Comparative Review of Life Cycle Inventory Platforms: Indonesia and Selected Countries

Nugroho Adi Sasongko
Research Center for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency

Novy Ariyanto
Research Center for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency

Isnaeni Kumalasari
Research Center for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency

Annisa Indah Pratiwi
Research Center for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency

他

https://doi.org/10.5109/7402652

出版情報：Evergreen. 12 (4), pp.2236-2252, 2025-12. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan
バージョン：

Comparative Review of Life Cycle Inventory Platforms: Indonesia and Selected Countries

Nugroho Adi Sasongko[1,2,3], Novy Ariyanto[1,3,*], Isnaeni Kumalasari[1,4], Annisa Indah Pratiwi[1,5], Virny Zasyana Eka Putri[1,3], Maya Larasati Donna Wardani[1,3], Ahmad Ismed Yanuar[1,3], Agam Wira Sani[1,3], Nurus Sahari Laili[1,4], Yoyon Wahyono[1,3], Anisah Anisah[1,3], Muhammad Raihan Farras Hakim[1,3], Edi Iswanto Wiloso[1,3], Siswanto[1,3], Kusrestuwardhani[1], Ihsan Supono[6,7], Hendro Subagyo[8,9], Acep Furqon[10]

[1]Research Center for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, Tangerang Selatan, Banten 15314, Indonesia
[2]Energy Security Graduate Program, Faculty of Defense Management, Republic of Indonesia Defense University, Bogor, Jawa Barat 16810, Indonesia
[3]Research Center for Sustainable Industrial and Manufacturing Systems, National Research and Innovation Agency, Tangerang Selatan, Banten 15314, Indonesia
[4]Directorate for Laboratory Management, Research Facilities, and Science and Technology Park, National Research and Innovation Agency, Jakarta Pusat 10340, Indonesia
[5]Research Center for Limnology and Water Resources, National Research and Innovation Agency, Bogor, Jawa Barat 16911, Indonesia
[6]Research Center for Testing Technology and Standards, National Research and Innovation Agency, Tangerang Selatan, Banten 15314, Indonesia
[7]Research Center for Electrical Technology, National Research and Innovation Agency, Tangerang Selatan, Banten 15314, Indonesia
[8]Center for Data and Information, National Research and Innovation Agency, Jl. M.H. Thamrin No. 8, Jakarta Pusat 10340, Indonesia
[9]Directorate for Repositories, Multimedia, and Scientific Publishing, National Research and Innovation Agency, Jakarta Pusat 10340, Indonesia
[10]Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, 40132, Indonesia

*Author to whom correspondence should be addressed:
E-mail: novy001@brin.go.id

(Received June 16, 2025; Revised August 15, 2025; Accepted December 16, 2025)

Abstract: Sustainability assessment is essential for industries to meet global environmental standards. This study explores Indonesia's Life Cycle Inventory (LCI) database development and its alignment with international frameworks. Through a comparative analysis of LCI roadmaps from Japan, Thailand, and Malaysia, the research identifies best practices and challenges. Findings emphasize the role of Product Category Rules (PCRs) in standardizing Life Cycle Assessment (LCA). Indonesia's LCI development, in collaboration with Japan, aims to enhance competitiveness, improve emissions quantification, and support a low-carbon transition. The study provides insights and recommendations for integrating international best practices into Indonesia's sustainability strategy.

Keywords: Life Cycle Assessment (LCA); Life Cycle Inventory (LCI); Platform; Sustainability

Cite: N. Sasongko et al., "Comparative Review of Life Cycle Inventory Platforms: Indonesia and Selected Countries". Evergreen, 12 (04) 2236-2252 (2025). https://doi.org/10.5109/7402652.

1. Introduction

The industrial response to sustainability is essential for Indonesia to preserve its competitive advantage, especially in resource-dependent sectors such as forestry, agriculture, fisheries, and mining[1,2]. These industries are foundational to the nation's economy but face mounting challenges due to increasing demand and resource depletion[3,4,5]. Quantifying the carbon footprint—denoted as carbon dioxide equivalent (CO_2e)—is crucial for evaluating greenhouse gas (GHG) emissions resulting from human activities such as fossil fuel use, industrial operations, and alterations in land use. These emissions cause environmental damage, including droughts, severe weather events, reduced water availability, and ecological changes[6,7,8].

GHG emissions, specifically carbon dioxide (CO_2) and methane (CH_4), are primary contributors to global warming due to their capacity to retain heat in the atmosphere[9-12]. Over time, the accumulation of GHG emissions triggers climate change, which has boarder impacts such as flooding caused by rising sea levels, starting with ice melting at the Earth's poles due to global warming[13,14,15]. Changes in the Earth's climate can also increase the frequency and intensity of extreme weather events such as hurricanes and unusual heat waves[16,17]. In addition, climate change is damaging the life of marine ecosystems, such as coral reefs, which are very important in Indonesia[18,19,20].

To address these challenges, institutions can assess their emissions using the GHG Protocol, which categorizes emissions into Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased energy), and Scope 3 (indirect emissions across the value chain)[21,22,23]. This classification provides a structured approach to identifying emission sources and implementing effective mitigation strategies[24,25,26].

In parallel with emission management, the concept of a "green product" has emerged, which refers to products designed with the primary objective of minimizing environmental impacts throughout their lifecycle[27,28]. These products aim to minimize their carbon footprint, reduce resource consumption, and minimize adverse environmental effects throughout their life cycle1[29,30,31].

The concept of a green product encompasses several vital principles: (1) Environmental Responsibility: Reducing energy use, GHG emissions, and resource depletion[32]; (2) Sustainable Sourcing: Using renewable or recycled materials to conserve natural resources[33]; (3) Energy Efficiency: Consuming less electricity, water, or fuel during use; (4) Low Toxicity: Reducing toxic chemicals for safety; (5) Longevity and Durability: Designed to last longer and reduce replacements; (6) Minimal Waste: Producing less waste, often recyclable or biodegradable; (7) Minimal Environmental Impact: Reducing ecological footprints from production to disposal; and (8) Eco-Friendly Labels and Certifications: Certifications like Energy Star, USDA Organic, and Fair Trade confirm environmental credentials[34].

To standardize green products, Product Category Rules (PCRs) are essential[35]. PCRs are specific guidelines and rules developed for a particular product category within the context of LCA[36,37]. They are used to standardize the assessment process for products in the same category, ensuring consistency and comparability of environmental performance data[38-41]. In Life Cycle Assessment (LCA), PCRs relate green products by providing a framework for evaluating the environmental performance of green products within specific product categories [42,43,44]. PCRs help manufacturers identify improvement areas, ensuring transparency, credibility, and consistency in promoting sustainability in product design [45,46,47].

Indonesia has demonstrated its commitment to sustainability through Presidential Regulation No. 98/2021, addressing the economic value of carbon and setting the stage for a carbon tax to mitigate climate change[48,49]. On the global stage, the EU has implemented the most extensive carbon pricing system in the world, the Emissions Trading System "ETS"[50,51]. They would introduce a new Carbon Border Adjustment Mechanism (CBAM) and plan to collect the tax in stages, starting in 2026[52,53,54]. They propose to implement the CBAM mechanism in a phased manner for specific goods from non-EU countries[55,56]. The CBAM will initially be implemented on imports within five sectors that are considered emissions-intensive and face a higher risk of carbon leakage. These sectors are cement, iron and steel, aluminum, fertilizers, and power, requiring non-EU countries to meet equivalent carbon costs[57-61].

CBAM entered its transitional phase in 2023[62,63]. During this period, importers are required to report emissions data for certain carbon-intensive goods without paying fees[64,65]. If the entrepreneur wants to export products included in the scope of CBAM, the first thing the entrepreneur must do is get permission from the authorities and then declare the shipped goods[66,67,68].

A "Deforestation-Free Product" (DFP) is a product manufactured or produced in a way that does not contribute to deforestation[69]. Deforestation refers to clearing forests, typically converting the land for agriculture, logging, or other forms of development[70,71]. It has significant environmental and social impacts, including the loss of biodiversity, disruption of ecosystems, and contributions to climate change[72,73,74]. DFP initiatives and certifications have emerged as a response to the need for sustainable and environmentally responsible production practices[75,76]. Companies and organizations that produce DFPs commit to sourcing their raw materials and ingredients from suppliers who adhere to strict environmental standards, particularly regarding forest conservation[77]

DFPs are often associated with products that use palm oil, soy, beef, and paper, linked to deforestation in some regions[78]. Companies that promote DFPs aim to reduce their environmental footprint and contribute to preserving of forests and the ecosystems they support[79]. Consumers concerned about deforestation and its environmental impacts may choose to support DFPs to make more sustainable choices in their purchasing decisions[80,81,82]. However, verifying the claims and certifications associated with such products is essential to ensure their credibility and effectiveness in combating deforestation.

In the context of the proposed carbon trading regulations, several sectors are of primary focus, including cement, palm oil, iron and steel, and soybean sectors[83]. Additionally, the aluminum, cocoa, and fertilizer sectors are also included in these regulations[84,85]. Energy resources such as natural gas, oil, and coal, as well as the livestock sector, which includes beef and cattle, are significant components of this discussion[86,87,88,89]. Other relevant energy sectors include electricity, timber, and wood pulp, as well as commodities such as coffee and rubber[90,91,92]. These sectors will be impacted by carbon-related trade regulations, in line with regional regulatory frameworks such as the EU's CBAM and the US carbon border policies[93-97]. Therefore, these sectors are crucial for Indonesia's export industry and must adapt to emerging regulations to maintain competitiveness in global markets. Given that products from these sectors, such as palm oil and soybeans, are often associated with deforestation issues, it is essential for companies to adopt DFP practices to meet the growing market demand for sustainability[98,99].

To comply with CBAM and DFPs, in the context of environmental sustainability and transparency in product labeling, CBAM and DFPs need PCRs[100,101,102]. Relevance to DFPs, when claiming that a product is deforestation-free, there is a need for transparent and standardized criteria to define deforestation-free production. PCRs can be developed for specific product categories (e.g., palm oil, soy, and timber) to establish the LCA methodology for assessing the impact of deforestation and ensuring that products meet the deforestation-free criteria[103,104]. CBAM can use LCA and PCR methodologies to accurately assess the carbon footprint of imported products[105]. This assessment involves considering emissions associated with production processes, transportation, and potentially the carbon intensity of the energy used[106,107]. When assessing the carbon footprint of imported goods, CBAM can also consider the carbon intensity of the energy sources used in their production, which aligns with LCA principles[108,109,110].

Applying LCA and PCR methodologies enables the evaluation of supply chain environmental impact and ensures compliance with deforestation-free criteria for DFPs[111,112]. LCA and PCR methodologies play a crucial role in both the implementation of CBAM and the certification of DFPs. They provide the scientific foundation for assessing environmental impacts and ensuring the transparency and credibility of claims related to carbon emissions and deforestation-free practices in various product categories[113,114,115].

In recent years, several Southeast Asian countries have made significant strides in developing national Life Cycle Inventory (LCI) databases to support environmental sustainability and carbon management[116,117,118]. Thailand has established the Thai National LCI Database, focusing on key sectors such as energy and agriculture[119,120,121]. Malaysia, through SIRIM, has developed its own LCI database to enhance transparency in industrial processes[122,123]. Indonesia, in collaboration with Japan and Thailand, is working on expanding its LCI database, focusing on key export commodities. Despite these efforts, the integration and harmonization of these national databases, particularly in relation to the Global Database of PCR, remain underexplored.

This study addresses this gap by analyzing the Global Database of PCR and its applications across industries, comparing LCI database development procedures in Southeast Asia, and outlining a roadmap for establishing Indonesia’s LCI database in collaboration with Japan, Thailand, and Malaysia. Understanding these integration pathways is essential for enhancing sustainability performance, improving international trade readiness, and reducing environmental impacts in line with global standards[124,125].

2. Methodology

This research undertook an extensive qualitative analysis, focusing on the Global Database of PCR and it is application across industries and supply chains[126,127,128]. It involved a comparative assessment of National Life Cycle Inventory (LCI) database development procedures in diverse countries. Notably, the study emphasized elucidating the roadmap employed in partnership with AIST, Japan for establishing Indonesia’s LCI database.

Based on Figure 1, the methodology involved evaluating LCI database development procedures in countries such as Japan, Thailand, and Malaysia to identify best practices and challenges. It also analyzed Japan’s Inventory Database for Environmental Analysis (IDEA) formats to assess their applicability for structuring Indonesia’s LCI database[129]. Furthermore, the study examined the significance of National PCRs in standardizing Life Cycle Assessment (LCA) across international contexts, supported by case studies from Japan, Thailand, Malaysia, and Indonesia. Challenges and opportunities specific to Indonesia’s environmental sustainability efforts and LCA management were also identified and addressed.

The findings highlighted the pivotal role of PCRs in

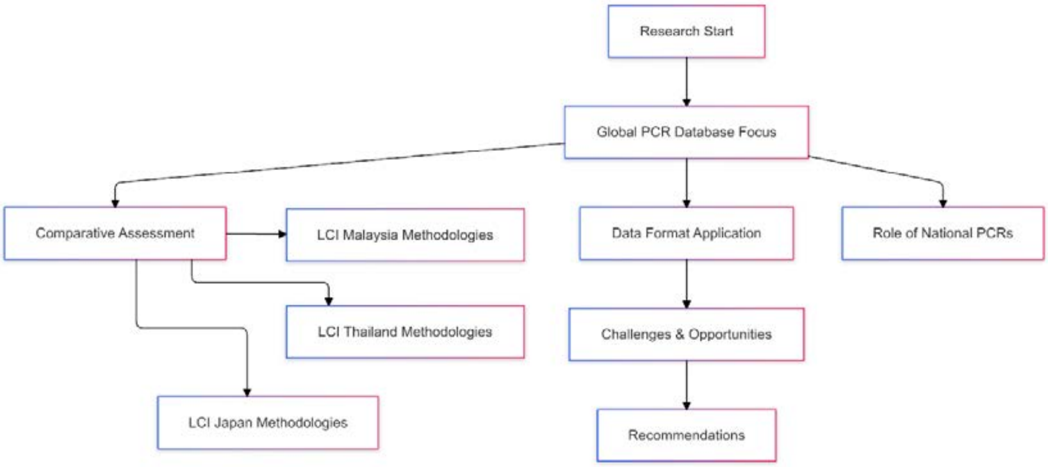

Fig. 1: Research Flowchart

ensuring consistency, reliability, and comparability in LCA studies. The study emphasized the necessity of developing tailored PCRs and industry-specific LCI databases to enable more precise environmental impact assessments and informed decision-making. Based on these findings, the research proposed a comprehensive strategy for advancing the development of industry-specific PCRs and improving LCI database infrastructure to support Indonesia's sustainability goals.

The following outlines the stages involved in writing the article:

- Preparation

The author identifies a problem or establishes a theme to be explored in the article concerning the LCI platform for industries in Indonesia.

- Literature Review

This stage involves reviewing relevant studies and references related to the development of the LCI platform in Indonesia. The focus is on the national LCI database and PCRs to understand existing developments, challenges, and standards. This review serves as a foundation for further research in developing an LCI platform tailored to Indonesia's needs. A structured search was conducted in Scopus, Web of Science, and Google Scholar (January 1991–June 2025) using combinations of "life cycle inventory", "LCI", "platform", "database", "development", "establishment", and the country names Japan, Thailand, and Malaysia. The search yielded 40, 31, and 60 records, respectively. Only peer-reviewed journal articles relevant to national or sectoral LCI database development or PCR frameworks in English were included; proceedings, reports, corporate-level LCIs, and studies lacking methodological detail were excluded. After screening titles, abstracts, and full texts, 20 journal articles were retained for qualitative synthesis, ensuring transparency and reproducibility in the literature selection process (Table 1).

- Article composition

The writing process incorporates references from conference proceedings, national and international journal articles, books, workshops, and official websites. During this phase, the author presents the current status of LCI platform development in other countries and compares it with the needs in Indonesia, beginning with the background of the issue, the objectives of the article, and concluding with the results and recommendations.

3. Results and Discussion

3.1. Literature of Development and Application of LCI Platform

We conducted an analysis of recent journals discussing the model, development, and implementation of LCI platforms (including databases) in Japan, Thailand, and Malaysia, as presented in Table 1.

Research from Japan, Thailand, and Malaysia provides valuable insights for the development of LCI platforms in Indonesia, each with a focus relevant to the local context. Japan, with its advanced development of LCA methodologies and the implementation of LCI database systems across various industrial sectors, serves as an example of how a country can establish an integrated environmental data system for policymaking and natural resource management[130-133]. In contrast, Thailand demonstrates the application of LCA in the agriculture and renewable energy sectors, particularly for biomass-based products such as rubber and corn, which could inspire Indonesia in managing the environmental impacts of agriculture and the development of renewable energy[134-137]. Meanwhile, Malaysia, having developed normalization values and LCI weighting based on local data, emphasizes the importance of a context-based approach in designing LCI platforms tailored to national needs[138-141]. From these three countries, Indonesia can draw lessons on adapting LCI methodologies and systems to local conditions, as well as the significance of collaboration between government and industry to ensure the successful implementation of LCI platforms that support sustainability policies.

3.2. A Comparison of National Life Cycle Inventory (LCI) Databases Roadmap

The roadmap for the development of national Life Cycle Inventory (LCI) databases demonstrates significant variations between countries, reflecting their distinct approaches and levels of maturity in life cycle assessment (LCA) practices[142]. The development roadmap of two countries that have partnered with Indonesia in establishing its national LCI database—Japan and Thailand—provides valuable insights into best practices and challenges. Japan, a pioneer in LCA practices, began its journey in 1995. Unlike many nations adhering to the United Nations Environment Programme (UNEP) guidance, Japan followed an independent pathway that emphasized self-reliance and innovation. With a focus on creating extensive data repositories, Japan has cemented its global leadership in the field. In contrast, Thailand has adopted a more regional approach, aligning with Southeast Asian sustainability goals while integrating lessons from international practices.

Indonesia's initiative, spearheaded by the Agency for the Assessment and Application of Technology (BPPT) and subsequently managed under the National Research and Innovation Agency (BRIN), was conceptualized in 2019. Indonesia's roadmap, depicted in Figure 2, aims to emulate the strengths of both regional and international examples, incorporating best practices from global leaders like Japan.

LCI constitutes an essential element within the life cycle assessment (LCA) framework, a methodology for evaluating the environmental consequences of products or processes across their complete life cycle, encompassing activities from raw material acquisition to disposal. LCI involves collecting data on the resources (e.g., materials, water, energy) used and the by products (e.g., emissions, waste) generated at each stage of the product's life cycle. LCI databases are data repositories providing information on the environmental impacts of various products, processes, and materials. These databases serve as the foundation for accurate, comparable, and systematic LCA.

The integration of international standards, such as the Greenhouse Gas (GHG) Protocol, is essential in ensuring the comparability and reliability of LCI databases. The GHG Protocol categorizes emissions into three scopes:

- Scope 1 (Direct Emissions): Emissions originating from sources that are directly owned or controlled by the business, including fuel combustion in manufacturing facilities or company-operated vehicles.
- Scope 2 (Indirect Emissions): Emissions arising from the production of acquired energy, including electricity, steam, or heat utilized by the company.

Scope 3 (Other Indirect Emissions): Emissions generated throughout the value chain, encompassing both upstream and downstream operations, including raw material extraction, transportation, distribution, waste disposal, and product utilization.

By aligning its LCI database development with the GHG Protocol, Indonesia can enhance the capacity to quantify emissions across all scopes, ensuring transparency and compliance with international sustainability standards. This approach will provide robust data to assess environmental impacts, monitor pollution sources, and identify opportunities for mitigation. Lessons from Japan's roadmap underscore the importance of incorporating global standards into national databases to establish a comprehensive and internationally recognized LCI database, facilitating informed policymaking and industrial practices.

3.3. Data Format for National Life Cycle Analysis (LCA) Databases

The organization of data within LCI databases is critical to ensuring accessibility and usability. Japan's LCI database, maintained by IDEA, employs a highly structured data format that facilitates efficient retrieval and utilization. Two primary components define this format:

Item Code: A 9-digit identifier created by combining a classification code (6 digits) with a 3-digit identification number. Zeros are added to the classification code to achieve the required length.

Product Code: A 13-digit identifier that includes the 9-digit item code, a single-digit attribute flag, and a 3-digit country code.

This structured approach, ensures that data is organized systematically, allowing for easy identification and analysis. The adoption of such formats in Indonesia's LCI database development can significantly enhance data organization and user-friendliness. This format's clarity and efficiency will support more accurate and consistent environmental assessments.

Adopting the IDEA data format provides Indonesia with a standardized framework that aligns with international practices, enabling greater interoperability and comparability of environmental data. This alignment will support Indonesia's integration into global sustainability initiatives and enhance its capacity for environmental monitoring and decision-making.

3.4. National Product Category Rule (PCR) Development

PCRs are typically developed by industry associations, environmental organizations, or regulatory bodies to ensure consistency and comparability in LCA studies for similar products[144]. PCRs specify aspects such as the functional unit, system boundaries, data sources, allocation methods, and impact categories to be considered when

Table 1: Literature review of LCI platform development in Japan, Thailand, and Malaysia

Authors	Significance	Contribution
M. Yano, and K. Kamiya, (2000)[130]	Details the objectives and key achievements of Japan's national LCA project in the development of LCA methodologies and databases.	Provides a framework for the development of comprehensive LCA methodologies and databases, along with their applications for industry and environmental administration in Japan.
M. Finkbeiner, and Y. Matsuno, (2000)[131]	Provides an overview of the development of LCA in Japan, from the past to the present.	Provides the methodological foundation and development of LCA in Japan, with a focus on industrial implementation and government applications.
M. Yano, R. Aoki, Y. Nakahara, N. Itsubo, and T. Ohta (2000)[132]	Presents an update on the national LCA project launched by MITI to develop an LCA database and methodology applicable across Japan.	Introduces the role of this project in the development of LCA methodology and a national database system for Japan, as well as its applications in the industrial and government sectors.
Y. Nakahara, (1999)[133]	Focuses on the progress of the database committee in the national LCA project, as well as the development of the public LCA database system in Japan.	Explains the development of LCA data formats and the role of the database system in providing accessible data for industries and users.
T. Supasri, N. Itsubo, S.H. Gheewala, S. Sampattagul, (2020)[134]	Assesses the environmental impact of maize cultivation and biomass utilization in northern Thailand.	Provides data and analysis on the environmental impacts of maize agriculture and biomass energy production, along with recommendations for more sustainable biomass management policies.
N. Lecksiwilai, and S.H. Gheewala (2020)[135]	Evaluates the environmental impact of biofuels in Thailand, focusing on land-use changes and water resource utilization.	Provides insights into the trade-offs between environmental impacts such as greenhouse gas emissions and the use of other resources in biofuels, which can aid in policymaking decisions.
S. Pyay, W. Thanungkano, J. Mungkalasiri, and C. Musikavong (2019)[136]	Evaluates the environmental impact of intermediate rubber products in Thailand based on the Product Environmental Footprint (PEF) framework.	Contributes to Thailand's efforts to enhance the competitiveness of its rubber industry in the European market by applying the PEF framework to reduce environmental impacts.
S.H. Gheewala, and T. Mungcharoen (2017)[137]	Provides a comprehensive overview of the development and application of LCA in Thailand.	Presents the history of LCA development in Thailand, from academic research to its application in policy and industry.
S. Muhaba, M.R. Darun, and A.N. Oumer (2024)[138]	Assesses the environmental impact of petrochemical industrial wastewater treatment in Malaysia.	Provides a comprehensive analysis of energy use and the potential for energy recovery in petrochemical wastewater treatment, with a comparison between existing and ideal scenarios.
N.M. Rusli, Z.Z. Noor, and S.M. Taib (2023)[139]	Assesses the environmental impact of rice production in the Muda Granary Area, Kedah, Malaysia.	Identifies the impacts of fertilizer and pesticide use, and provides recommendations for better nutrient management to reduce environmental impacts.
N.A. Abu Bakar, A.M. Roslan, M.A. Hassan, M.H.A. Rahman, K.N. Ibrahim, M.D.A. Rahman, and R. Mohamad (2022)[140]	Provides an LCI model for glucose production from rice waste in Malaysia.	Identifies the greatest impacts in glucose production from rice waste, with an emphasis on biomass management and the reduction of greenhouse gas emissions.
C. Hafizan, N. Hussein, and Z.Z. Noor (2021)[141]	Presents an overview of the application of the LCA framework in Malaysia.	Provides an overview of the application of LCA in Malaysia's government and industrial sectors, along with the challenges faced in adopting this approach.

assessing the environmental performance of products within a specific category[145,146]. Table 2 summarizes PCR distributions across countries, illustrating the diversity of focus areas. Globally, the product category with the highest number of PCRs is Food & Beverages, with a total of 31 PCRs. This indicates significant attention to

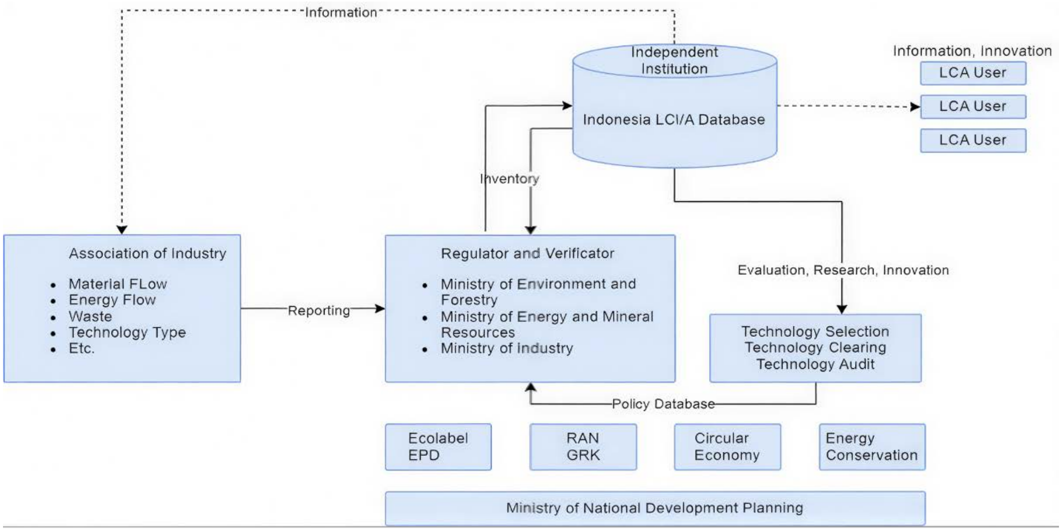

Fig. 2: Development concept of Indonesian National LCI database, redrawn and adapted from N.A. Sasongko et al. (2022)[143)]

sustainability within the food and beverage sector, considering its impact on natural resources, greenhouse gas emissions, and waste. This category may be driven by increasingly stringent regulations regarding sustainability and environmental concerns in food production, which require comprehensive life cycle assessments of product[150)].

In Southeast Asia, Thailand stands out as the country with the highest number of PCRs, reflecting the country's commitment to adopting and developing sustainability standards through life cycle assessments of products. This suggests that Thailand has a more developed infrastructure and supportive policies for PCR development, which could

Table 2: PCR database for several countries[147,148,149)]

No.	Country	Product Category	Number
1	International	Chemical	15
		Construction	64
		Electricity, Steam & Fuels	2
		Food & Beverages	31
		Furniture & other goods	5
		Infrastructure & Buildings	15
		Machinery & equipment	18
		Metal, mineral, plastics & glass products	19
		Paper and plastic products	8
		Services	14
		Textiles, footwear & apparel	20
		Vehicles & transport equipment	8
2	Japan	All categories	83
3	Thailand	National Product	53
		General Product	188
4	Malaysia	National Product	25

serve as an example for other countries in Southeast Asia to follow in enhancing the consistency of environmental impact assessments and supporting global sustainability goals[151,152)].

The development of the National LCI Database is related to PCR, namely in the following cases:

Data Source: LCI databases are primary data sources for life cycle assessments. They provide data on the environmental impacts of various materials, processes, and energy sources. PCRs often specify which data sources and quality requirements should be used when performing an LCA for a particular product category. LCI databases may contain data that aligns with these requirements.

Consistency and Comparability: PCRs help ensure that LCA studies for products within the same category are consistent and comparable. By adhering to the PCR for a specific product category, LCA practitioners can use the same set of rules and guidelines, making it easier to compare the environmental performance of similar products. LCI databases that follow these rules can facilitate this consistency.

LCI Data Development: LCA database developers may collect and organize data that meet the criteria specified in PCRs to align LCI databases with the requirements. For instance, they may undertake this process to support LCA studies when a new PCR is established for a specific product category.

The relationship between National LCI Database Development and PCRs is that LCI databases serve as valuable data sources for conducting LCAs following PCR guidelines[153,154)]. PCRs help standardize the LCA process for specific product categories, ensuring consistency and comparability in environmental assessments[155)]. LCI databases can be structured to align with these PCR requirements, making it easier for LCA practitioners to perform assessments within those categories. Figure 3

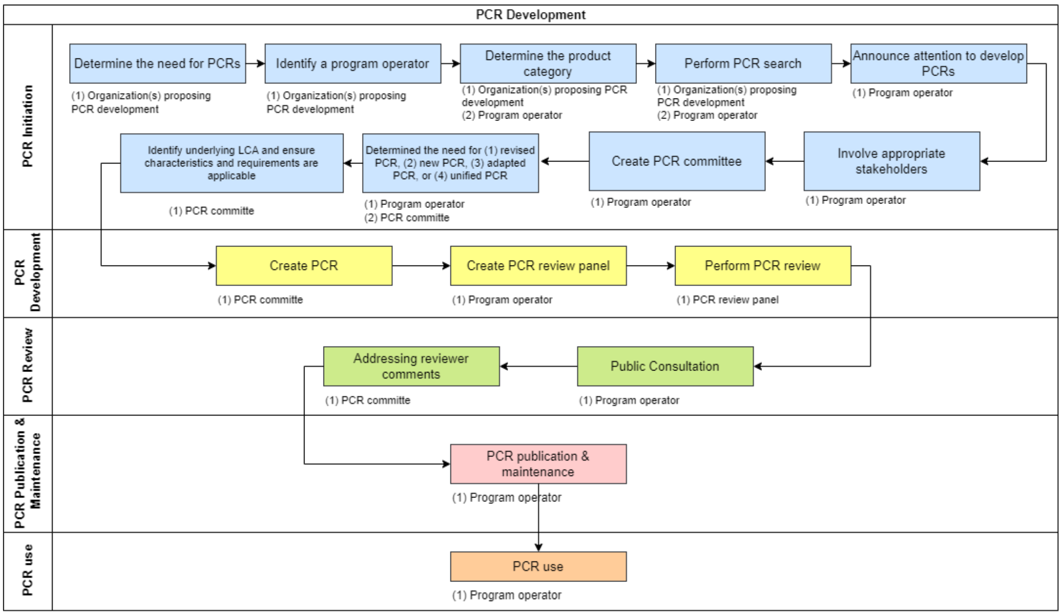

Fig. 3: PCR Development, redrawn in a different style, adapted from Ingwersen and Subramanian (2013)[156]

Table 3: Comparison of national LCI platform[157,158,159]

Aspect	Japan	Thailand	Malaysia
Platform Name	JEMAI-LCA, MiLCA	Thailand LCI Database	Malaysia LCI Database
Leading Initiative	Ministry of Economy, Trade, and Industry (METI), AIST	Thailand Greenhouse Gas Management Organization (TGO)	Malaysian Green Technology Corporation (MGTC)
Focus Sectors	Industry, energy, transportation, agriculture	Agriculture, industry, energy	Industry, agriculture, energy
Data Availability	Comprehensive database with local and global data	Developing database, focus on local data	Developing database, focus on local data
Integration with LCA	Integrated with LCA tools like SimaPro and OpenLCA	Integrated with LCA tools like OpenLCA	Integrated with LCA tools like SimaPro and OpenLCA
International Collaboration	Active in ISO, UNEP, and global projects	Collaboration with UNEP and ASEAN	Collaboration with UNEP and ASEAN
Challenges	Data maintenance, expansion to new sectors	Limited data availability, capacity building	Limited data availability, capacity building

illustrates the steps involved in the development of Product Category Rules (PCRs).

In the global context, regulatory frameworks like as the Carbon Border Adjustment Mechanism (CBAM), implemented by the European Union, underscore the necessity for comprehensive and standardized environmental assessments. The CBAM requires non-EU suppliers to assess the carbon footprint of their products before entering the EU market. This highlights the critical role of LCI databases in providing precise life cycle data for compliance with international standards.

A clear overview of the CBAM process, highlighting its crucial role in fostering carbon accountability among non-EU suppliers. By visualizing the mechanism, stakeholders can better understand the importance of adopting standardized environmental assessments to meet these regulatory requirements.

3.5. National Life Cycle Inventory (LCI) Platform

Japan, Thailand, and Malaysia are more advanced in the implementation of Life Cycle Inventory (LCI) due to well-structured LCI platforms and strong government support. Japan has the JEMAI-LCA platform, widely used in industry and research, while Thailand and Malaysia are beginning to adopt LCI for key sectors with a focus on sustainability. Comparison of the three countries is shown in Table 3.

Japan has the most advanced LCI Platform with a comprehensive database and global integration, while Thailand and Malaysia are still in the development phase, focusing on local data. All three countries face similar challenges, such as limited data availability and the need for capacity building, but they are also actively engaged in international collaborations to strengthen LCI and LCA infrastructure. For Indonesia, the comparative analysis indicates that developing a robust LCI database and standardized PCRs is needed to address the data gaps identified in this studyand enhance compliance with emerging global regulatory frameworks, such as the EU's CBAM. The lack of a dedicated governing body to supervise LCA and PCR operations in Indonesia constitutes a substantial obstacle. Creating such an agency is crucial for defining, maintaining, and enforcing environmental standards, ensuring Indonesia's alignment with global sustainability frameworks and compliance with international trade obligations.

4. Conclusion

The development of a comprehensive Product Category Rule (PCR) system and a National Life Cycle Inventory (LCI) Database is pivotal for enabling robust life cycle assessments (LCAs) and strengthening Indonesia's sustainability transition. . This review uniquely integrates technical recommendations, stakeholder frameworks, and regional collaboration strategies—linking PCR and LCI development directly to compliance with global mechanisms such as CBAM and deforestation-free product requirements. By consolidating experiences from other Southeast Asian countries and emphasizing harmonization with the Global Database of PCR, this work offers a practical roadmap tailored to Indonesia's industrial and policy context.

To operationalize this vision, the following strategic recommendations are proposed: :

Establish the national Program Operator for Carbon Footprint of the Products (CFPs) and Type III ecolabel certification system based on ISO 14025, involving all relevant technical parties nationally (referred to Figure 3: Development concept of Indonesian National LCI database)

National Consensus of Stakeholders (Governments, Industrial Associations) on Product Category Rules (PCR) Documents as Product Trade References;

Multidisciplinary Team Formation. Assemble a diverse team of researchers or experts with backgrounds in environmental science, industrial processes, data management, and industry-specific knowledge. Collaborative expertise is essential for a successful project.

Clear Scope and Objectives. Define the project's scope, including the specific industries and product categories intended to cover. Establish clear objectives for the PCR and LCI Database, outlining how they will support sustainability assessments, industry improvements, and policy decisions.

Stakeholder Engagement. Identify and involve key stakeholders, including industry associations, governmental bodies, research and academic institutions, and relevant businesses. Understand their needs and expectations to ensure the PCR and LCI Database meet with their requirements.

Review Existing Standards and Guidelines. Use established standards and guidelines for PCRs and LCI Databases, such as ISO 14025 for PCRs, ISO 14040 and 14044 for LCAs, and 14064 and 14067 for carbon footprint. Ensure that the project adheres to best practices and international standards.

Data Collection Strategy. Develop a systematic data collection strategy, including methodologies for acquiring life cycle inventory data from various sources, such as industry surveys, literature reviews, and data providers.

Robust Data Management System. Implement a robust data management system to ensure data quality, consistency, and security. Consider using dedicated software tools designed for LCI data management and analysis.

Standardization and Documentation. Develop standardized procedures for creating PCRs and populating the LCI Database, and thoroughly document methodologies, assumptions, data sources, and data quality assessments to enhance transparency and reproducibility.

Industry Collaboration. Collaborate closely with industry representatives to obtain industry-specific data, insights, and expertise. Encourage industry participation and support by highlighting the value of LCAs and sustainability assessments.

Quality Assurance and Verification. Implement rigorous quality assurance and data verification processes to ensure the accuracy and reliability of the PCR and LCI Database.

Continuous Updates and Maintenance. Recognize that PCRs and LCI Databases must be dynamic and regularly updated to reflect technological changes, industry practices, and environmental knowledge. Establish a process for ongoing maintenance and improvement.

Education and Training. Training and guidance to PCR and LCI Database users to ensure effective employment of these resources for sustainable decision-making.

Legal and Ethical Considerations. To ensure compliance and trust, address legal and ethical issues, such as data privacy, intellectual property, and sensitive industry information.

Promotion and Adoption. Promote using of PCR and LCI Database among stakeholders and work to gain industry-wide adoption. Share success stories and case studies to demonstrate the practical benefits of using these resources.

Funding and Resources. Secure sufficient funding and resources to sustain and facilitate the project's growth over time.

Monitoring and Evaluation. Establish key performance indicators (KPIs) to assess the impact and effectiveness of PCR and LCI Database in advancing sustainable practices.

Acknowledgements

The authors would like to express their gratitude to Research and Innovation for a Great Indonesia (RIIM), The Research Center for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency (BRIN), Indonesia.

References

1) C. Zou, W. Gao, and F. Ai, "Strategic mineral policies for Indonesia: Enhancing global competitiveness, economic growth, and environmental sustainability through innovation and renewable energy," Renewable Energy, 244, 122593 (2025), doi: 10.1016/j.renene.2025.122593.
2) N.T.S.A. Putra, and R. Satria, "Bridging the Gap: Indonesia and the Path to Sustainable Development in the Global South," Proc. 8th Int. Conf. Soc. Polit. Sci. (ICoSaPS 2024), Adv. Soc. Sci. Educ. Humanit. Res., (2024), doi:10.2991/978-2-38476-368-9_5.
3) R. Kurniawan, and S. Managi, "Economic Growth and Sustainable Development in Indonesia: An Assessment," Bull. Indones. Econ. Stud., 54 (3) 339–361 (2018). doi:10.1080/00074918.2018.1450962.
4) I.W. Ngarayana, J. Sutanto, and K. Murakami, "Predicting the future of Indonesia: energy, economic and sustainable environment development," IOP Conf. Ser.: Earth Environ. Sci., 753 (1) 012038 (2021). doi:10.1088/1755-1315/753/1/012038.
5) R. Garnaut, "Indonesia's resources boom in international perspective: policy dilemmas and options for continued strong growth," Bull. Indones. Econ. Stud., 51 (2) 189–212 (2015). doi:10.1080/00074918.2015.1061910.
6) C. Mora, D. Spirandelli, E.C. Franklin, et al., "Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions," Nat. Clim. Change, 8 (12) 1062–1071 (2018). doi:10.1038/s41558-018-0315-6.
7) R. Gakaev, L.S. Gatsaeva, and M.A. Eskiev, "Impacts of greenhouse gas-induced climate change: Risks, vulnerabilities, and adaptation strategies," E3S Web Conf., 537, 03009 (2024). doi:10.1051/e3sconf/202453703009.
8) T. Ohno, "Should the government privatize polluting firms?" J. Novel Carbon Resour. Sci., 7 26–32 (2013).
9) L. Al-Ghussain, "Global warming: review on driving forces and mitigation," Environ. Prog. Sustainable Energy, 38 (1) 13–21 (2019). doi:10.1002/ep.13041.
10) M. Filonchyk, M.P. Peterson, L. Zhang, V. Hurynovich, and Y. He, "Greenhouse gases emissions and global climate change: Examining the influence of CO_2, CH_4, and N_2O," Sci. Total Environ., 935, 173359 (2024). doi:10.1016/j.scitotenv.2024.173359.
11) Y. Prasad, and S. Deswal, "A comprehensive carbon footprint assessment using integration of GHG Protocol and LCA: A case study of an engineering institute in India," Evergreen, 11 (1) 143–155 (2024), doi: 10.5109/7172251
12) M. Filonchyk, M.P. Peterson, L. Zhang, V. Hurynovich, and Y. He, "Greenhouse gases emissions and global climate change: Examining the influence of CO_2, CH_4, and N_2O," Sci. Total Environ., 935 173359 (2024). doi:10.1016/j.scitotenv.2024.173359
13) A.A. Khan, "TEMPORARY REMOVAL: Why would sea-level rise for global warming and polar ice-melt?," Geosci. Front., 10 (2) 481–494 (2019). doi:10.1016/j.gsf.2018.01.008.
14) V. Kumar, D. Ranjan, and K. Verma, "Global climate change: the loop between cause and impact," in Global Climate Change, S. Singh, P. Singh, S. Rangabhashiyam, and K.K. Srivastava (Eds.), Elsevier, 2021, pp. 187–211. doi:10.1016/B978-0-12-822928-6.00002-2.
15) S. Bolan et al., "Impacts of climate change on the fate of contaminants through extreme weather events," Sci. Total Environ., 909 168388 (2024). doi:10.1016/j.scitotenv.2023.168388
16) W. Marx, R. Haunschild, and L. Bornmann, "Heat waves: a hot topic in climate change research," Theor. Appl. Climatol., 146 (1–2) 781–800 (2021). doi:10.1007/s00704-021-03758-y
17) B. Clarke, F. Otto, R. Stuart-Smith, and L. Harrington, "Extreme weather impacts of climate change: an attribution perspective," Environ. Res. Clim., 1 (1) 012001 (2022). doi:10.1088/2752-5295/ac6e7d
18) O. Hoegh-Guldberg, E.S. Poloczanska, W. Skirving, and S. Dove, "Coral reef ecosystems under climate change and ocean acidification," Front. Mar. Sci., 4, 158 (2017). doi:10.3389/fmars.2017.00158.
19) B.J. Harvey, K.L. Nash, J.L. Blanchard, and D.P. Edwards, "Ecosystem-based management of coral reefs under climate change," Ecol. Evol., 8, 6354–6368 (2018). doi:10.1002/ece3.4146.
20) S. Nurdjaman, M.I. Nasution, O. Johan, G. Napitupulu, and E. Saleh, "Impact of Climate Change on Coral Reefs Degradation at West Lombok, Indonesia," J. Kelaut. Trop., 26 (3) 451–463 (2023). doi:10.14710/jkt.v26i3.18540
21) J. Patchell, "Can the implications of the GHG Protocol's scope 3 standard be realized?," J. Clean. Prod., 185, 941–958 (2018). doi:10.1016/j.jclepro.2018.03.003.
22) T. Wiedmann, G. Chen, A. Owen, et al., "Three-scope carbon emission inventories of global cities," J. Ind. Ecol., 25, 735–750 (2021). doi:10.1111/jiec.13063.

23) L. Klaaßen, and C. Stoll, "Harmonizing corporate carbon footprints," Nat. Commun., 12, 6149 (2021). doi:10.1038/s41467-021-26349-x.
24) M. Röck, M.R.M. Saade, M. Balouktsi, F.N. Rasmussen, H. Birgisdottir, R. Frischknecht, G. Habert, T. Lützkendorf, and A. Passer, "Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation," Appl. Energy, 258, 114107 (2020). doi:10.1016/j.apenergy.2019.114107.
25) L. Zhang, R. Long, H. Chen, and J. Geng, "A review of China's road traffic carbon emissions," J. Clean. Prod., 207, 569–581 (2019). doi:10.1016/j.jclepro.2018.10.003.
26) B. Groß, "Greenhouse Gas Emissions of Universities: Chances and Challenges on the Way to Greenhouse Gas Neutrality," Challenges in the Turbulent Economic Environment and Organizations' Sustainable Development, 5 (1) 10–25 (2024). doi:10.18690/um.epf.5.2024.10
27) R.M. Dangelico, "Green product innovation: Where we are and where we are going," Bus. Strat. Env., 25, 560–576 (2016). doi:10.1002/bse.1886.
28) N. Mohd Suki, "Green product purchase intention: impact of green brands, attitude, and knowledge," Br. Food J., 118 (12), 2893–2910 (2016). doi:10.1108/BFJ-06-2016-0295.
29) B. He, and Q. Yu, "Product sustainable design for carbon footprint during product life cycle," J. Eng. Des., 32 (9), 478–495 (2021). doi:10.1080/09544828.2021.1921130.
30) M. Andersson, P. Bolton, and F. Samama, "Hedging climate risk," Financ. Anal. J., 72 (3), 13–32 (2016). doi:10.2469/faj.v72.n3.4.
31) A.K. Bhardwaj, A. Garg, S. Ram, Y. Gajpal, and C. Zheng, "Research Trends in Green Product for Environment: A Bibliometric Perspective," Int. J. Environ. Res. Public Health, 17 (22) 8469 (2020). doi:10.3390/ijerph17228469
32) T.D. Moshood, G. Nawanir, F. Mahmud, F. Mohamad, M.H. Ahmad, A. AbdulGhani, and S. Kumar, "Green product innovation: A means towards achieving global sustainable product within biodegradable plastic industry," J. Clean. Prod., 363, 132506 (2022). doi:10.1016/j.jclepro.2022.132506.
33) R. Seif, F.Z. Salem, and N.K. Allam, "E-waste recycled materials as efficient catalysts for renewable energy technologies and better environmental sustainability," Environ. Dev. Sustain., 26, 5473–5508 (2024). doi:10.1007/s10668-023-02925-7.
34) I. Ghazali et al., "Embedding Green Product Attributes Preferences and Cultural Consideration for Product Design Development: A Conceptual Framework," Sustain., 15 (5) (2023). doi:10.3390/su15054542
35) W.W. Ingwersen, and M.J. Stevenson, "Can we compare the environmental performance of this product to that one? An update on the development of product category rules and future challenges toward alignment," J. Clean. Prod., 24, 102–108 (2012). doi:10.1016/j.jclepro.2011.10.040.
36) W.W. Ingwersen, and V. Subramanian, "Guidance for product category rule development: process, outcome, and next steps," Int. J. Life Cycle Assess., 19, 532–537 (2014). doi:10.1007/s11367-013-0659-0.
37) I. Nadirah, I.M.A.D. Susila, A.L. Sihombing, A.I. Yanuar, I. Febijanto, Rosmeika, A.D. Santoso, I.Z. Kurniawati, E.S. Kadir, and N. Ghazali, "Product category rules development as a reference for PROPER life cycle assessment reporting: recommendations," IOP Conf. Ser.: Earth Environ. Sci., 1267, 012040 (2023). doi:10.1088/1755-1315/1267/1/012040.
38) D. Egas, V. Vasilaki, E. Katsou, P. Stanchev, S. Ponsá, and J. Colón, "Implementation of the Product Environmental Footprint Category Rules for dairy products: An approach to assess nitrogen emissions in a mass balanced dairy farm system," J. Clean. Prod., 215, 1149–1159 (2019). doi:10.1016/j.jclepro.2019.01.110.
39) N. Minkov, L. Schneider, A. Lehmann, and M. Finkbeiner, "Type III environmental declaration programmes and harmonization of product category rules: status quo and practical challenges," J. Clean. Prod., 94, 235–246 (2015). doi:10.1016/j.jclepro.2015.02.012.
40) M. Galindro, N. Bey, I. Olsen, and S. et al., "Use of data envelopment analysis to benchmark environmental product declarations—a suggested framework," Int. J. Life Cycle Assess., 25, 2417–2431 (2020). doi:10.1007/s11367-019-01639-1.
41) F.B. Moré, B.M. Galindro, and S.R. Soares, "Assessing the completeness and comparability of environmental product declarations," J. Clean. Prod., 375, 133999 (2022). doi:10.1016/j.jclepro.2022.133999.
42) M. Rangelov, H. Dylla, and N. Sivaneswaran, "Environmental product declarations (EPDs)/product category rules (PCRs) of waste plastics and recycled materials in roads," in Plastic Waste for Sustainable Asphalt Roads, F. Giustozzi and S. Nizamuddin, Eds., Woodhead Publishing Series in Civil and Structural Engineering, Woodhead Publishing, pp. 303–334 (2022). doi:10.1016/B978-0-323-85789-5.00015-0.
43) J. Laso, M. Margallo, P. Fullana, A. Bala, C. Gazulla, Á. Irabien, and R. Aldaco, "Aiding eco-labelling process and its implementation: Environmental Impact Assessment Methodology to define Product Category Rules for canned anchovies," MethodsX, 4,

143–152 (2017). doi:10.1016/j.mex.2017.03.001.

44) S. Welling, and S.O. Ryding, "Distribution of environmental performance in life cycle assessments—implications for environmental benchmarking," Int. J. Life Cycle Assess., 26 (1) 275–289 (2021). doi:10.1007/s11367-020-01852-3.

45) J.L. Casamayor, and D. Su, "Review of Directives, Regulations and Standards Related to Sustainable Product Design and Manufacture," in Sustainable Product Development, D. Su (ed.), Springer, Cham, pp. 19–47 (2020). doi:10.1007/978-3-030-39149-2_2.

46) M. Rangelov, H. Dylla, A. Mukherjee, and N. Sivaneswaran, "Use of environmental product declarations (EPDs) of pavement materials in the United States of America (U.S.A.) to ensure environmental impact reductions," J. Clean. Prod., 283, 124619 (2021). doi:10.1016/j.jclepro.2020.124619.

47) O.I. Olanrewaju, W.I. Enegbuma, and M. Donn, "Challenges in life cycle assessment implementation for construction environmental product declaration development: A mixed approach and global perspective," Sustain. Prod. Consum., 49, 502–528 (2024). doi:10.1016/j.spc.2024.06.021.

48) H. Hariyadi, S.S. Moersidik, T.E.B. Soesilo, S.W. Utomo, M. Mulyadi, D. Djaenudin, D. Yuniati, N.A. Ulya, S.F. Purba, and S. Darma, "Target an assertive geothermal power development from Indonesia's Omnibus Law: A critical review," Evergreen, 11 (3) 1676–1694 (2024). doi:10.5109/7236821

49) Nurkamelia, S. Sugihardjo, B. Widarsono, U. Usman, S. Suliantara, S. Kepies, D. Dwiyanarti, D. Sunarjanto, M. Romli, and T.M. Susantoro, "Potential of CCS in East Kalimantan's coal-power sector for achieving net-zero emissions," Evergreen, 11 (3) 2555–2566 (2024). doi:10.5109/7236896

50) C. Brink, H.R.J. Vollebergh, and E. van der Werf, "Carbon pricing in the EU: Evaluation of different EU ETS reform options," Energy Policy, 97, 603–617 (2016). doi:10.1016/j.enpol.2016.07.023.

51) F.M. D'Arcangelo, and M. Galeotti, "Environmental policy and investment location: The risk of carbon leakage in the EU ETS," Energy Policy, 202 (2025) 114587. doi:10.1016/j.enpol.2025.114587.

52) X. Pan, and S. Liu, "The development, changes and responses of the European Union carbon border adjustment mechanism in the context of global energy transition," World Dev. Sustain., 4, 100148 (2024). doi:10.1016/j.wds.2024.100148.

53) C. Bellora, and L. Fontagné, "EU in search of a Carbon Border Adjustment Mechanism," Energy Econ., 123, 106673 (2023). doi:10.1016/j.eneco.2023.106673.

54) M. Wróblewska, and M. Zmitrowicz, "Carbon Border Adjustment Mechanism as proposed EU regulation to combat climate change," in Sustainable Economy and Sustainable Development, 2024. doi:10.2478/9788367405331-030.

55) E. Erdogdu, "The Carbon Border Adjustment Mechanism: Opportunities and Challenges for Non-EU Countries," WIREs Energy Environ., 14 e70000 (2025). doi:10.1002/wene.70000.

56) G. Magacho, E. Espagne, and A. Godin, "Impacts of the CBAM on EU trade partners: consequences for developing countries," Climate Policy, 24 (2) 243–259 (2023). doi:10.1080/14693062.2023.2200758.

57) L. Eicke, S. Weko, M. Apergi, and A. Marian, "Pulling up the carbon ladder? Decarbonization, dependence, and third-country risks from the European carbon border adjustment mechanism," Energy Res. Soc. Sci., 80, 102240 (2021). doi:10.1016/j.erss.2021.102240.

58) E. Lydgate, and L.A. Winters, "The UK's border carbon leakage trilemma," Energy Policy, 198, 114393 (2025). doi:10.1016/j.enpol.2024.114393.

59) E. Kozarević, M. Baraković Nurikić, and M. Ibrić, "Financial impacts of the carbon border adjustment mechanism on selected trade partners: cross-national and cross-sectoral analysis," INDECS, 22 (6) 684–700 (2024). doi:10.7906/indecs.22.6.4.

60) K. Koch, A. Munzur, and J. Winter, "Climate policy as a geopolitical tool: how the European Union's carbon border adjustment mechanism affects its relationships with Africa and China," in The Palgrave Handbook on China-Europe-Africa Relations, Y. Li, F.J.B.S. Leandro, J. Tavares da Silva, and C. Rodrigues, Eds., Palgrave Macmillan, Singapore (2024). doi:10.1007/978-981-97-5640-7_48.

61) A. Michaelowa, L. Chu, T. Do, Q.H. Nguyen, M.H. Nguyen, L. Nguyen, and L.P. Pham, "Carbon border adjustment mechanism impact assessment report for Vietnam," VnLawFind, NHQuang & Associates, Hanoi (2023). doi:10.5167/uzh-257039.

62) W. Zhang, and B.K. Sovacool, "The geopolitics of net-zero transitions: exploring the political economy of carbon border adjustment mechanism implementation in the Global South," SSRN, (2024). doi:10.2139/ssrn.4853573.

63) M. Kendrick, "Chapter 18: The Emissions Trading Scheme (ETS) and the Carbon Border Adjustment Mechanism (CBAM)," in Research Handbook on Post-Pandemic EU Economic Governance and NGEU Law, Edward Elgar Publishing, Cheltenham, UK, (2024). doi:10.4337/9781035328161.00029.

64) U. Sarangi, "Implications of Carbon-Border Adjustment Mechanism (CBAM) and Its Ramifications in Achieving Sustainable Development Goals and the United Nations 2030 Agenda," Int. J. Legal Stud., 2023 (1) 2783 (2023).

doi:10.5604/01.3001.0054.2783

65) S. Shin and Y. An, “Correct Understanding and Action on the Transitional Period of EU Carbon Border Adjustment Mechanism (CBAM),” J. Korean Soc. Environ. Eng., 46 (4) 167–175 (2024). doi:10.4491/ksee.2024.46.4.167

66) F. Ekardt, T. Rath, C. Gätsch, P.C. Klotz, and K. Heyl, “EU energy law: insufficient for the 1.5-degree Celsius limit—The examples of EU emissions trading and hydrogen policies,” Ecol. Civiliz., 2 (2) 10019 (2025). doi:10.70322/ecolciviliz.2024.10019.

67) N. Radovanovic, and H. Stevanovic Carapina, “Green transition and Smart Specialisation in the Western Balkans,” European Commission, Joint Research Centre, Luxembourg: Publications Office of the European Union, (2024). doi:10.2760/370696.

68) M. Conte Grand, P. Schulz-Antipa, and J. Rozenberg, “Potential exposure and vulnerability to broader climate-related trade regulations: an illustration for LAC countries,” Environ. Dev. Sustain., 26 6195–6220 (2024). doi:10.1007/s10668-023-02958-y.

69) H. Ratnaningsih, N.M. Rachman, R.K. Permatasari, and S. Agustina, “Will the sustainability issue be a game changer for Indonesia’s export to the EU?,” AIP Conf. Proc., 2970 (1) 030029 (2024). doi:10.1063/5.0208297.

70) R. Kumar, A. Kumar, and P. Saikia, “Deforestation and forests degradation impacts on the environment,” in Environmental Degradation: Challenges and Strategies for Mitigation, V.P. Singh, S. Yadav, K.K. Yadav, and R.N. Yadava, Eds., Water Sci. Technol. Libr., vol. 104, Springer, Cham, 2022. doi:10.1007/978-3-030-95542-7_2.

71) R.L. Chazdon, P.H.S. Brancalion, L. Laestadius, et al., “When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration,” Ambio, 45 (2016). doi:10.1007/s13280-016-0772-y.

72) S.M. Horan, “Deforestation and forests degradation impacts on the environment,” Springer eBooks, 19–46 (2022). doi:10.1007/978-3-030-95542-7_2.

73) M. Rahmaditio, “Disentangling the Interlinkages Between Humans, Biodiversity Loss, and Climate Change in the Tropical Region,” in Environment and Sustainable Development. ACESD 2023. Environmental Science and Engineering, K. Ujikawa, M. Ishiwatari, and E.v. Hullebusch, Eds. Singapore: Springer, 2024. doi:10.1007/978-981-97-3320-0_13.

74) E. Commission, “Staff Working Document on the Impact Assessment: Minimising The Risk Of Deforestation and Forest Degradation Associated with Products Placed on The EU Market,” 2021. [Online]. Available: https://circabc.europa.eu/ui/group/34861680-e799-4d7c-bbad-da83c45da458/library/de1e09c6-8221-4f59-82b3-a5d6bb1e1f02/details?download=true

75) W.T. Douma, "From the EU Timber Regulation to the EU Regulation on Deforestation-Free Products: Making a Difference?," in EU External Relations Law and Sustainability, R.A. Wessel, J. Bergamaschine Mata Diz, J. Péret Tasende Társia, and S.E. Akdogan, Eds. The Hague: T.M.C. Asser Press, 2024, vol. 4. doi:10.1007/978-94-6265-655-0_16.

76) L.H.E. Cosimo, M. Masiero, A. Mammadova, and D. Pettenella, “Voluntary sustainability standards to cope with the new European Union regulation on deforestation-free products: A gap analysis,” Forest Policy Econ., 164, 103235 (2024). doi:10.1016/j.forpol.2024.103235.

77) T. E. Parliament, PE-CONS 82/22 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of … on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (E, vol. 275, no. 995. 2023, pp. 88–90. [Online]. Available: https://data.consilium.europa.eu/doc/document/PE-82-2022-INIT/en/pdf

78) E. Zhunusova, V. Ahimbisibwe, L.T.H. Sen, A. Sadeghi, T. Toledo-Aceves, G. Kabwe, and S. Günter, "Potential impacts of the proposed EU regulation on deforestation-free supply chains on smallholders, indigenous peoples, and local communities in producer countries outside the EU," Forest Policy and Economics, 143 102817 (2022). doi:10.1016/j.forpol.2022.102817.

79) R. Ostfeld, and D.M. Reiner, "Seeing the forest through the palms: developments in environmentally sustainable palm oil production and zero-deforestation efforts," Front. Sustain. Food Syst., 8 (2024). doi:10.3389/fsufs.2024.1398877.

80) R. Pirard, P. Pacheco, and C. Romero, “The role of hybrid governance in supporting deforestation-free trade,” Ecological Economics, 210 (107867) 2023. doi:10.1016/j.ecolecon.2023.107867.

81) X. Giam, L. Mani, L.P. Koh, and H.T.W. Tan, "Saving Tropical Forests by Knowing What We Consume," CONSERVATION LETTERS, 9 (4) 267–274 (2016). doi:10.1111/conl.12209.

82) H. Balzter, N. Acil, I. Reading, K. Bika, T. Drakesmith, C. McNeill, S. Cheesbrough, and J. Byrne, "Due diligence for deforestation-free supply chains with Sentinel-2 imagery from the Copernicus DataSpace Ecosystem," EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-21708, 2024. doi:10.5194/egusphere-egu24-21708.

83) S. Henders, J.R. Winkler, R.C. Janke, J.M. Smith, and M.A. Miller, “Understanding the environmental

impact of sustainable agriculture practices," Environ. Res. Lett., 10 (12) 125012 (2015). doi:10.1088/1748-9326/10/12/125012.

84) Z. Yang, G. Fang, and W. Sun, "Embodied carbon emissions and their transfer pathways in global aluminum trade: The value chain perspective," J. Clean. Prod., 494 145057 (2025). doi:10.1016/j.jclepro.2025.145057.

85) T.-C. Liu, Y.-C. Wu, and C.-F. Chau, "An Overview of Carbon Emission Mitigation in the Food Industry: Efforts, Challenges, and Opportunities," Processes, 11 (7) 1993 (2023). doi:10.3390/pr11071993.

86) Zhang, H. and Zhang, B., "The unintended impact of carbon trading of China's power sector," Energy Policy, 147 111876 (2020). doi:10.1016/j.enpol.2020.111876.

87) H.-D. Jiang, L.-J. Liu, K. Dong, and Y.-W. Fu, "How will sectoral coverage in the carbon trading system affect the total oil consumption in China? A CGE-based analysis," Energy Economics, 110 105996 (2022). doi:10.1016/j.eneco.2022.105996.

88) Y. Chen, and H. Mu, "Natural resources, carbon trading policies and total factor carbon efficiency: A new direction for China's economy," Resour. Policy, 86 (A) 104183 (2023). doi:10.1016/j.resourpol.2023.104183.

89) S. Sirohi, "Opportunities and Challenges for Carbon Trading from Livestock Sector," in Climate Change Impact on Livestock: Adaptation and Mitigation, V. Sejian, J. Gaughan, L. Baumgard, and C. Prasad, Eds. Springer, 2015. doi:10.1007/978-81-322-2265-1_15.

90) P. Purohit, and V. Chaturvedi, "Biomass pellets for power generation in India: a techno-economic evaluation," Environ. Sci. Pollut. Res., 25 (2018) 29614–29632. doi:10.1007/s11356-018-2960-8.

91) D. Baccas, and E.A. Warnatzsch, "Awareness and engagement of listed companies in combating deforestation and forest degradation in Brazil," Corporate Social Responsibility and Environmental Management, 31 (5) 3968–3987 (2024). doi:10.1002/csr.2777.

92) P.H.S. Brancalion, D. Lamb, E. Ceccon, D. Boucher, J. Herbohn, B. Strassburg, and D.P. Edwards, "Using markets to leverage investment in forest and landscape restoration in the tropics," Forest Policy and Economics, 85 (1) 103–113 (2017). doi:10.1016/j.forpol.2017.08.009.

93) T. Choudhury, A. Tiwari, and R. Jakhar, "Beyond Borders: CBAM's Revolutionary Potential and Challenges in Achieving Carbon Neutrality," Int. J. Innov. Technol. Explor. Eng., 13 (4) 7–16 (2024). doi:10.35940/ijitee.d9818.13040324.

94) J. Zhu, Y. Zhao, and L. Zheng, "The Impact of the EU Carbon Border Adjustment Mechanism on China's Exports to the EU," Energies, 17 (2) 509 (2024). doi:10.3390/en17020509.

95) M.A. Mehling, H. van Asselt, K. Das, S. Droege, and C. Verkuijl, "Designing Border Carbon Adjustments for Enhanced Climate Action," Am. J. Int. Law, 113 (3) 433–481 (2019). doi:10.1017/ajil.2019.22.

96) E. Erdogdu, "The Carbon Border Adjustment Mechanism: Opportunities and Challenges for Non-EU Countries," WIREs Energy Environ., 14 e70000 (2025). doi:10.1002/wene.70000.

97) M. C. Grand, P. S. Antipa, and J. Rozenberg, "Background Note 3. Potential exposure and vulnerabilityto broader climate-related trade regulations: anillustration for LAC countries," 2022. [Online]. Available: https://openknowledge.worldbank.org/server/api/core/bitstreams/bfd68288-15d3-5686-bf4f-0bbb80e9e460/content

98) J. Lyons-White, and A.T. Knight, "Palm oil supply chain complexity impedes implementation of corporate no-deforestation commitments," Global Environmental Change, 50 303–313 (2018). doi:10.1016/j.gloenvcha.2018.04.012.

99) H. van der Ven, C. Rothacker, and B. Cashore, "Do eco-labels prevent deforestation? Lessons from non-state market driven governance in the soy, palm oil, and cocoa sectors," Global Environmental Change, 52 141–151 (2018). doi:10.1016/j.gloenvcha.2018.07.002.

100) Gajdzik, B., Nagaj, R., Wolniak, R., Bałaga, D., Žuromskaitė, B., & Grebski, W. W., "Renewable Energy Share in European Industry: Analysis and Extrapolation of Trends in EU Countries," Energies, 17 (11) 2476 (2024). doi:10.3390/en17112476.

101) S. Kim, M. Kim, J. Jeon, and T. Kim, "Strategy for responding to the extension of global carbon border adjustment mechanisms to the agricultural sector by establishing life cycle inventory databases," J. Clim. Change Res., 16 (2) 283–296 (2025). doi:10.15531/KSCCR.2025.16.2.283.

102) J.-S. Woo, A.-H. Jin, W.-C. Choi, S.-Y. Seo, and H.-D. Yun, "Conductive performance of mortar containing Fe-activated biochar," J. Korea Inst. Struct. Maint. Insp., 28 (2) 27–34 (2024). doi:10.11112/JKSMI.2024.28.2.27.

103) A. Rainville, R. Hawkins, and J. Bergerson, "Building consensus in life cycle assessment: the potential for a Canadian product category rules standard to enhance credibility in greenhouse gas emissions estimates for Alberta's oil sands," Journal of Cleaner Production, 103 525–533 (2015). doi:10.1016/j.jclepro.2014.06.067.

104) Anne Rainville, Richard Hawkins, and Joule Bergerson, "Building consensus in life cycle assessment: the potential for a Canadian product category rules standard to enhance credibility in

greenhouse gas emissions estimates for Alberta's oil sands," J. Clean. Prod., 103 525–533 (2015). doi:10.1016/j.jclepro.2014.06.067.

105) P. Mayer, and D.T. Birkocak, "Carbon Footprint of Fashion: Assessing and Addressing Carbon Emissions in Textile Production," in S.S. Muthu (eds) Carbon Footprint Assessments. Environmental Footprints and Eco-design of Products and Processes. Springer, Cham, 2024. doi:10.1007/978-3-031-70262-4_5.

106) A.I. Yanuar, I.K. Afianto, E. Oktavia, and A. Erliza, "The PROPER program evaluation to support the development of a national life cycle inventory database: recommendations," IOP Conf. Ser. Earth Environ. Sci., 1267 (1) 012029 (2023). doi:10.1088/1755-1315/1267/1/012029.

107) N.A. Sasongko, G.A. Pertiwi, H. Hardiani, E. Oktavia, A. Erliza, R. Noguchi, and W. Biswas, "The printing and writing paper industry and product in Indonesia: A life cycle assessment case study," Evergreen, 11 (4) 3640–3652 (2024). doi:10.5109/7326996.

108) T. Bayat, E. Ozsalman, and O.F. Derindag, "Evaluating export vulnerability through import demand elasticity in carbon border adjustment contexts: a focus on Türkiye," Environ. Sci. Pollut. Res., 32 (2025). doi:10.1007/s11356-024-35861-8.

109) K.B. Dy, and H. Yang, "Global emissions and international trade: Quantifying the impact of carbon border adjustments," Energy Economics, 145 108373 (2025). doi:10.1016/j.eneco.2025.108373.

110) Li, W., X. Liu, X. Yuan, and C. Lu, "Impact of CBAM on carbon emission reduction in global steel foreign trade: projections based on the embodied carbon emission intensity of major countries," Energy Sources, Part B: Economics, Planning, and Policy, 19 (1) (2024). doi:10.1080/15567249.2024.2360443.

111) K. Sahoo, R. Bergman, S. Alanya-Rosenbaum, H. Gu, and S. Liang, "Life Cycle Assessment of Forest-Based Products: A Review," Sustainability, 11 (17) 4722 (2019). doi:10.3390/su11174722.

112) D. Ruiz-Méndez and L.P. Güereca, "Streamlined Life Cycle Assessment for the Environmental Evaluation of Products in the Supply Chain," in Sustainable Development Goals and Sustainable Supply Chains in the Post-global Economy, N. Yakovleva, R. Frei, and S. Rama Murthy, Eds. Cham: Springer, 2019, ch. 7. doi:10.1007/978-3-030-15066-2_7.

113) Saumitra Saxena, "Pyrolysis and beyond: Sustainable valorization of plastic waste," Applications in Energy and Combustion Science, 21 100311 (2025). doi:10.1016/j.jaecs.2024.100311.

114) A. Bher, and R. Auras, "Life cycle assessment of packaging systems: A meta-analysis to evaluate the root of consistencies and discrepancies," J. Clean. Prod., 476 143785 (2024). doi:10.1016/j.jclepro.2024.143785.

115) D. Yang, C. Vezzoli, and H. Su, "Comprehensive life cycle assessment of 25 furniture pieces across categories for sustainable design," Sci. Rep., 15 (13968) (2025). doi:10.1038/s41598-024-84025-8.

116) E. I. Wiloso, N. Nazir, J. Hanafi, K. Siregar, S. S. Harsono, A. A. R. Setiawan, Muryanto, M. Romli, N. A. Utama, B. Shantiko, J. Jupesta, T. H. A. Utomo, A. A. Sari, S. Y. Saputra, and K. Fang, "Life cycle assessment research and application in Indonesia," Int. J. Life Cycle Assess., 24 (3) 386–396 (2019). doi:10.1007/s11367-018-1459-3.

117) A. Ciroth, C. Foster, J. Hildenbrand, and A. Zamagni, "Life cycle inventory dataset review criteria—a new proposal," Int. J. Life Cycle Assess., 25 (3) 483–494 (2020). doi:10.1007/s11367-019-01712-9.

118) N. Sasongko, N. Ariyanto, V. Eka Putri, H. Subagyo, S. Siswanto, M. Wardani, N. Laili, A. Pratiwi, A. Yanuar, M. Septiani, A. Hakim, Y. Erlambang, C. Sari, I. Supono, and R. Widiyaningrum, "National platform of Life Cycle Inventory database in Indonesia," ASEAN J. Syst. Eng., 9 (1) 9–15 (2025). doi:10.22146/ajse.v9i1.101472.

119) K. Chomkhamsri, T. Mungcharoen, and C. Yuvaniyama, "10-year experience with the Thai national LCI database: Case study of 'refinery products'," Int. J. Life Cycle Assess., 22 (11) 1760–1770 (2017). doi:10.1007/s11367-016-1160-3.

120) N. Poolsawad, W. Thanungkano, J. Mungkalasiri, R. Wisansuwannakorn, P. Suksatit, A. Jirajariyavech, and K. Datchaneekul, "Thai national life cycle inventory readiness for product environmental footprint," Int. J. Life Cycle Assess., 22 (2017) 1731–1743. doi:10.1007/s11367-016-1257-8.

121) S.H. Gheewala, and T. Mungcharoen, "Perspectives on life cycle assessment application and research in Thailand," Indones. J. Life Cycle Assess. Sustain., 1 (1) 8–12 (2017).

122) C. Hafizan, N. Hussein, and Z.Z. Noor, "Life cycle assessment framework application in Malaysia," IOP Conf. Ser. Mater. Sci. Eng., 1051 (1) 012101 (2021). doi:10.1088/1757-899X/1051/1/012101.

123) C.C. Onn, and S. Yusoff, "The formulation of life cycle impact assessment framework for Malaysia using Eco-indicator," Int. J. Life Cycle Assess., 15 (8) 985–993 (2010). doi:10.1007/s11367-010-0219-9.

124) T. Pajula, K. Behm, S. Vatanen, and E. Saarivuori, "Managing the Life Cycle to Reduce Environmental Impacts," in Dynamics of Long-Life Assets, S. Grösser, A. Reyes-Lecuona, and G. Granholm, Eds. Cham: Springer, 2017. doi:10.1007/978-3-319-45438-2_6.

125) Q. Munir, V. Lahtela, T. Kärki, and A. Koivula, "Assessing life cycle sustainability: A comprehensive review of concrete produced from construction waste fine fractions," J. Environ. Manage., 366 121734 (2024). doi:10.1016/j.jenvman.2024.121734.
126) N. Asias, and Y. Pollalis, "Quantitative and qualitative research in business & technology: Justifying a suitable research methodology," Rev. Integr. Bus. Econ. Res., 7 91–105 (2018).
127) A.J. Fletcher, "Applying critical realism in qualitative research: methodology meets method," International Journal of Social Research Methodology, 20 (2) 181–194 (2016). doi:10.1080/13645579.2016.1144401.
128) S.J. Taylor, R. Bogdan, and M.L. DeVault, "Introduction to Qualitative Research Methods: A Guidebook and Resource," John Wiley & Sons, 2015.
129) K. Tahara, T. Onoye, and K. Kobayashi, "Development of inventory database for environmental analysis (IDEA)," Proc. 9th Int. Conf. Ecobalance, Tokyo, p. 119 (2010).
130) M. Yano, and K. Kamiya, "The national LCA project in Japan," Environ. Prog., 19 (2) 140–145 (2000). doi:10.1002/ep.670190213.
131) M. Finkbeiner, and Y. Matsuno, "LCA in Japan — the past, the present, the future," Int. J. Life Cycle Assess., 5 (5) 253–254 (2000). doi:10.1007/BF02977575.
132) M. Yano, R. Aoki, Y. Nakahara, N. Itsubo, and T. Ohta, "Current activities of the national LCA project in Japan," Int. J. Life Cycle Assess., 5 (5) 261–264 (2000). doi:10.1007/BF02977577.
133) Y. Nakahara, "The progress of the database study committee in the national LCA project of Japan," Int. J. Life Cycle Assess., 4 (6) 310 (1999). doi:10.1007/BF02978517.
134) T. Supasri, N. Itsubo, S.H. Gheewala, S. Sampattagul, "Life cycle assessment of maize cultivation and biomass utilization in northern Thailand," Sci. Rep., 10 (1) 3516 (2020). doi:10.1038/s41598-020-60532-2.
135) N. Lecksiwilai, and S.H. Gheewala, "Life cycle assessment of biofuels in Thailand: Implications of environmental trade-offs for policy decisions," Sustainable Prod. Consump., 22 177–185 (2020). doi:10.1016/j.spc.2020.03.004.
136) S. Pyay, W. Thanungkano, J. Mungkalasiri, and C. Musikavong, "A life cycle assessment of intermediate rubber products in Thailand from the product environmental footprint perspective," J. Clean. Prod., 237 117632 (2019). doi:10.1016/j.jclepro.2019.117632.
137) S.H. Gheewala, and T. Mungcharoen, "Perspectives on life cycle assessment application and research in Thailand," Indones. J. Life Cycle Assess. Sustain., 1 8–12 (2017). doi:10.52394/ijolcas.v1i1.6.
138) S. Muhaba, M.R. Darun, and A.N. Oumer, "Life cycle assessment of an industrial-scale petrochemical wastewater treatment plant," J. Clean. Prod., 475 143673 (2024). doi:10.1016/j.jclepro.2024.143673.
139) N.M. Rusli, Z.Z. Noor, and S.M. Taib, "Life cycle assessment of rice production in Muda Granary Area, Kedah Malaysia," J. Adv. Res. Appl. Sci. Eng. Technol., 35 (2) 69–83 (2023). doi:10.37934/araset.35.2.6983.
140) N.A. Abu Bakar, A.M. Roslan, M.A. Hassan, M.H.A. Rahman, K.N. Ibrahim, M.D.A. Rahman, and R. Mohamad, "Development of life cycle inventory and greenhouse gas emissions from damaged paddy grain as fermentation feedstock: A case study in Malaysia," J. Clean. Prod., 354 131722 (2022). doi:10.1016/j.jclepro.2022.131722.
141) C. Hafizan, N. Hussein, and Z.Z. Noor, "Life cycle assessment framework application in Malaysia," IOP Conf. Ser.: Mater. Sci. Eng., 1051 012101 (2021). doi:10.1088/1757-899X/1051/1/012101.
142) M. Fritter, R. Lawrence, B. Marcolin, and et al., "A survey of Life Cycle Inventory database implementations and architectures, and recommendations for new database initiatives," Int J Life Cycle Assess, 25 (2020). doi:10.1007/s11367-020-01745-5.
143) N.A. Sasongko, "Life cycle inventory (LCI) dalam mendukung transformasi digital dan circular economy di sektor industri," Proc., pp. 343–352 (2022).
144) W. Ingwersen, V. Subramanian, R. Schenck, et al., "Product category rules alignment workshop, October 4, 2011 in Chicago, IL, USA," Int. J. Life Cycle Assess., 17 (2) 258–263 (2012). doi:10.1007/s11367-011-0357-8.
145) A. Passer, S. Lasvaux, K. Allacker, et al., "Environmental product declarations entering the building sector: critical reflections based on 5 to 10 years experience in different European countries," Int. J. Life Cycle Assess., 20 (2015) 1199–1212. doi:10.1007/s11367-015-0926-3.
146) V. Subramanian, W. Ingwersen, C. Hensler, et al., "Comparing product category rules from different programs: learned outcomes towards global alignment," Int. J. Life Cycle Assess., 17 (2012) 892–903. doi:10.1007/s11367-012-0419-6.
147) EPD International AB, "Search the PCR Library," 2023. https://environdec.com/pcr-library/with-documents (accessed Sep. 12, 2023).
148) SIRIM Academy, "SIRIM Standards Store," 2025. https://standards.sirimacademy.my/catalog?std_type=120 (accessed Feb. 17, 2025).
149) SuMPO, "EcoLeaf Environmental Label," 2023.

http://www.ecoleaf-jemai.jp/eng/pcr.html (accessed Sep. 12, 2023).
150) M. Guiton, and E. Benetto, "Special session on product environmental footprint," in Designing Sustainable Technologies, Products and Policies, Cham: Springer International Publishing, pp. 515–520 (2018). doi:10.1007/978-3-319-66981-6_57.
151) K. Makprang, "Sustainability in supply chains: Strategies and practices for a greener future," RMUTT Glob. Bus. Account. Financ. Rev., 8 (1) 85–108 (2024). doi:10.60101/gbafr.2024.273498.
152) R. Mungkung, K. Sorakon, and S.H. Gheewala, "Ecolabelling and sustainable public procurement to promote sustainable consumption and production in Thailand," Chem. Eng. Trans., 63 241–246 (2018). doi:10.3303/CET1863041.
153) J.D. Silvestre, S. Lasvaux, J. Hodková, et al., "NativeLCA - a systematic approach for the selection of environmental datasets as generic data: application to construction products in a national context," Int. J. Life Cycle Assess., 20 (2015) 731–750. doi:10.1007/s11367-015-0885-8.
154) N. Qiu, M. Sha, and X. Xu, "Evaluation and future development direction of paper straw and plastic straw," IOP Conf. Ser. Earth Environ. Sci., 1011 (1) 012029 (2021). doi:10.1088/1755-1315/1011/1/012029.
155) B.M. Galindro, S. Welling, N. Bey, S.I. Olsen, S.R. Soares, and S.-O. Ryding, "Making use of life cycle assessment and environmental product declarations: A survey with practitioners," J. Ind. Ecol., 24 (5) 965–975 (2020). doi:10.1111/jiec.13007.
156) W. Ingwersen, and V. Subramanian, "Guidance for product category rule development," Guidance Development Initiative Product Category Rule (2013).
157) A. Inaba, "Introduction of Japanese LCA networks and their activities," no. March. p. 10, 2021. [Online]. Available: https://seminaire2021.scorelca.org/storage/doc/4-atsushi-inaba.pdf.
158) J. Mungkalasiri, "Life Cycle Inventory of Renewable Energy from Primary Data: Case studies in Thailand." Bangkok, p. 33 (2023).
159) N. A. Sasongko et al., "National Platform of Life Cycle Inventory Database in Indonesia," ASEAN J. Syst. Eng., vol. 9, no. 1, pp. 9–15, 2025, [Online]. Available: https://journal.ugm.ac.id/ajse/article/view/101472.