoelectric power plants provided more reliable results compared to secondary data, highlighting the importance of using primary data for robust LCA outcomes (Monache et al., 2024)

In the cement industry, primary data collected from Indian cement plants allowed for a more accurate assessment of environmental impacts, such as CO2 emissions, and facilitated the identification of process improvements (Basavaraj & Gettu, 2024)

The quality of LCA data is often assessed using DQIs, which consider factors such as technological, geographical, and temporal representativeness. Primary data typically scores higher on these indicators due to its direct relevance and specificity (Carlesso et al., 2024)

(Tian, 2003)

Primary data reduces uncertainty in LCA models by providing more precise input data, which is crucial for reliable decision-making. This is particularly important in sectors like fiber-reinforced polymer composites, where data quality and traceability are significant concerns (Dissanayake, 2022)

This is particularly important in sectors where environmental impacts are closely scrutinized, such as energy production, manufacturing, and materials processing. The following sections explore the role of primary data in LCAs, its impact on data quality, and the methodologies for assessing data quality. Various methodologies, such as pedigree matrices, are used to assess and communicate data quality in LCAs. These methods evaluate data based on attributes like age, geographic relevance, and acquisition method, and are essential for ensuring the reliability of LCA results (Edelen & Ingwersen, 2018)

(Kennedy et al., 1997)

Conclusion

In conclusion, the integration of primary data into Life Cycle Assessments (LCAs) serves as a critical factor in enhancing the accuracy, reliability, and relevance of environmental impact evaluations. As demonstrated throughout this research, primary data provides a specific and detailed representation of the processes and conditions at particular sites, thereby facilitating more precise assessments of environmental impacts. This is especially pertinent in industries where variability in data quality can lead to significant discrepancies in LCA outcomes. The challenges associated with primary data collection, including resource constraints and the need for skilled personnel, highlight the importance of developing robust methodologies and frameworks to improve data acquisition and integration. By adopting the measure of primary data share as a quality indicator, practitioners can better assess the specificity and reliability of their LCAs, ultimately contributing to more informed decision-making and effective strategies for sustainability. This research underscores the necessity of prioritizing primary data in LCA practices to support the transition towards sustainable development and circular economy initiatives.

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