https://doi.org/10.53587/25792865-2025.14-46

ENVIRONMENTAL ASPECTS OF PRODUCT IMPACT ON THE ENVIRONMENT WITHIN THE LIFE CYCLE FRAMEWORK

Konishi R., Yamaoka J.

Environmental Control Center Co., Ltd.,
Tokyo, Japan

The article examines the methodology of Life Cycle Assessment (LCA) as a universal scientific and analytical tool for the quantitative evaluation of the environmental impacts of goods and services at all stages of their life cycle from raw material extraction and production to use, disposal, and recycling. The conceptual essence of LCA is revealed, along with its significance under the conditions of escalating global environmental challenges, including climate change, depletion of natural resources, and the growth of waste volumes. Particular attention is paid to the role of LCA in identifying hidden environmental costs and preventing erroneous conclusions that may arise when analyzing individual stages of a product's life cycle.

The article analyzes the main areas of LCA application in industry, corporate environmental management, and public policy. The regulatory and methodological framework of LCA, established by international standards ISO 14040/14044, is considered, and the key stages of the study are described in detail.

Special attention is devoted to Japanese practice in applying LCA, including the use of the LIME method for integrated eco-economic impact assessment, as well as institutional examples of mandatory LCA implementation. In conclusion, it is emphasized that despite methodological uncertainties and the necessity of expert assumptions, LCA remains one of the most effective tools for systemic evaluation of the environmental consequences of products and for scientifically substantiated support of sustainable development.

Keywords: *Life Cycle Assessment (LCA), environmental impact, carbon footprint (CFP), environmental sustainability, ISO 14040, ISO 14044, environmental certification, environmental assessment methodology.*

1. What is Life Cycle Assessment (LCA)?

In everyday life, indiviaduals continuously interact with a wide range of goods and services – from household appliances and vehicles to food products and service facilities. Their creation, operation, and subsequent disposal require large volumes of heterogeneous resources: agricultural raw materials (such as vegetables, grains, and meat), industrial materials (including

---

Correspondence address: Konishi Ryosuke, deputy manager of Research and Consulting division, Environmental Control Center Co., Ltd., Tokyo, Japan, 3-7-23 Sanda-machi, Hachioji, Tokyo P.O.193-0832, Tel: +81-42-673-0503, e-mail: rkonishi@kankyo-kanri.co.jp metals and polymers), as well as various forms of energy, including electrical and thermal. Importantly, resource and energy consumption occurs not only at the production stage, but also during the operational phase and at the stage of waste management associated with the end of a product's life cycle. For example, a refrigerator requires continuous electrical power throughout its period of use, while its decommissioning and transportation for recycling demand additional fuel and logistical resources.

To obtain an objective and quantitatively substantiated understanding of the environmental impact of a product or service, the Life Cycle Assessment (LCA) method has recently been increasingly applied. Its fundamental value lies in the ability to identify hidden environmental costs that remain undetectable when analyzing isolated stages of production or operation.

In the context of escalating global environmental challenges-primarily climate change, depletion of natural resources, and the growing volume of waste, the relevance and significance of LCA are substantially increasing. The methodology makes it possible to move from a fragmented perception of environmental performance to a systemic understanding of how decision-making at one stage of a product's life cycle may generate significant consequences at other stages.

This approach makes it possible to analyse the full range of environmental consequences - from raw material extraction and preparation, through manufacturing and use, to end-of-life scenarios such as disposal, recycling, or final landfilling. LCA covers a broad set of environmental indicators, including resource consumption, pollutant emissions, and impacts on the climate system, ecosystems and human health.

The relevance of Life Cycle Assessment (LCA) at the present stage is determined by several key factors. First, the tightening of international and national environmental standards requires manufacturers to provide more accurate reporting on the environmental impact of their products, which makes LCA one of the essential instruments for assessing corporate compliance with environmental requirements. Second, the growing interest in "green" technologies and sustainable consumption is generating a demand for comparable and scientifically grounded data that enable a correct evaluation of alternative solutions. Third, the rising attention to carbon footprint (CFP) issues stimulates the application of LCA for calculating and subsequently optimizing greenhouse gas emissions throughout the complete life cycle of a product.

Figure 1 presents a comparative assessment of carbon dioxide (CO_2) emissions, one of the key drivers of global climate change for two products, conventionally referred to as A and B. When considering only the production stage, Product B demonstrates a lower carbon footprint (CFP) and may, therefore, be misinterpreted as the more environmentally preferable option (left graph). However, when the full life cycle is accounted for including raw material extraction, transportation, use phase, and end-of-life disposal the total carbon dioxide emissions are lower for Product A (right graph). This outcome highlights a fundamental principle of the LCA methodology: the environmental superiority of a product cannot be accurately determined without an assessment encompassing all stages of its life cycle.

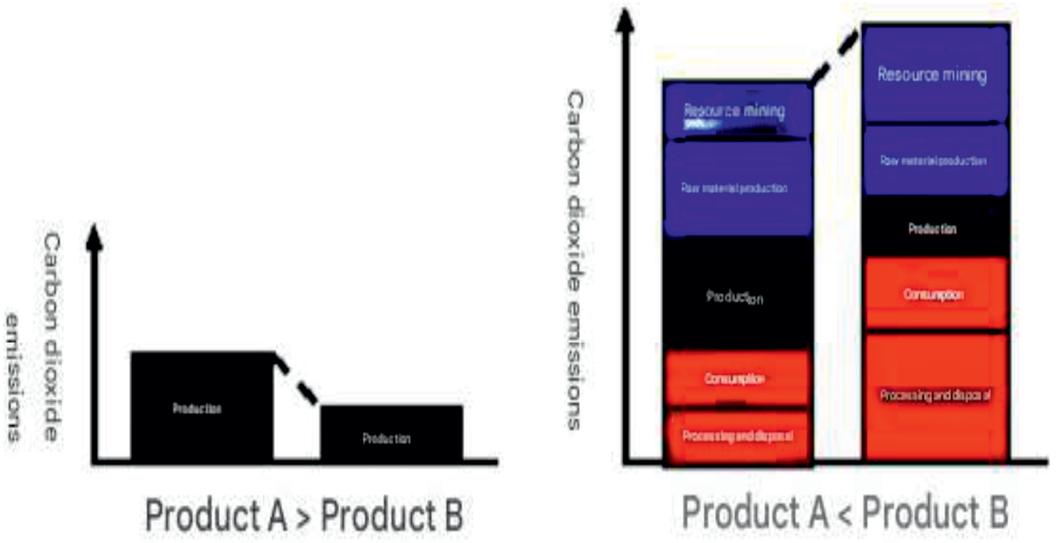

Figure 1. Comparison of product-related CO_2 emissions (example)
Source: National Institute for Environmental Studies (NIES),[1].

Thus, LCA functions not merely as an analytical method but also as a strategic tool, providing scientifically grounded support for the development of environmentally oriented products, the design of low-impact supply chains, and the formulation of responsible governmental and corporate environmental policies.

2. When do you perform an LCA study?

The LCA methodology is applied across an exceptionally wide range of professional, industrial, and regulatory contexts. It is used not only in the development of fundamentally new products, but also for comparing alternative design solutions, selecting materials with a lower environmental profile, assessing the viability of innovative technologies, and planning the transition from linear to circular production models.

At early stages of product design, LCA enables the forecasting of environmental consequences associated with different technical concepts even before the start of industrial manufacturing, which makes this tool indispensable for engineering analysis, strategic planning, and technology risk management.

At all stages of upgrading or optimizing existing production processes, LCA serves as a scientifically grounded approach for the detailed mapping of material and energy flows, identifying emission and resource-consumption “hot spots”, evaluating the degree of technological obsolescence of equipment, and determining critical elements of supply chains.

The LCA methodology is also applied as a decision-support instrument: it enables companies to build realistic decarbonization pathways, compare the effectiveness of various measures aimed at reducing environmental impacts, justify investments in green technologies, optimize logistics systems, and analyze the potential advantages of using secondary raw materials.

The integration of LCA results into corporate sustainability management systems improves the accuracy of environmental monitoring, strengthens operational transparency, and supports regulatory compliance under increasingly stringent international market requirements.

From a practical perspective, the implementation of LCA becomes increasingly relevant in situations where it is necessary to quantitatively validate the environmental advantages of a product, fulfill ecological certification criteria, prepare environmental declarations (such as EcoLeaf[*], CFP[**], and others), and ensure transparency in corporate reporting in compliance with international standards. In the sphere of public policy, LCA functions as an analytical instrument for developing regulatory requirements, shaping environmentally oriented industrial and energy strategies, and evaluating the introduction of innovative materials and technologies. For companies, a significant incentive to conduct LCA lies in the need to comply with regulatory demands particularly when entering markets where CFP calculations are mandatory or where minimum environmental performance thresholds have been established.

The range of environmental aspects analyzed within LCA encompasses an extensive set of impact categories: atmospheric emissions, photochemical smog formation, human and ecosystem toxicity, ozone layer depletion, acidification and eutrophication processes, energy consumption, natural resource depletion, and impacts on biodiversity. In recent years, a noticeable shift has occurred toward the quantitative assessment of CFP as a key indicator of the climate resilience of products. Alongside this trend, requirements have intensified for calculating the water footprint, analyzing the use of secondary resources, and evaluating contributions to the circular economy.

A characteristic example of institutionalized LCA integration is the European Battery Regulation, which establishes the mandatory calculation of the carbon footprint for all categories of batteries placed on the EU market. Under this regulation, starting in 2025, a CFP declaration must include a properly executed LCA study covering all stages of the life cycle. For instance, one of the leading lithium-ion battery manufacturers conducted a comprehensive LCA assessment that incorporated lithium extraction and processing, cathode and anode production, battery assembly, logistics, and end-of-life management.

The analysis revealed that up to 70% of the total carbon footprint is generated during the early stages of raw material extraction and processing, while approximately 20% originates from component manufacturing. Based on these findings, the company implemented more energy-efficient production procedures, optimized transportation routes, and shifted to the use of partially

---

[*] EcoLeaf environmental label uses the LCA method to quantitatively show the environmental information of products through life cycle stages from the extraction of resources to manufacturing, assembly, distribution, use, discarding and recycling. EcoLeaf has been integrated with CFP (see below) and operated as “Japan EPD Program by SuMPO” since 2022. (Sustainable management Promotion Organization)

[**] CFP (Carbon Footprint of Products) is the amount of greenhouse gases emitted throughout the entire lifecycle of a product or service, from the procurement of raw materials to disposal and recycling, expressed as carbon dioxide (CO_2) equivalent.

recycled raw materials, which enabled a 15–20% reduction in the product CFP and ensured compliance with the new EU requirements.

3. LCA Study Methodology

The Life Cycle Assessment methodology is formalized by the international standards series ISO 14040 and ISO 14044, which constitute the fundamental regulatory framework for conducting environmentally oriented analytical studies [3]. These standards regulate conceptual principles, terminological consistency, mandatory procedural requirements, and data quality criteria, thereby ensuring comparability of results, their reproducibility, and methodological transparency.

ISO 14040 defines the general concepts and the structural framework of LCA, including four core phases, rules for establishing system boundaries, principles for determining the functional unit, and requirements for result interpretation (see Fig. 2).

ISO 14044 specifies methodological prescriptions, including:

- criteria for the inclusion and exclusion of material and energy flows,
- procedures for assessing data quality (completeness, accuracy, temporal and geographical representativeness),
- requirements for sensitivity and uncertainty analysis,
- rules for critical review, ensuring an independent evaluation of the validity of conclusions.

Together, these standards form a universal methodological framework applicable both to detailed full life cycle assessments and to screening LCA studies widely used in industrial environmental management, sustainable product design, the development of environmental product declarations, and the formation of environmentally oriented public policy.

Accordingly, an LCA study proceeds through four major phases:

3.1. Goal and Scope Definition

At the initial stage, the goal and scope of the study are formulated. The scope definition includes:

- the functional unit, which provides a quantitative measure of the product’s useful function (e.g., 1 kg of product or 1000 use cycles),
- system boundaries, defining the life cycle stages included in the assessment (cradle-to-gate, cradle-to-grave, etc.),
- geographical and temporal representativeness,
- environmental impact categories to be evaluated (global warming, eutrophication, resource depletion, photochemical oxidation, etc.),
- data characteristics, including the use of primary (site-specific) and secondary (literature-based or database-based) data.

A precise definition of the goal and scope ensures methodological consistency and enables accurate interpretation of results in accordance with the research objectives-whether the study aims at comparative LCA, technological process optimisation, or preparation of environmental reporting (e.g., an Environmental Product Declaration, EPD).

3.2. Life Cycle Inventory (LCI) Analysis

The life cycle inventory analysis is a structured quantitative assessment of all material and energy flows entering and leaving the system. At this stage, the following are determined:

- Input flows – raw materials, water, auxiliary materials, fuel, and energy sources,
- Output flows – atmospheric emissions, wastewater, solid waste, and by-products.

Example for office paper:

- Inputs: A kg of cellulose, B kW of electricity, C kg of chemical reagents,
- Outputs: D kg of solid waste, E liters of wastewater.

Inventory analysis shows what and how much was used at which stage, and what sort of environmental load substances were emitted.

Databases are used to calculate environmental impacts based on the inputs obtained from inventory analysis. Databases used in inventory analysis include the IDEA database developed by the National Institute of Advanced Industrial Science and Technology (AIST) and the Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables (3EID) provided by the National Institute for Environmental Studies.

3.3. Impact assessment (LCIA).

Life Cycle Impact Assessment (LCIA) is aimed at transforming inventory data into quantitative indicators of environmental damage across selected impact categories. The stage includes:

- Classification - allocation of flows to impact categories,
- Characterization - application of factors that reflect causal relationships between emissions and environmental effects,
- If necessary - normalization, weighting, and aggregation of results.

In Japanese practice, the LIME method occupies an important place, enabling the conversion of impact indicators into the monetary expression of environmental damage. This approach ensures cross-category comparability and allows for integral assessment, for example, the calculation of the cumulative eco-economic damage (in US dollars) from producing a paper cup with a mass of 1 kg, accounting for contributions from global warming, degradation of water resources, air pollution, and other factors.

3.4. Interpretation.

The interpretation stage is aimed at the analytical comprehension of the obtained results in light of the original research objectives. It includes:

- Verification of completeness and correctness of data,
- Sensitivity assessment of key parameters,
- Analysis of internal consistency of methodological choices,
- Identification of sources of uncertainty and evaluation of their influence on final conclusions,

When methodological limitations or inconsistencies are identified, the process returns to previous stages to adjust system boundaries, initial hypotheses, or input data. The interpretation stage ensures the scientific substantiation, transparency, and validity of the final LCA conclusions.

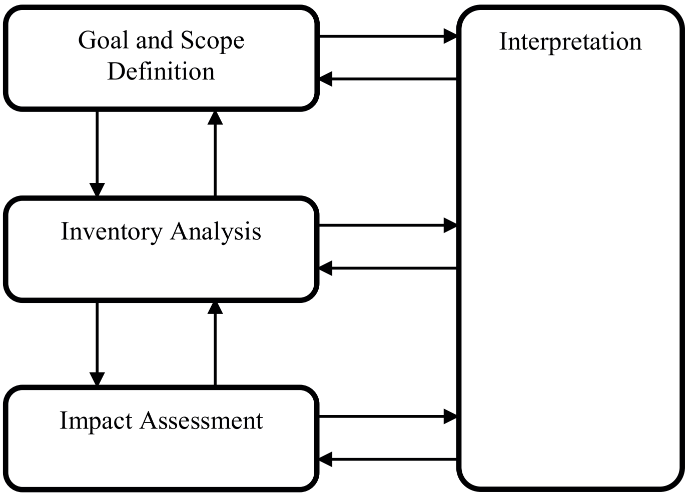

Figure 2: LCA framework according to ISO14040

4. Conclusion

International standards of the ISO 14040/14044 series establish the fundamental principles, structure, and requirements for conducting product life cycle studies. However, the practical implementation of the LCA methodology is inevitably associated with a number of methodological and organizational challenges. Among the most typical issues arising during assessment, the following can be highlighted:

- whether to include a particular process in the model, especially in the case of complex or branched production chains,
- how to correctly account for energy consumption when production facilities are simultaneously used for manufacturing several types of products,
- how to allocate impacts in situations where waste streams are returned to the technological cycle or utilized as secondary raw materials.

There are no uniquely correct answers to these questions, and the standards themselves imply the necessity of research judgments. However, careful justification of assumptions, transparency of the criteria for their selection, and continuous orientation toward the goals and scope of the study make it possible to ensure the reliability and reproducibility of results. It is precisely the analytical reflection on the validity of assumptions and scenarios that makes the LCA method a valuable tool, capable of revealing the actual environmental consequences of a product's life cycle.

Concluding the presentation of methodological principles and practical aspects of conducting LCA, it is appropriate to indicate authoritative sources containing extended explanations, examples, and materials for independent study. Below is a list of resources that may be useful for a deeper understanding of the concept and application of life cycle assessment (unfortunately, some of the sources are available only in Japanese).

More about LIME, by LCA Society of Japan (JLCA),
https://lca-forum.org/english/lime/

(1) Environmental Technology Commentary Life Cycle Assessment (LCA), by National Institute for Environmental Studies (NIES)
https://tenbou.nies.go.jp/science/description/detail.php?id=57

(2) Carbon Footprint Guidelines, Ministry of Economy, by Trade and Industry (METI), Ministry of the Environment (MOE)
https://www.meti.go.jp/policy/energy_environment/global_warming/LCA_CFP/LCA_CFP.html

References

1. National Institute for Environmental Studies (NIES) website https://www-cycle.nies.go.jp/magazine/mame/20070702.htm (accessed Nov 25, 2024)
2. Sustainable management Promotion Organization (SuMPO) website https://www.ecoleaf-jemai.jp/eng/element.html (accessed Nov 25, 2024)
3. ISO (International Organization for Standardization). 2006. Environmental management-Life cycle assessment-Principles and framework. ISO 14040:2006.

ԱՐՏԱԴՐԱՆՔԻ ԱԶԴԵՑՄԱՆ ԷԿՈԼՈԳԻԱԿԱՆ ԱՍՊԵԿՏՆԵՐԸ ԿՅԱՆՔԻ ՑԻԿԼԻ ՇՐՋԱՆԱԿՈՒՄ

Կոնիշի Ռ., Յամաոկա Զ.

Հոդվածում դիտարկվում է արտադրանքի կյանքի ցիկլի գնահատման (Life Cycle Assessment, LCA) մեթոդաբանությունը՝ որպես համընդհանուր գիտավերլուծական գործիք, որը հնարավորություն է տալիս քանակականորեն գնահատել ապրանքների և ծառայությունների ազդեցությունը շրջակա միջավայրի վրա կյանքի ցիկլի բոլոր փուլերում՝ հումքի արդյունահանումից և արտադրությունից մինչև շահագործում, օգտազրկում և երկրորդային վերամշակում: Բացահայտվում է LCA-ի հայեցակարգային էությունը, դրա նշանակությունը գլոբալ աճող էկոլոգիական մարտահրավերների պայմաններում, ներառյալ՝ կլիմայի փոփոխությունը, բնական ռեսուրսների սպառումը և թափոնների ծավալների աճը: Հատուկ ուշադրություն է դարձվում LCA-ի դերին՝ թաքնված էկոլոգիական ծախսերի բացահայտման և սխալ եզրակացությունների կանխման գործում, որոնք կարող են առաջանալ արտադրանքի կյանքի ցիկլի առանձին փուլերի վերլուծության ժամանակ:

Հոդվածում վերլուծվում են LCA-ի կիրառման հիմնական ոլորտները արդյունաբերության մեջ, կորպորատիվ էկոլոգիական կառավարման և հանրային քաղաքականության շրջանակներում: Դիտարկվում է LCA-ի նորմատիվ-մեթոդական բազան, որը ձևավորվել է ISO 14040/14044 միջազգային ստանդարտներով, ինչպես նաև մանրամասն նկարագրվում են հետազոտության հիմնական փուլերը:

Հատուկ ուշադրություն է դարձվում LCA-ի կիրառման ճապոնական փորձին, ներառյալ LIME մեթոդի օգտագործումը՝ ազդեցության ինտեգրալ էկո-տնտեսական գնահատման համար, ինչպես նաև LCA-ի պարտադիր ներդրման ինստիտուցիոնալ օրինակներին: Վերջաբանում ընդգծվում է, որ, չնայած մեթոդաբանական անորոշություններին և *փորձագիտական ենթադրությունների անհրաժեշտությանը, LCA-ն շարունակում է մնալ արտադրանքի էկոլոգիական հետևանքների համակարգային գնահատման և կայուն զարգացման գիտականորեն հիմնավորված աջակցության ամենաարդյունավետ գործիքներից մեկը:*

Բանալի բառեր՝ *կյանքի ցիկլի գնահատում (LCA), ազդեցություն շրջակա միջավայրի վրա, ածխածնային հետք (CFP), էկոլոգիական կայունություն, ISO 14040, ISO 14044, էկոլոգիական սերտիֆիկացում, էկոլոգիական գնահատման մեթոդաբանություն:*

ЭКОЛОГИЧЕСКИЕ АСПЕКТЫ ВОЗДЕЙСТВИЯ ПРОДУКЦИИ НА ОКРУЖАЮЩУЮ СРЕДУ В РАМКАХ ЖИЗНЕННОГО ЦИКЛА

Кониши Р., Ямаока Дж.

В статье рассматривается методология оценки жизненного цикла продукции (Life Cycle Assessment, LCA) как универсальный научно-аналитический инструмент количественной оценки воздействия товаров и услуг на окружающую среду на всех стадиях их жизненного цикла - от добычи сырья и производства до эксплуатации, утилизации и вторичной переработки. Раскрывается концептуальная сущность LCA, его значение в условиях нарастающих глобальных экологических вызовов, включая изменение климата, истощение природных ресурсов и роста объёмов отходов. Особое внимание уделено роли LCA в выявлении скрытых экологических издержек и предотвращении ошибочных выводов, возникающих при анализе отдельных стадий жизненного цикла продукции.

В статье проанализированы основные области применения LCA в промышленности, корпоративном экологическом менеджменте и публичной политике. Рассматривается нормативно-методическая база LCA, сформированная международными стандартами ISO 14040/14044, а также подробно описаны ключевые этапы исследования.

Отдельное внимание уделено японской практике применения LCA, включая использование метода LIME для интегральной эколого-экономической оценки воздействия, а также институциональным примерам обязательного внедрения LCA. В заключении подчёркивается, что, несмотря на наличие методических неопределённостей и необходимости экспертных допущений, LCA остаётся одним из наиболее эффективных инструментов системной оценки экологических последствий продукции и научно обоснованной поддержки устойчивого развития.

Ключевые слова: *оценка жизненного цикла (LCA), воздействие на окружающую среду, углеродный след (CFP), экологическая устойчивость, ISO 14040, ISO 14044, экологическая сертификация, методология экологической оценки.*

The article was submitted: 11.02.2025
The article was accepted: 11.09.2025