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Life cycle assessment in Indonesia forestry sector: A scoping review

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ABSTRACT

Life cycle assessment (LCA) is a tool to analyze the environmental impact of the process of production or services. Forest provides enormous environmental benefits through ecosystem services, but some forest management activities (nursery, thinning, pruning, pest control, and harvesting) have produced some negative impacts, such as pollution from machine utilization, fertilizer and pesticide, and water consumption. Furthermore, this paper describes the application of LCA in the forestry sector in Indonesia. We used the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) approach to identify, screen, and inclusion the relevant articles. Identified 35 articles related to life cycle assessment in Indonesia's forestry sector, and only 11 articles were eligible for content analysis. The findings have shown that the research trend on LCA in the Indonesia forestry sector started in 2009, but since 2015 the number of publications has been relatively constant. The functional unit used in LCA varied (mass, energy, time, and area size). The system boundary also varied from cradle to gate, gate to gate, and cradle to grave. The environmental impacts found in the articles were global warming potential, acidification, and eutrophication parameters. In conclusion, LCA has been applied in Indonesia's forestry sectors (roundwood production, furniture industries, biomass and wood pellet production). We propose that the future research direction is specific research in the site forest operation, such as seedling production, forest maintenance, and forest harvesting activities. We also recommend a more varied research scope to elaborate the LCA in private forest and non-timber forest product processes.
Keyword: Environmental impact, Climate change, Eutrophication, System boundary, Production forest

1. Introduction

The forest is vital for human life. Forest provides a wide range of environmental services, namely provisioning services (wood, food, fresh water), regulating services (climate change regulation, flood regulation, water purification), supporting services (biodiversity, nutrient cycling, soil formation, primary production), and cultural services (aesthetic, spiritual, educational, recreational) [1]. Forests do not negatively impact the environment in the conservation or protection forest with fewer human activities. The process goes naturally, and the environment works on its balance system.

However, in the production forest, the primary purpose of the forest is to provide products or services. Many human activities include nursery, forest maintenance (thinning, pruning, pest management), and timber harvesting. These human activities have negatively affected the environment, such as air pollution from machinery, water and soil pollution from fertilizer and pesticide utilization, and water consumption [2-6]. Since the 1990s, life cycle assessment (LCA) method has been used to analyze the environmental impacts of forestry activities and to suggest potential solutions to these problems [7].

LCA helps the stakeholders (private sector, government, community) identify the improvement they can make to improve environmental performance at various phases of the products/services life cycle [8]. LCA has been developed since the 1960s and applied in forest production in the early 1990s [7]. For instance, LCA between integrated and non-integrated among agriculture, animal husbandry, and forestry systems [9], LCA of cross-laminated timber production [10], and LCA of bioenergy from forest harvesting residues [11,12]. LCA in forestry activities also have been applied in Asia [13], Africa [14], Australia [15], America[10], [12], [16], and the European region [17].

Although the study of LCA has been applied in many sectors, based on the authors' knowledge through literature search, the application of LCA in Indonesia’s forestry sector is still limited. This study takes the form of a scoping review, which aims to identify the application of LCA in Indonesia’s forestry sector. A scoping review was simpler than a systematic review and emphasized specific questions [18]. The main question in this scoping review is: how does the application of LCA assess environmental performance in Indonesia's forestry sector?. Answering the question, we follow the guidance to conduct scoping review through i). Identification of the research question, ii). Selecting relevant articles, iii). Charting the data, and iv). Summarizing and reporting the findings [19–22].

2. Method

2.1. Literature identification and screening

The scoping review process started with literature identification, screening, and exclusion criteria, and the final stage was included for further analysis. We used the Scopus and Web of Science (WoS) database in literature identification. The articles published in Scopus and WoS databases are recognized for their quality in peer review. The process from identification to article inclusion used the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) approach. PRISMA approach was initially used in medical science to answer the specific question on the review process [23,24]. Afterward, the PRISMA approach has been applied in forestry research, such as the systematic review and meta-analysis on Shinrin-yoku (forest bathing), a healing method in Japan through activities in the forest [25], forest inventory [26,27], and economic benefits and costs of urban forest [28].

Articles retrieved from Scopus dan WoS on 5 July 2023. In the database of Scopus, we used *TITLE-ABS-KEY ((life cycle assessment) OR (LCA) AND (forest*) AND (Indonesia)* and found 19 articles. Moreover, we used the topic (TS) TS: life cycle assessment AND forest* AND Indonesia from the WoS database and found 16 documents. Furthermore, we carefully checked 35 articles (title, author, journal, and year of publication) and found 8 duplicated articles. From 27 screened articles, 1 article could not retrieve the full paper. Furthermore, we read carefully the title and abstract of 26 downloaded articles and excluded 8 articles. The criteria of exclusion were

1. The article type was a review paper.
2. The article is unrelated to the Indonesian forestry sector's LCA.

The diagram of the PRISMA approach from identification, screening, and inclusion of the articles (Figure 1) followed the guideline from Page et al. [29] and used the software that developed by Haddaway et al. [30]. The flow diagram showed a transparent and replicable procedure for article inclusion or exclusion [30]. Furthermore, the 11 included articles will be read carefully to answer the research question.

2.2. Summarizing and reporting the findings

Reading 11 included articles to get information on land use, activities, functional units, system boundaries, and impact categories. Based on the functions, forests in Indonesia were divided into forest production, forest conservation, and forest protection [31]. Dominant species information is based on the findings from the articles. Functional unit, system boundaries, and impact category following the ISO 14044 on environmental management, life cycle assessment requirements, and guidelines [8].

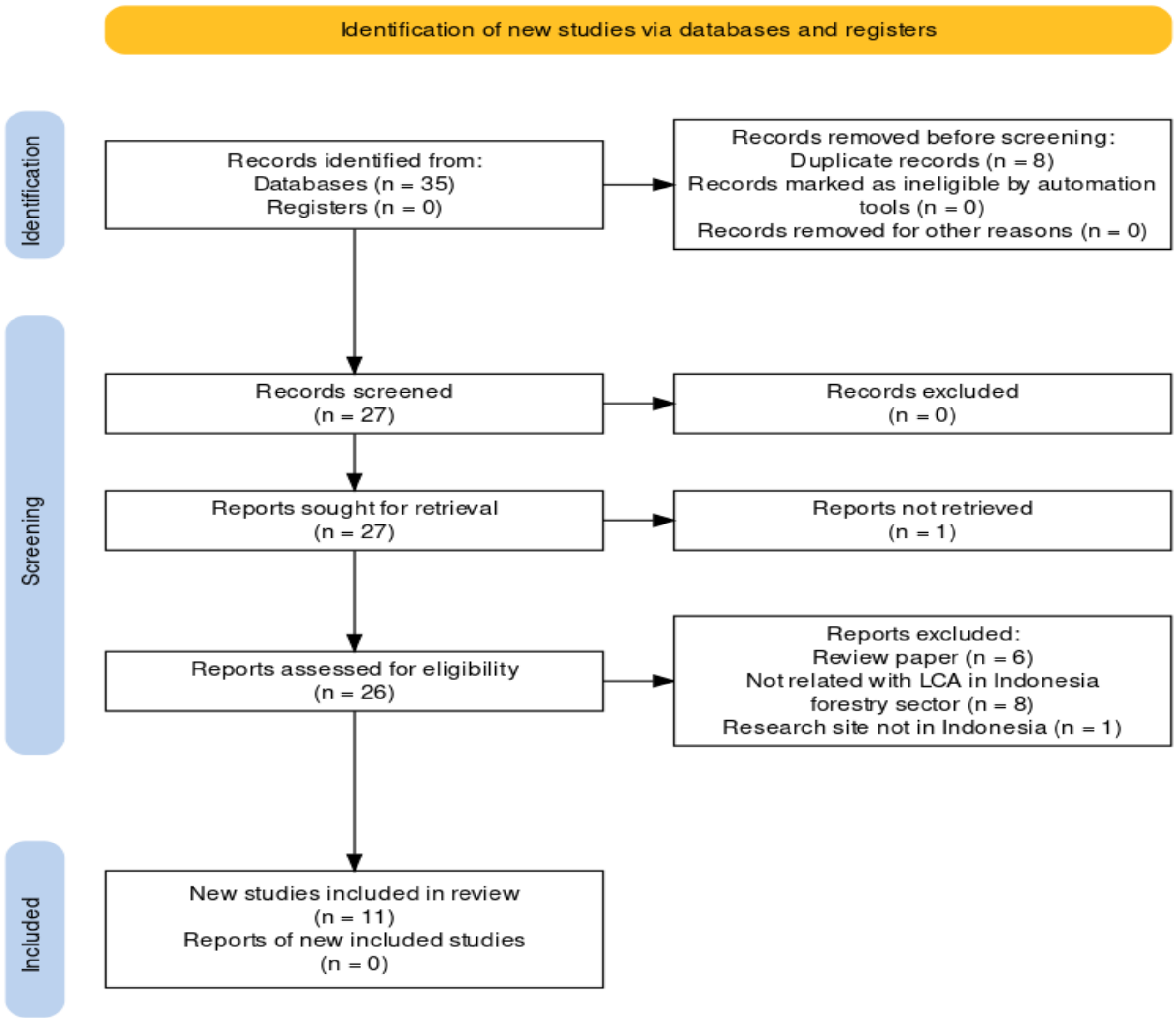

Figure 1. Flow diagram on article inclusion and exclusion

3. Result and Discussion

3.1. Research Trends on Life Cycle Assessment in Forestry Sector in Indonesia

The idea of LCA started in the 1960s, and the LCA methodological and standardization development increased from 980s to the 1990s [32]. Furthermore, the first concrete LCAs developed in the European forestry and wood products sector in the 1990s, with the goal of objectively analyzing the impacts of nonrenewable inputs into a system [7]. However, the research on LCA in the forestry sector in Indonesia, which the article indexed in Scopus or WoS, started in 2009 (Table 1).

Table 1. Articles on life cycle assessment in the forestry sector in Indonesia

Article ID	Year	Journal/Proceeding	Cited by	References
1	2016	Environmental Science & Technology	77	[33]
2	2016	Journal of Cleaner Production	51	[34]
3	2020	Nature Communications	40	[35]
4	2009	Applied Energy	36	[36]
5	2015	Landscape Ecology	12	[37]
6	2018	E3S Web of Conferences	10	[38]
7	2022	Science of the Total Environment	8	[39]
8	2022	Journal of Cleaner Production	2	[40]
9	2021	Jurnal Manajemen Hutan Tropika	1	[41]
10	2022	ACM International Conference Proceeding Series	0	[42]
11	2019	IOP Conference Series: Earth and Environmental Science	0	[43]

Compared to the Scopus database with the string *TITLE-ABS-KEY* ((*life cycle assessment*) *AND TITLE-ABS-KEY* (*forest**)), there were 1,724 articles. Moreover, the publications on life cycle assessment in Indonesia based on the Scopus database were 279 articles. Eleven articles on life cycle assessment in Indonesia's forest were too small. These phenomena can be seen as challenges and opportunities for Indonesian scholars. Scholars should elaborate on forestry activities to identify the potential environmental impacts for continuous improvement in the future.

This scoping review covered a total of 11 articles. Seven of them have been released in the last five years. The majority of these papers (82%) were journal articles, and three papers were published as conference proceedings (Figure 2). Although the number of articles is relatively low in the database of Scopus or WoS, it does not mean that the research on life cycle assessment in Indonesia's forestry sector was not progressing. The Ministry of Environment and Forestry Republic of Indonesia has integrated the life cycle assessment into the PROPER program [44].

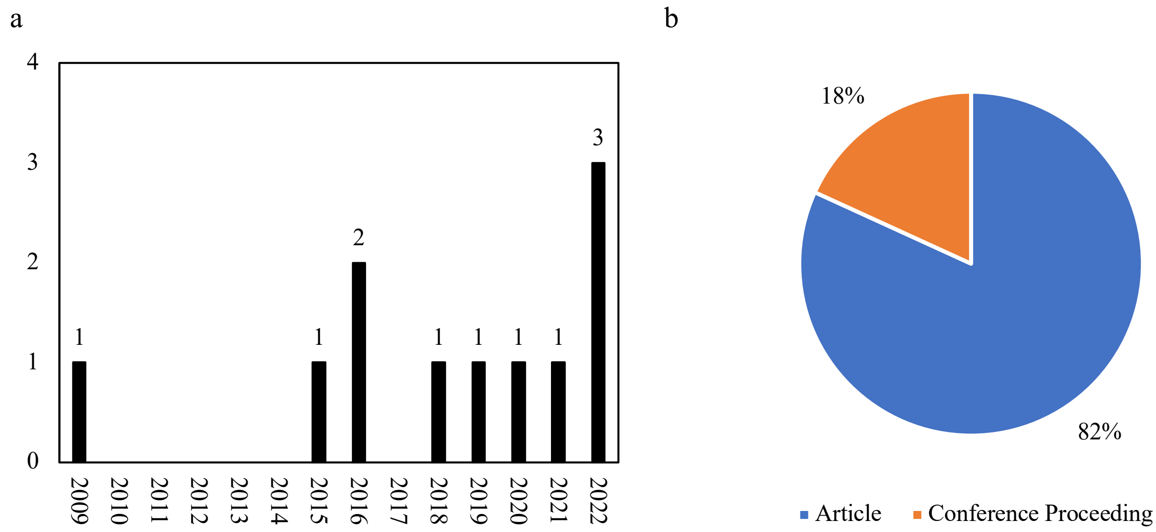

Figure 2. Article distribution (a) year of publication; (b) type or article (n=11)

Refer to Figure 2, the first article published in 2009 entitled Bio-methanol potential in Indonesia: Forest biomass as a source of bio-energy that reduces carbon emissions. The authors of this paper were a collaboration among Indonesian scientists from the Indonesian Ecolabeling Institute and Americans scientist from the University of Washington, Interforest, and ARU associates. The finding was that carbon emission could be reduced by about 8-35% by utilizing forest biomass converted to methanol to supply fuel cells for electricity [36].

No articles related to LCA in Indonesia's forestry sector in the next five years were found. The article on LCA in Indonesia's forestry sector was published again in 2015. During the period 2018 to 2021, the number of articles on Indonesia's forestry sector was one paper/year. However, in 2022, the number of articles on LCA in Indonesia's forestry sector increased to 3 papers.

3.2. Life Cycle Assessment in Indonesia's Forestry Sector

This scoping review discovered the activities for palm oil for bioenergy, roundwood, furniture, and woody biomass production (Table 2). The Ministry of Environment and Forestry Republic of Indonesia stated clearly that oil palm plantation is not included as forest plantation [45]. However, in this scoping review, the oil palm plantation was included in the reviewed articles because of land use change. Land use change is one of the environmental impacts that is assessed in the impact category on LCA.

The functional unit in LCA of Indonesia's forestry sectors was varied, such as mass (kg), energy (MJ), area (ha), and time (hour). Functional units must be i). Consistent with the study's purpose and scope, and ii). Clearly defined and measured [46]. This review paper found that the dominant functional unit was mass (kg). The main product of forest is timber which will be processed for wood products, furniture, or biomass for energy. Furthermore, the functional unit relevant to the purpose and scope of the LCA study was mass (kg).

The objective of the study determines the system boundaries and amount of detail in LCA [8]. In LCA, system boundaries should be determined in few aspects: boundaries between the technological system and nature, boundaries of the geographical area and time horizon under consideration, boundaries between production and capital goods production, and boundaries between the life cycle of the product studied and related life cycles of other products [47]. System boundaries in LCA can be divided into cradle to gate, gate to gate, cradle to grave, and gate to grave [48]. Moreover, in this research, we found that the system boundaries were cradle to gate, gate to gate, and cradle to grave.

Cradle to gate was dominant in this research. The system boundary limits the assessment process from raw material supply processes until ready to enter manufacturing or industries. For example, the cradle-to-gate in wood processing was the cultivation activities in forest plantations, starting from seedling preparation, establishing a permanent nursery, seedling maintenance, land preparation, planting activities, fertilizer application, weeding, and the final process was wood harvesting [41]. Moreover, the process in mill activities, namely raw material storage, chipping material, drying the chips, and compressing the pellet, were categorized as gate-to-gate system boundary [41]. Furthermore, the gate-to-grave system boundary distributes the wood pellet to the consumers. In this system boundary, the potential environmental impacts come from the warehouse's transportation activity and energy utilization to keep the wood pellet in specific moisture content.

Table 2. Summary of life cycle assessment in Indonesia's forestry sector

ID	Land use	Activities	Functional unit	System boundary	Impact Category	References
1	Oil palm plantation	Palm oil biodiesel production	Mass	Cradle to grave	AC, CC, EU, RC	[37]
2	n.a	Rayon production process	Mass	Gate to gate	AC, CC, CED, EU, RD	[42]
3	Oil palm plantation	Palm oil processing	Mass	Cradle to gate	AC, CC, CED, EC, EU, HH, HT, LU, OD, POF, RD	[43]
4	Oil palm plantation	Palm oil biofuel production	Energy	Cradle to grave	CC, LU	[35]
5	Production forest	Wood production	Area	Cradle to grave	CC	[39]
6	Production forest	Furniture products process	Mass	Gate to gate	AC, CC, CED, ET, EU, HH, HT, LU, RD	[38]
7	Cocoa plantation (monoculture and agroforestry system)	Cocoa production	Mass	Cradle to gate	AC, CC, EU	[34]
8	Forest plantation	Wood pellet production	Time	Cradle to grave	AC, CC, EU	[41]
9	Production forest (natural forest and forest plantation)	Biomass (wood waste and small diameter tree) utilization for forest biomass-based bioenergy	Mass	Cradle to gate	CC	[36]
10	Oil palm plantation	Palm oil production	Mass	Cradle to gate	CC, LU	[40]
11	Cocoa, coffee, palm oil plantation	Roundwood production and plantation productions	Mass Volume	Cradle to gate	CC, LU	[33]

Adopted from Quevedo-Cascante et al. [49]

Note: AC is acidification; CC is climate change; CED is cumulative energy demand; E is ecosystem; EC is ecotoxicology; EU is eutrophication; HH is human health; HT is human toxicology; LU is land use; OD is ozone depletion; PO is photochemical oxidation; POC is photochemical oxidant creation; POF is photochemical ozone formation R is resources; RC is resources consumption; RD is resources depletion, and n.a is data not available.

3.3. Future research direction

Forestry activities are a complex system: forest establishment, forest treatment, forest harvesting, forest product processing, and forest product marketing. Refer to Table 2, the system boundary in LCA for forestry can be grouped as cradle to gate, gate to gate, and cradle to grave. However, the cradle boundary in forestry contains many sub boundary. Thoroe and Schwinle [50] have given examples that the forest production boundary contains sub-boundary: stand establishment, tending, road building, and harvesting. In the future, scholars in Indonesia can look at the system boundary cradle to cradle in detail. For example, assessing the environmental impacts through LCA in different harvesting work systems for short rotation energy plantations in Hungary [2,3], and assessing seedling production for walnut trees [5]. The potential research that can be elaborated in natural forests or forest plantations in Indonesia for the system boundary cradle to cradle is LCA in the nursery for seedling production, forest treatments (weeding, thinning, pruning, pest control), and harvesting activities.

Based on 11 included articles for scoping review process, we found that four articles have assessed the LCA in forest production, either forest plantation or natural forest [36], [38], [39], [41], and seven articles have been conducted in non-forested areas (oil palm, cocoa, and coffee plantation). Forest plantations in Indonesia are varied, either based on the management purpose or dominant species. For example, the forest plantation for pulp (mineral soil and peat land) and the forest plantation for bioenergy, such as gliricidia (*Gliricidia sepium* (Jacq.) Kunth ex Walp.) and calliandra (*Calliandra calothyrsus* Meissn.), are potential research sites for further LCA research. Furthermore, scholars also can elaborate on the LCA in private or non-timber forest products. For instance, LCA in bamboo [51], beekeeping or honey production [52,53].

4. Conclusion

In Indonesia, the research of LCA have been applied in the forestry sector. The activities were varied from roundwood production, furniture industries, biomass and wood pellet production. The system boundary also varies, cradle to gate, gate to gate, and cradle to grave. However, the research in system boundary cradle to cradle such as seedling production, forest establishment (planting, thinning, pruning, pest management) and forest harvesting are lack of information. In the future, research in Indonesia's forestry sector should be developed to compile the comprehensive database.

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