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COMMENTARY AND DISCUSSION ARTICLE

Life cycle assessment research and application in Indonesia

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Abstract

Purpose This paper presents a review of the research and application of life cycle assessment (LCA) in Indonesia over the last 20 years and analyzes challenges and opportunities for future development.

Methods The study assessed 107 peer-reviewed scientific publications on LCA about Indonesia or written by authors affiliated with institutions in Indonesia. Relevant programs and recommendations to advance LCA adoption were elaborated.

Results and discussion The first paper on the subject of LCA appeared as early as in 1996, while the number of publication significantly increased since 2010. The majority of these articles came from universities, research institutions, and international organizations. Drivers were mainly related to product competitiveness aiming to fulfill sustainability requirements of the global commodities market. Government policies also played an essential role in many aspects, including a reduction in greenhouse gas emissions, sustainable consumption and production, green public procurement, eco-labeling, and green industry. Simultaneously, life cycle thinking has been embraced by governments and industries, especially with an immediate increase in the number of organizations implementing the recent version of ISO 14001. Increased participation in voluntary sustainability reporting also provides evidence of the prevalence of the sustainability concept. We believe that this development can serve as an essential step toward the spread of LCA studies in the future. Furthermore, the recent adoption of ISO 14040/44 as national standards in 2016/2017 also marked the commitment of Indonesian governments in LCA and is expected to stimulate the adoption of LCA-based environmental labels, such as carbon footprint, environmental product declaration, and product environmental footprint.

Conclusions The research and application of LCA in Indonesia are still in its infancy, as partly proved by a relatively small number of publications as compared to some other Southeast Asian countries. However, there was a notable increase in publication over the last 5 years, indicating a growing interest in LCA, mainly from academics and to less extent from private sectors. Although LCA has not been explicitly formulated in the national strategies and legislation, Indonesian governments do require life cycle thinking to inform policy-making. Nevertheless, the lack of incentives for green products, LCA programs, LCA expertise, and localized inventory data hampers its implementation. In the future, improvement should focus on LCA capacity

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building, the establishment of a forum to communicate LCA studies and resources, development of national life cycle inventory databases, and provision of market incentives for green products.

Keywords Environmental labeling · Environmental policy · Life cycle thinking · Product competitiveness · Sustainability standards

1 Introduction

1.1 The country and issues

Indonesia possesses a diverse and valuable natural environment. It consists of an archipelago of more than 17 thousand islands, and 70% of the territory is sea areas (Bappenas 2017). It is also the third largest tropical forest country (Margono et al. 2014), making Indonesia one of the world's primary carbon storage. The population of Indonesia was 258.7 million in 2016 (BPS 2017) and projected to grow to over 300 million by 2035 (Bappenas-BPS-UNFPA 2013). With people as a valuable social asset, the country still depends on a domestic market that drives massive industrialization. It is reflected as the dominant contribution of the industrial sector to the gross domestic product (GDP) followed by the agricultural sector (Bappenas 2017).

In response to the challenges of fast-growing population size and economic growth, it is critical for Indonesia to ensure sustainable development to meet human needs while preserving the country as a pleasant place for living and as a source of welfare. The economic growth has further implications for the environment. Indonesia has been known as the third largest greenhouse gas (GHG) emitter in the world after China and the USA and, or the fourth if European Union is included in the list (World Bank and DFID 2007). In 2012, the total GHG emissions amounted to 1454 million tons of carbon dioxide equivalent. The main contributing sectors were land use change and forestry including peat fires (47.8%), followed by energy (34.9%), agriculture (7.8%), waste (6.7%), and industrial process and product use (2.8%) (MoEF 2015). Sectoral wise, energy consumption in industry, power generation, and transportation are overgrowing.

1.2 Policies and sustainability context

While climate change becomes a global concern, the government of Indonesia has committed to a 26% reduction in GHG emission by 2020 through Presidential Decree No. 62/2013, and further to 29% by 2030 against a business as usual scenario (Bappenas 2017). On 25th September 2015, many countries around the world formally agreed to adopt a set of goals to end poverty, protect the planet, and ensure prosperity for all by proposing a new agenda called sustainable development goals (SDGs). To put SDGs in a local context, a recent Presidential Decree No. 59/2017 formulates a roadmap for achieving the goals. Realizing human prosperity remains largely dependent on natural resources, Goal 12 regarding sustainable consumption and production (SCP) has been included in the mid-term development plan 2015–2019 under the Presidential Decree No. 2/2015.

To ensure sustainable development without deteriorating the environment, the government of Indonesia has set relevant regulations. For instance, the Law No. 32/2009 on Environmental Protection and Management call on central and local governments to develop and implement environmental economic instruments, such as green public procurement (GPP), ecolabel, and environmental financing. Regulated through Presidential Decree No. 54/2010, GPP gives preference to goods and services that have environmental labels, with the main intention of promoting product sustainability at the national level (MoEF 2017).

To support this, the Ministry of Environment and Forestry (MoEF) have developed and implemented certification schemes for various products through its Ministerial Decree No. 2/2009. It consists of type II (self-declared) and type I (multi criteria) ecolabels that require life cycle consideration; meanwhile, type III ecolabel (environmental product declaration) which requires a full life cycle assessment (LCA) has not been regulated. In line with this, harmonization between industrial development and the preservation of ecosystem coined as a green industry has become one priority of Ministry of Industry (MoI) through the Law No. 3/2014. A complete list of certification schemes which are mostly voluntary and managed by various government and non-government organizations is shown in Table 1.

Environmental management system (EMS) and sustainability reporting are already quite popular among businesses in Indonesia. In 2016 alone, there were more than two thousands new ISO 14001 (ISO 2015) certificate holders and 56 sustainability reports submitted to Global Reporting Initiative (GRI). Sustainability reporting is the most popular for public-listed companies and state-owned enterprises, while ISO 14001 is applied by a large number of firms of broader levels, ranging from small to big ones. These certifications are based on a voluntary scheme. Although the ISO standard is voluntary, EMS is required by major sustainability programs such as company environmental performance rating (PROPER), ecolabel, and green industry by MoEF and MoI (see Table 1). These private and regulatory initiatives show the

Table 1 Standards and programs on environmental sustainability prevailing in Indonesia

No.	Standard or program	Scope	Scheme developer	Implementation scheme	Number of companies following standard or program
1	Ecolabel (types I and II)	Goods and services	MoEF (ministry)	Voluntary	8 [a] 9 [a]
2	Green industry	Organization	MoI (ministry)	Voluntary	129 [b]
3	Green building	Building	Local government (Jakarta and Bandung)	Voluntary/mandatory	–
4	Sustainable tourism	Tourism	MoT (ministry)	Voluntary	17 [c]
5	SKEM	Energy	MoEMR (ministry)	Mandatory	29 [d]
6	ISPO	Palm oil	MoA (ministry)	Mandatory/voluntary	565 [e]
7	SVLK	Forestry	MoEF (ministry)	Voluntary	2239 [f]
8	PROPER	Organization	MoEF (ministry)	Mandatory	1764 [g]
9	LEI	Forestry	LEI (private)	Voluntary	54 [h]
10	FSC	Forestry	FSC Indonesia (private) FSC (international)	Voluntary	391 [i]
11	RSPO	Palm oil	RSPO (international)	Voluntary	115 [j]
12	MSC	Fisheries	MSC (international)	Voluntary	3 [k]
13	ASC	Fisheries	ASC (international)	Voluntary	12 [k]
14	Greenship	Building	GBCI (private) WGBC (international)	Voluntary	20 [l]
15	Sustainability reporting	Organization	GRI (international)	Voluntary	56 [m]
16	ISO 14001	Organization	ISO (international)	Voluntary	2001 [n]

Information provided from websites and personal communication were collected between June and October 2017

MoEF, Ministry of Environment and Forestry; *MoI*, Ministry of Industry; *MoEMR*, Ministry of Energy and Mineral Resources; *MoT*, Ministry of Tourism; *MoA*, Ministry of Agriculture; *SKEM*, Standar Kinerja Energi Minimum/Minimum Energy Performance Standard; *ISPO*, Indonesian Sustainable Palm Oil; *SVLK*, Sistem Verifikasi Legalitas Kayu/Indonesian Timber Legality Assurance System; *PROPER*, Program Penilaian Peringkat Kinerja Perusahaan/Company Environmental Performance Rating Program; *LEI*, Lembaga Ekolabel Indonesia/Indonesian Ecolabelling Institute; *FSC*, Forest Stewardship Council; *RSPO*, Roundtable on Sustainable Palm Oil; *MSC*, Marine Stewardship Council; *ASC*, Aquaculture Stewardship Council; *GBCI*, Green Building Council Indonesia; *WGBC*, World Green Building Council; *GRI*, Global Reporting Initiative; *ISO*, International Standard Organization

[a] http://standardisasi.menlhk.go.id/index.php/barangjasateknologi-ramah-lingkungan/barang-berlabel-lingkungan/ekolabel-yang-berbasis-sni/ and http://standardisasi.menlhk.go.id/index.php/barangjasateknologi-ramah-lingkungan/barang-berlabel-lingkungan/ekolabel-swadeklarasi/ (October 20th 2017)

[b] http://www.kemenperin.go.id/artikel/16770/Kemenperin-Serahkan-152-Penghargaan-Bidang-Industri, award (October 24th 2017)

[c] http://kemenpar.go.id/asp/detil.asp?c=17&id=3755, award (October 24th 2017);

[d] Edi Sartono (MoEMR)

[e] http://ispo-org.or.id/index.php?option=com_content&view=article&id=79&Itemid=225&lang=ina (October 24th 2017)

[f] http://silk.dephut.go.id/index.php/info/iuiphhk (October 24th 2017)

[g] Keputusan Direktur Jendral Pengendalian Pencemaran dan Kerusakan Lingkungan Nomor: SK.10/PPKL/SET/WAS-O/3/2017 Tentang Penetapan Peserta Penilaian Peringkat Kinerja Perusahaan Dalam Pengelolaan Lingkungan Hidup Tahun 2016–2017, award

[h] http://www.lei.or.id/files/LEI%20Certified%20FMU%20web.pdf

[i] https://info.fsc.org/certificate.php#result (October 24th 2017)

[j] http://www.rspo.org/certification/supply-chain-certificate-holders/page/12?keywords=&country=Indonesia (October 24th 2017)

[k] ISEAL Alliance, Global Sustainability Standards Symposium, 3rd May 2017, Jakarta, Indonesia

[l] http://gbcindonesia.org/bangunan-tersertifikasi (October 24th 2017)

[m] http://database.globalreporting.org/search/, year 2016 only (October 24th 2017)

[n] https://www.iso.org/the-iso-survey.html, year 2016 only (October 24th 2017)

prevalence of the sustainability concept in Indonesia. In fact, LCA as a tool to determine metrics for environmental sustainability is still facing challenges. The newest version of the EMS standard has recently been adopted as local standard namely Standar Nasional Indonesia. It does not require LCA; instead, it only requires the use of a life cycle perspective. It means that organizations are responsible for taking into consideration their indirect influence in addition to where they

have direct control. In the next few years, it is expected that "life cycle perspective" will become a common business practice in Indonesia as this could serve as a means to increase awareness about LCA.

1.3 LCA implementation in developing countries

Sustainability is a theme of growing importance that is present in most strategic and political agendas around the world. Sustainability is recognized as an evolving concept that has now been closely associated with LCA approach globally (Zamagni et al. 2012). In that regard, LCA becomes a valuable tool to understand the impact of products and processes. Despite the increasing awareness of the importance of sustainability, making this concept operational in practice is still a challenge. Guinée et al. (2011) predicted that the second decade of the twenty-first century would be the era of sustainability analysis in which LCA research will be used to investigate the sustainability of products and services.

LCA has been increasingly used by industries to communicate environmental performance of a product. This method is standardized as ISO 14040 and 14044 (ISO 2006a, b). Formally, it is defined as a method to evaluate the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle. LCA considers environmental impacts of a product or service by considering raw material provision, conversion into products, use phases, and final disposal. Often used as a tool in the decision-making process, LCA is a systemic approach that provides quantitative results related to potential impacts on humans, ecosystems, and resources. Since the inception of LCA, the technique has been adopted broadly for research and development, education, product labeling, product design, process improvement, and business plan support.

While at the very beginning of the twenty-first century, LCA was still a topic promoted by a relatively small group of experts mostly from Europe, North America, Australia, and Japan, life cycle approaches have started to become mainstream around the world (UNEP 2016). Developing countries in Asia such as India, Thailand, and China have taken notable strides in this regard (Arena 2000). However, developing countries face some obstacles that need to be tackled before measuring environmental burdens becomes a priority in national policies. Despite this, industry, research institutions, government, and academia in developing countries have started to attend to environmental problems. This development leads to the use of sustainability analysis tools like LCA.

The nature of life cycle perspective in ISO 14001 is a qualitative approach, while LCA is a quantitative one since the latter involves an impact assessment stage utilizing characterization factors. Standards that use LCA like product carbon footprint (ISO 14067) and environmental product declaration (ISO 14025) have not been regulated in Indonesia. Nevertheless, GRI standards for sustainability reporting, for example, have recently recommended the use of LCA to determine the material content of the report (GRI 2016). Also, the adoption of the LCA standards (ISO 14040 and 14044) as a national standard in 2016 and 2017 indicates an initiative by the government to set a foundation for the implementation of LCA in Indonesia.

1.4 Problem identification and objective of the paper

Material strength, nutrition value, energy content, and durability are some expressions of product quality. In trades, a description based solely on functional quality is however not often sufficient. Additional information on the environmental performance of a product is critical if it is intended for environmentally aware consumers or for trades to countries who apply strict environmental standards. Failing to declare product environmental sustainability may cause rejection by potential buyers and reduce the competitiveness of a product to penetrate potential markets.

Therefore, sustainability metrics are important, and its usage is growing as an approach to improve a country's trade competitiveness. The adoption of this parameter in product declaration and labels will undoubtedly support sustainable development. Statement on the environmental sustainability of products is very much relevant to regional and global trades. This paper intends to answer two key questions: first, to what extent LCA has been utilized in the Indonesia context; second, what are the potentials and challenges concerning capacity and network of LCA application particularly in industrial sectors.

To perform an LCA study, one may need to recognize background processes of a product system under study (Maepa et al. 2017). This information is essential in applying the methodology to assess products, processes, or services. In this regard, it is quite challenging to do LCA in a country that has not developed its national inventory database. On the other hand, Indonesia offers many potential LCA applications in industrial sectors, particularly for those relying on natural resources such as oil, gas, mining, forestry, and agriculture. Above all, despite its global popularity, little is known about LCA's status, capacity, networking, and progress in Indonesia. This paper presents an overview of the research and implementation of LCA in Indonesia over the past 20 years and analyzes challenges and opportunities for future development. It is also aimed at promoting LCA activities in Indonesia and further linking researchers and practitioners in the country with the global LCA community.

2 Methods

Bibliometric analysis based on records retrieved from literature indexing systems has been used to analyze the status of

LCA research and application (Chen et al. 2014; Hou et al. 2015). This study reviews scientific publications on LCA related to Indonesian cases and written by authors affiliated with institutions in Indonesia in the last 20 years. The list of publications was derived from Web of Science (WoS, Thomson Reuters) and Scopus (Elsevier) on 17 January 2017. Both represent major indexing systems of peer-reviewed articles and have covered a vast range of academic fields. Choice of keywords used in the Boolean search was "life cycle assessment," "life cycle analysis," "life cycle sustainability assessment," "life cycle costing," "life cycle inventory," and "life cycle impact assessment." A complete list of criteria including database used in each indexing systems and time span are summarized in Table 2. These criteria were applied to the case of not only Indonesia, but also the other Southeast Asian countries (Thailand, Malaysia, Singapore, Cambodia, Brunei, Myanmar, and Lao). To provide a more comprehensive picture in the case of Indonesia, additional terms typically used concerning life cycle concept were also added to the Boolean search. These were "life cycle thinking" and similar terms used in various international standards such as "life cycle perspective" (ISO 14001: Environmental Management System), "life cycle consideration" (ISO 14020: Environmental Labeling), and "life cycle approach" (ISO 14031: Environmental Performance Evaluation).

We identified authors' affiliations in Indonesia and the corresponding research topics by manually listing them from each reviewed articles. The research topics were also analyzed using analytical features available in WoS and SCOPUS. Since the way "fields of study" in these indexing systems are classified differently, they were examined separately. Finally, we analyzed the challenges and opportunities related to future development of LCA research and application. Relevant programs and recommendations to advance LCA adoption in Indonesia were also elaborated.

3 Results

Using the search criteria shown in Table 2, we came up with a total of 107 articles on LCA in Indonesia or written by authors affiliated with institutions in Indonesia, of which 23 were indexed in WoS only, 45 in SCOPUS only, and 39 in both (see Fig. 1). The citations and databases where these articles were indexed can be found in the Electronic Supplementary Material (Reference SM and Table SM1). Additional search keywords such as life cycle thinking, life cycle perspective, life cycle consideration, and life cycle approach yield only two other records. Therefore, for further analyses, we proceeded with the initial criteria as presented in Table 2.

3.1 Publication in the last 20 years

As indicated in Fig. 2, the first article of 107 appeared as early as in 1996. It was a PhD dissertation from a university in Japan. In fact, there are many LCA publications of similar nature over the past two decades, i.e., written by Indonesian graduates studying abroad. After a pause of several years, the next papers appeared in 2003 and continued after that. The tendency for a significant increase can be seen particularly in the past 5 years between 2012 and 2016, which demonstrates growing interest in research and application of LCA. Noticeable difference in the number of publication is seen between SCOPUS and WoS-indexed publications notably in 2006 and 2012, where SCOPUS recorded a much greater number. This difference was due to many papers from a number of conferences that were indexed in SCOPUS but were not indexed in WoS. Similar findings observed in Fig. 1 support this result.

3.2 Author's affiliation in Indonesia

Figure 3 shows 13 organizations publishing at least two papers. They consist of most universities and governmental and non-governmental research institutions. Several multinational companies of consumer products such as Unilever and Nestle (personal communication: Endah Sulistyowati and Putut Pramono, respectively) also carried out LCA studies for their internal purposes but did not publish the reports. Therefore, their results could not be included in this analysis.

Table 2 Boolean search criteria

Index	Database	Key words appeared in title, abstract, or keywords	Time span
Web of Sciences (Thomson Reuters)	Science citation index; Social science citation index; Arts and humanities citation index; and Emerging sources citation index	Life cycle assessment; Life cycle analysis; Life cycle sustainability assessment; Life cycle costing; Life cycle inventory; and Life cycle impact assessment	1996–2016
SCOPUS (Elsevier)	Life sciences; Health sciences; Physical sciences; and Social sciences and Humanities		

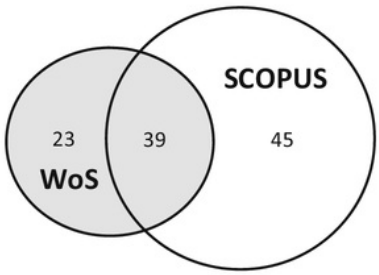


Fig. 1 Number of published articles on LCA

3.3 Research areas of interest

The features available in the WoS and SCOPUS indexing systems were used to provide information on research areas as shown in Fig. 4. The results revealed the diversity of LCA research areas, with major categories covering environmental sciences (26%), engineering (23–24%), and energy (14–17%) in each indexing system. The categories of these indexing systems are slightly different (four categories in WoS and three categories in SCOPUS) as indicated by the shading in Fig. 4.

The above classification, however, is still too general to identify who does what about LCA in Indonesia. Since LCA studies are typically described in terms of product systems, we can map the categories and names of different institutions along with product systems, as shown in Table 3. The organizations are classified as a university, a government research institution, a private company, and an international organization operating in Indonesia. In this table, authors' affiliations have been extended, from what is presented in Fig. 3, including also institutions that published only one article. Very few published LCA studies paid attention to end products, consumer goods; mostly to intermediary products. Biobased products such as bioenergy, palm oil, jatropha, rice, biomass, and fish dominate the list. Some of them are strategic export commodities of Indonesia. Other vital sectors with less interest included different types of renewable energy, waste, building and construction, transportation, and consumer products.

4 Discussion

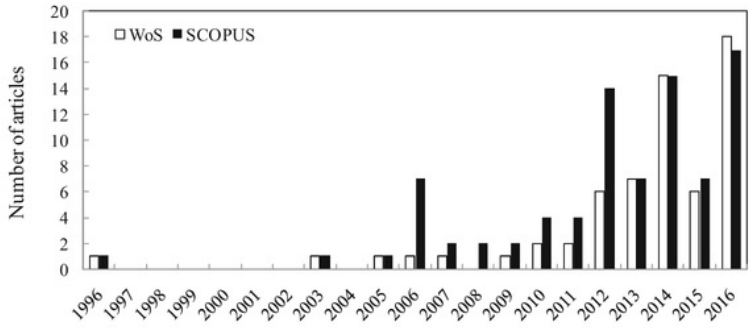
LCA has been globally accepted as a tool for policy-makers, producers, and consumers to achieve sustainability. However, in the Asian region, it has not been commonly used in business practice as well as in the legislation (UNEP 2016). Particularly for Indonesia, the implementation of life cycle thinking and LCA is now encountering unique challenges and opportunities.

4.1 Challenges

The review shows that development of research and application of LCA is growing substantially in the last 5 years. The publications have been carried out mostly by universities, followed by research institutions. Among them, only a few are coming from private sectors. The motivation to publish these articles is often driven by concern of international trade or promotion by parent companies. Trade initially fostered the implementation of LCA in Indonesia since buyers from developed countries had long requested a specific environmental product labeling or compliance with their sustainability standards. Among the various research topics that have been covered, energy is the most widely discussed one, principally related to bioenergy (see Table 3 and Table SM2, Electronic Supplementary Material) due to the expansion of oil palm, global debates around renewable energy, and conflict between fuel, feed, and food. Unlike the more developed regions of the world, the primary sectors (agricultural and mining activities) initially dominated economies in Indonesia and only during the last two decades manufacturing and the tertiary sectors have become more indispensable.

Many of the reviewed papers claimed as LCA studies limit their analysis to a single issue such as global warming. To name a few, examples include Khatiwada et al. (2016); Surahman et al. (2015); Bessou et al. (2014); Harsono et al. (2014); and Holmner et al. (2014). An LCA study is preferably based on a complete set of impact categories as we do not want to shift burdens from one problem to another. However, since data availability may be limited, a set of relevant impact

Fig. 2 LCA publications by year



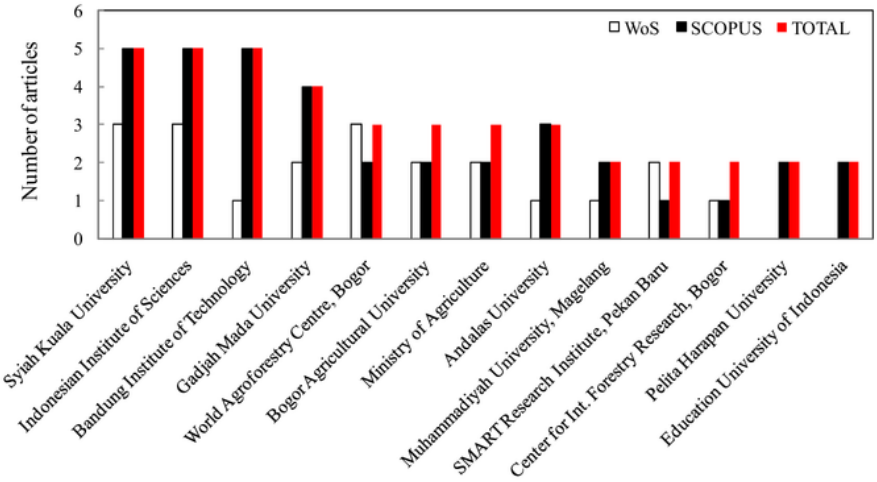
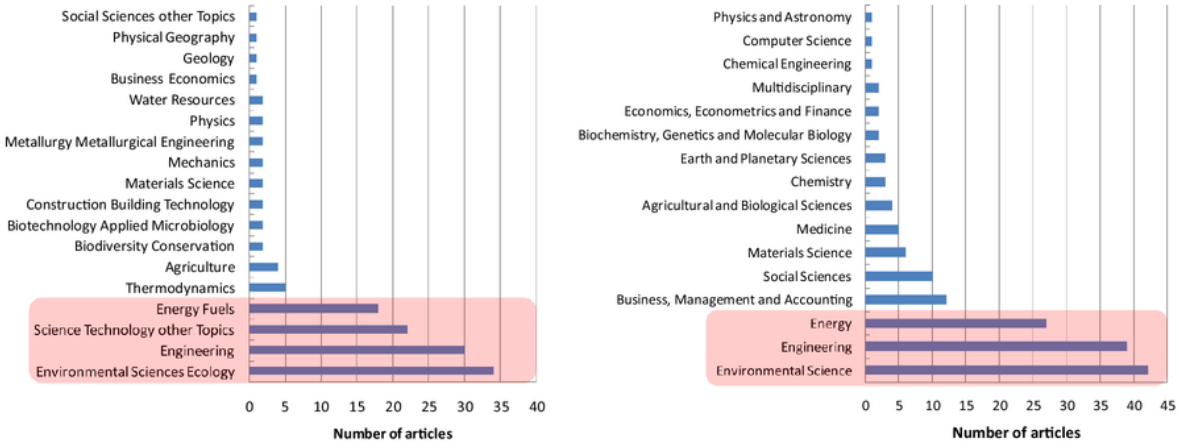


Fig. 3 Author's affiliation in Indonesia publishing at least two LCA papers

categories needs to be fixed to avoid biased results. Reasons for choosing specific parameters should be clearly identified in the goal and scope definition of the study.

Despite its potential advantages for business and policy-making, the level of implementation of life cycle approaches at the national level remains very limited. It indicates that LCA is still unpopular to the general public in Indonesia. The number of scholarly articles was reasonably considerable, but annual publications are still very low compared to those of other countries in Southeast Asia. Indonesia's position comes fourth after Thailand, Malaysia, and Singapore (see Fig. 5). The rest of Southeast Asian countries (Cambodia, Brunei, Myanmar, and Lao) play minor roles merely. According to Ramjeawon (2012), significant problems in developing countries lie in their insufficient capacity to do LCA, lack of national LCA projects and access to background datasets.

The number of green products which usually take advantage of life cycle thinking is still very few and limited in the category (see Table 1). Currently, green products are introduced at a ministry-level through MoEF, MoI, MoT, MoEMR, and MoA, which are now developed as regular programs of the government. The first product to get an ecolabel certificate was launched in 2006 (Nurmayanti 2014). The criteria for its development were in accordance with ISO standards using life cycle consideration as an approach. However, as of August 2016, there were only 8 product categories for type I ecolabel, consisting of 17 brands from 5 companies. Other sustainable certifications of green products such as marine and agro-based products existed but progressed slowly. In practice, these certification schemes can be integrated with GPP. However, the lack of published directory on green products and established criteria for GPP leads to difficulty in executing fair bidding. With growing global trade potency for developing countries



WoS (62 articles) SCOPUS (84 articles)

Fig. 4 Research areas according to WoS and SCOPUS

Table 3 Thirty-six author's affiliations in Indonesia and the research topics

Category	Author's affiliations[a]	Research topics
University	UNSYIAH; ITB; UGM; IPB; UNAND; U-Muhammadiyah; UPH; UPI; U-Ganesha; Polytechnic Medan; UNRI; UNS; UNEJ; U-Janabadra; UI; UnDip; UB; UII; U-Persada; and Polytechnic Bandung	Energy (electricity, biodiesel, bioethanol, biogas, wind, solar, hydro, and lighting); palm oil, jatropha, sugarcane, rice straw and husk, capture fisheries, and cattle milk; building, concrete, transportation, traffic road; healthcare; water, sanitation, and waste (solid, household, palm oil mill effluent, plastic, and hazardous); small scale enterprise, supply chain design, remanufacturing, recycling, and cleaner production; carbon-capture technology; LCA-method, carbon footprint, and GHG
Government research institution	LIPI; MoA; MoMAF; ICCRI; IOPRI; and BPPT	Energy (bioenergy, biodiesel, and charcoal); palm oil, cocoa, jatropha, agroforestry, and aquaculture; biomass residues; copper alloy; LCA-method, GHG, and carbon footprint
Private company	SMARTRI; Asian Agri; Asam Jawa; and LEI	Energy (biogas, biomethanol); palm oil, perennial crops; forest residues, soil nitrogen; palm oil mill effluent, GHG
International organization	ICRAF; CIFOR; UNDP; UNESCO; ATSEA program; and Haskoning DHV	Energy (biofuel, biodiesel, and biochar); palm oil, bioenergy crops, and jatropha; land use, soil carbon, soil amendment; water; waste (treatment, recoverable resources), recycling; marine debris

Detailed information on the 36 author's affiliations in Indonesia, research topics, and sources of information are given in in the Supplementary (Table SM2)

UNSYIAH, Syiah Kuala University; *ITB*, Bandung Institute of Technology; *IPB*, Bogor Agricultural University; *UNAND*, Andalas University; *U-Muhammadiyah*, Muhammadiyah University; *UPH*, Pelita Harapan University; *UPI*, Education University of Indonesia; *U-Ganesha*, Ganesha University of Education; *UnRi*, Riau University; *UNS*, Sebelas Maret University; *UNEJ*, Jember University; *U-Janabadra*, Janabadra University; *UI*, University of Indonesia; *UnDip*, Diponegoro University; *UB*, Brawijaya University; *UII*, Islamic University of Indonesia; *U-Persada*, Persada University; *LIPI*, Indonesian Institute of Sciences; *MoA*, Ministry of Agriculture; *MoMAF*, Ministry of Marine Affair and Fisheries; *ICCRI*, Indonesian Coffee and Cocoa Research Institute; *IOPRI*, Indonesian Oil Palm Research Institute; *BPPT*, Agency for the Assessment and Application of Technology; *SMARTRI*, Sinar Mas Agro Resource and Technology Research Institute; *LEI*, Indonesian Ecolabelling Institute; *ICRAF*, World Agroforestry Centre; *CIFOR*, Center for International Forestry Research; *ATSEA*, Arafura Timor Seas Ecosystem Action

and relevant policy support, Indonesian green products can expand beyond what has been achieved today. To that end, ecolabel and other environmental certification schemes could be seen as a key for LCA implementation in the future.

LCA studies provided little information in the policy-making process. Although the policies on green products exist, the enforcement is still low as most of them are on a voluntary basis. The green certification is not straightforward to impose as business pressure is high while consumers' demand is low. Nevertheless, niche markets are starting to develop among the wealthier classes who may demand greener or more sustainable products. Consumers also need to be encouraged to purchase environmentally friendly products. For example, the certification of timber and palm oil are mandatory for certain export markets. For domestic demand, both voluntary and mandatory schemes exist in the case of palm oil. The latter applies, particularly to integrated palm oil processing. A complete list of implementation schemes for certification of other products is shown in Table 1.

4.2 Opportunities

Environmentally conscious society in the global market has invoked sustainability-oriented business activities. Current market demands for transparencies throughout the whole supply chain, from the biggest enterprises to the smallest holders. This global trend will somehow influence the condition in Indonesia and subsequently force industries to comply with stricter environmental and social criteria from the market. Indonesian governments have already initiated some policies to advocate and enforce sustainable practices in industries, including bringing life cycle perspectives and life cycle assessment to technical ministries and industrial forums. The government realized that if enterprises cannot be advocated for being sustainable, they will lose market share in a globalized economy. In the future, companies will likely be encouraged to show the performance of their products utilizing LCA methods.

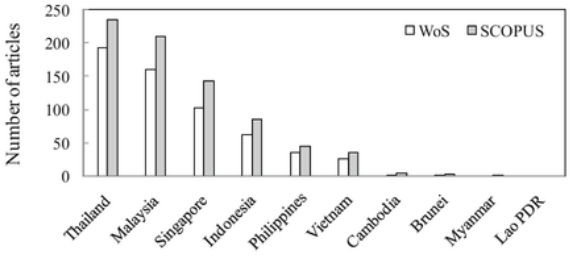


Fig. 5 LCA publications in the Southeast Asian countries

Indonesia has currently embraced policies related to sustainability and can use LCA as a tool to achieve sustainability targets such as reducing GHGs while improving economic and social benefits. Recently, a new government regulation (No. 46/2017) on environmental economics instrument has been issued. This regulation provides incentive mechanism in order to improve environmental management in Indonesia. It requires a release of a detailed roadmap on sustainable financing and mandatory sustainability report for publicly listed companies and financial institutions. Within the roadmap, the authority aimed to contribute to reducing GHG emissions by developing a low-carbon economy. One of the tools addressed was carbon footprint measurement and carbon market. Although there is not yet straightforward policy on LCA regulated by the government, this will create an opportunity for LCA study to make a contribution.

Most life cycle topics have not been acknowledged at the national level through scientific research, educational programs, business practices, and domestic policies. Increasing awareness about its potential application is essential. To enhance LCA implementation, strengthening the linkages between research, training, and development of national Life Cycle Inventory (LCI) databases and related regulations is the key to success. Policy-makers need to be informed about the LCA studies while LCA should also be more practical and realistic for decision makers. In that regard, LCA has been introduced to policy-makers at the Ministry of Forestry and Environment in the forms of introductory books (Hanafi and Utomo 2015). ISO LCA has recently been adopted as national standard. Technical training on the implementation of the standards for policy-making has also been carried out. To increase awareness, such activities shall be expanded to other technical ministries as well. In the remainder of Section 4, we will come up with two central proposals to advance LCA adoption in Indonesia, namely development of national LCI database and capacity building.

4.3 National LCI database

Another vital requirement to do an LCA is the availability of national LCI database. It is recognized as one of the signs of the development and mainstreaming of LCA in a country (Gheewala et al. 2017). LCI which is based on processes developed by other countries, such as in Ecoinvent (mostly data from Europe) and US-LCI (primarily data from the USA) are available on a commercial basis. However, direct use of such databases for LCA studies in Indonesia can lead to results with low reliability due to differences in practice. Therefore, a national LCI consisting of a collection of production data based on local processes is imperative. The key to successfully develop LCI databases depends largely on the government initiative and stakeholders' participation, particularly on the willingness of relevant industries to disclose their un-classified LCI data to the public. However, it is still a long way for Indonesia to develop its own national LCI database. Currently, setting up background data on electricity and transportation given the spatial distributions of many islands in Indonesia is a good starting point for achieving this goal.

4.4 Networking and capacity building

While there seems to be a consensus that capacity building is a key to promoting LCA, more attention needs to be drawn to the way to go about it (Ramjeawon 2012). To speed up the LCA development in Indonesia, the involvement of universities, research institutions, and industries on LCA research needs to be intensified. In line with this, Indonesian Life Cycle Assessment Network (ILCAN) launched at the end of 2014 has been listed as one of the national networks in the Asia Pacific (UNEP 2016). It is a voluntary, non-profit organization to promote LCA research and applications to support sustainable development in Indonesia. Its primary objectives are to share information on LCA methodology and to build capacity on LCA competency. ILCAN has been actively involved in LCA-related activities and playing an important role in advocating life cycle thinking by organizing conferences and training courses on LCA since 2015. Also, there were other LCA conferences held by international organizations, such as AgriFood Asia in 2013 (with the theme "Life Cycle Thinking on Energy, Food and Agriculture in Asia") and UNEP/SETAC Life Cycle Initiative in 2015 (with the theme "Mainstreaming Life Cycle Thinking"). Table 4 lists the primary activities related to LCA development in Indonesia, including policy and regulations discussed extensively in Section 1.2.

5 Conclusions

This study identified 36 Indonesian affiliations of authors publishing papers on LCA. The system product of interest was so far dominated by bioenergy, palm oil, jatropha, rice, biomass, fish, waste, and building. In addition to academic research, drivers to carry out LCA were mainly to enhance product competitiveness and to fulfill sustainability requirements of the global commodities market. Many of these papers limit their analyses to global warming impact, therefore, and can be improved to cover a broader range of impact categories.

The implementation of LCA in Indonesia is still in its infancy, as proved by a relatively small number of publications as compared to some other countries in the Southeast Asian region. However, there was a notable increase in the past 5 years, indicating growing interest in LCA. The trend captured mostly reports from academics and to less extent from private sectors. Although LCA has not been explicitly formulated in policy and legislation, government plans and

Table 4 LCA milestones in Indonesia

Year	Events
2009	Law No. 32/2009 (environmental protection and management)
2009	Ministry of Environment Decree No. 2/2009 (ecolabel for environmentally friendly products)
2010	Presidential Decree No. 54/2010 (green public procurement)
2013	LCA AgriFood Asia Conference on "Life cycle thinking on energy, food and agriculture in Asia", Jakarta, 24–26 June 2013
2013	Presidential Decree No. 62/2013 (national GHG emission reduction target)
2014	Law No. 3/2014 (development of green industry).
2014	Declaration of Indonesian Life Cycle Assessment Network (ILCAN), Tangerang Selatan, 17 December 2014
2015	Presidential Decree No. 2/2015 (sustainable consumption and production)
2015	UNEP/SETAC-Life Cycle Initiative Conference on "Mainstreaming life cycle thinking", Jakarta, 16–17 March 2015
2015	1st ILCAN conference on "Life Cycle Assessment Research in Indonesia", Tangerang Selatan, 24–25 November 2015
2015	Adoption of ISO 14001:2015 (environmental management system) as national standards (SNI)
2016	Adoption of ISO 14040:2006 and 14044:2006 (life cycle assessment) as national standards (SNI)
2017	1st issue of Indonesian Journal of Life Cycle Assessment and Sustainability (IJoLCAS), 6 January 2017
2017	Technical training on the implementation of LCA standards (SNI-ISO 14040 and 14044) for policy-making, organized by Ministry of Environment and Forestry, Jakarta, 5–6 April 2017
2017	Presidential Decree No. 59/2017 (achieving the sustainable development goals)
2017	Government Regulation No. 46/2017 (environmental economics instrument)

strategies requiring life cycle thinking exist. Nevertheless, lack of incentives for green products, LCA programs, LCA expertise, and local inventory data hamper the implementation of LCA.

This review could serve as a reference that shows state of the art in LCA research and applications in Indonesia, and link local researchers and practitioners with the global LCA communities. Improvement in the future should give higher priority to LCA capacity building through education and training, the establishment of multi-stakeholders' forums to communicate LCA studies and resources, development of national life cycle inventory databases, and provision of market incentives for green products. Further research to take into account "gray" publications would be needed to reflect better the challenges and opportunities facing LCA research and applications in Indonesia.

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