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Eco-Industrial Parks in the Palm Oil Industry: A Systematic Literature Review on Circular Economy and Sustainability Practices

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Abstract: As the world's largest palm oil producer, Indonesia has not only a significant economic opportunity but a huge environmental responsibility. Although the palm oil sector constitutes a major sector earning foreign income for the country and providing employment, it generates massive biomass waste. Incorporation of Circular Economy (CE) strategies, such as recover, reuse, recycle, and by-product valorization, provides a potential vehicle to help turn these wastes into renewable energy, organic manures, building materials, and biofuels, with both environmental conservation and long-term economic viability across the supply chain. This study utilizes a Systematic Literature Review (SLR) approach using PRISMA guidelines to synthesize 39 scientific articles from 2020-2025 discussing CE and Eco-Industrial Parks (EIPs) in the palm oil industry in Indonesia. A novelty is the combination of bibliometric mapping with thematic analysis to provide multidimensional synthesis, which discovers three dominant focus areas: (1) Biomass Utilization, (2) Circular Economy Applications, and (3) EIP Conceptualization. CE practices in these dimensions are broadly classified in Table 1 as energy recovery (e.g., biogas from POME), material reuse (e.g., composting EFB, application of POFA in construction), and process optimization (e.g., value chain integration and multi-stakeholder collaboration under EIPs). This study concludes that the structured adoption of CE principles through EIPs can significantly enhance environmental and economic outcomes in Indonesia's palm oil industry. Future research should focus on quantitative CE indicators and the development of localized EIP models tailored to regional contexts.

Keywords: *Eco-Industrial Park; Palm Oil Industry; Circular Economy; Waste Exchange; Materials Flow; Energy Flow.*

1. Introduction

Indonesia ranks as the largest producer of palm oil globally, making this commodity one of the leading sectors in the national economy. In 2023, palm oil production increased compared to the previous year, with Indonesia producing 47.08 million tons of palm oil (BPS, 2024). Globally, Indonesia accounts for 58% of the world's Crude Palm Oil (CPO) production [1]. This growth is also driven by high global market demand and the availability of abundant land and natural resources. The large scale of production and the widespread presence of small-scale sectors indicate that the palm oil industry is not only economically significant but also has great potential to exert environmental pressure if not managed sustainably. Therefore, approaches such as the development of Eco-Industrial Parks (EIPs) become relevant as integrative strategies that can optimize resource efficiency, minimize waste, and create synergies among industries within palm oil-based zones. The concept of Eco-Industrial Park (EIP) has become a strategic approach in achieving sustainable industrial development through industrial symbiosis, resource efficiency, and waste reduction. Indonesia, as one of the countries with the highest number of industrial estates in Southeast Asia, is recorded to have 170 industrial parks [2]. With the continuous increase in industrial zones across the country, the implementation of EIP principles in Indonesia needs to be realized in a tangible way. The low adoption of EIP in Indonesia presents both a challenge and a significant opportunity, especially in strategic sectors such as the palm oil industry, which is known as one of the largest contributors to foreign exchange, with export values reaching 24.01 billion USD [3]. On the other hand, the palm oil industry is also a significant contributor to waste and emissions. Therefore, the urgency to integrate circular economy practices within the EIP framework is becoming increasingly critical to support the sustainability of national industries. What is lacking is a comprehensive understanding of how circular economy practices, particularly waste exchange are integrated within EIP frameworks in the palm oil sector. What is the current state of research and practice concerning EIPs in Indonesia's palm oil industry remains unclear, especially in terms of thematic focus, technological applications, and stakeholder involvement. This study aims to provide an overall perspective on the applicability of the Eco-Industrial Park (EIP) strategy in Indonesia's context of the palm oil industry. Specifically, it seeks to establish the material, energy, water, and biomass waste streams as critical factors in evaluating the feasibility of EIPs. Further, the study looks at the application of Circular Economy (CE) activities such as reuse, recycling, and energy recovery throughout palm oil refining and investigates how these steps facilitate the construction of EIPs. Lastly, the study evaluates readiness, facilitation conditions, and barriers to implementing localized EIP models in the sector using insights gained from current literature.

2. Research Method

2.1. Data Sources and Search Strategy

The data sources in this study comprise a range of international and national journal articles retrieved from databases such as Dimensions.ai, Scopus, and Google Scholar, covering publications from 2020 to 2025. The literature search was conducted using mesh terms (keywords) such as Sustainable, Eco-Industrial Park, Palm Oil Industry, Industrial Symbiosis, Circular Economy, Biomass, Environmental Impact and Eco-Industrial Park Development.

These keywords were identified through bibliographic analysis using VOSviewer version 1.6.20, which enabled us to detect the most thematically relevant and high-density terms in the existing body of literature. The co-occurrence keyword map generated from this analysis is presented in Fig. 1 providing a visual representation of how frequently and closely certain concepts appear together in the literature.

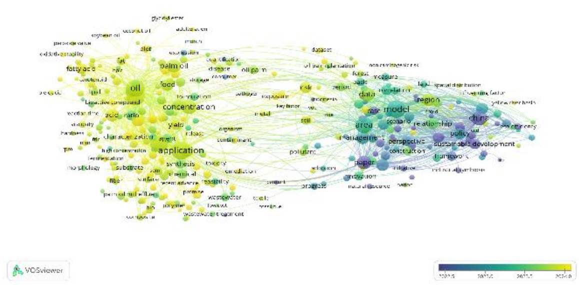

Fig. 1. Network visualization of eco-industrial parks and palm oil industry from VOSviewer version 1.6.20

This Systematic Literature Review (SLR) was conducted in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. This methodological framework ensures that the processes of article identification, screening, and data synthesis are conducted in a transparent, systematic, and replicable manner reinforcing the validity and reliability of the research findings.

2.2. Data selection process

Fig. 2 shows the systematic literature selection process used in this study. All relevant articles identified through database searches were imported into a web-based literature screening platform Rayyan.ai. Duplicate entries were automatically detected and removed for further screening.

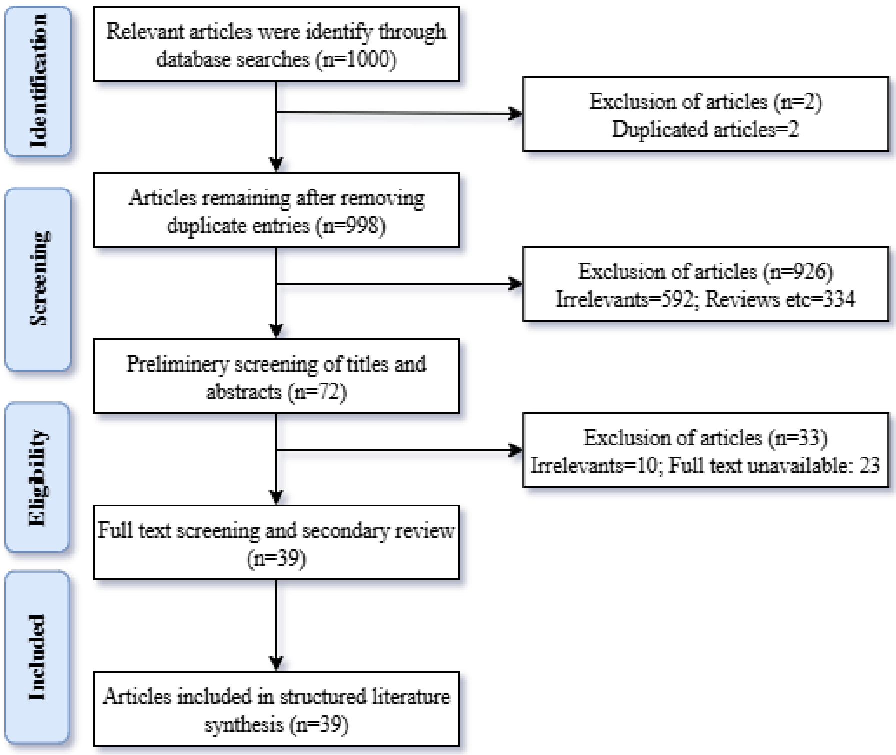

Fig. 2. Network visualization of eco-industrial parks and palm oil industry from VOSviewer version 1.6.20

An initial filtering process was carried out by examining the titles and abstracts. Articles that met the basic criteria were further assessed through full-text screening and an additional round of evaluation. The reference lists of the chosen papers, along with relevant systematic reviews identified earlier, were manually checked to locate any other suitable studies. All finalized articles were then analyzed in a structured manner to generate comprehensive findings aligned with the research objectives.

2.3. Data Analysis Method

This study integrates a Systematic Literature Review approach with the utilization of artificial intelligence technologies and bibliometric analysis to enhance the efficiency and validity of the literature review process.

One of the AI-based platforms employed is Dimensions.ai, which was used to systematically search and retrieve relevant scientific articles based on predefined keywords. Furthermore, the screening process was conducted using Rayyan.ai, a web-based literature screening tool that automatically detects duplicates and facilitates the initial screening process.

To analyze thematic patterns across the literature, VOSviewer version 1.6.20 was used for bibliometric analysis. This tool generated a keyword co-occurrence map, providing a visual representation of the most thematically relevant and densely connected terms within the body of literature.

The integration of AI and bibliometric techniques enabled an objective, transparent, and replicable analysis, strengthening the credibility of the research findings. This approach also enabled efficient data processing.

3. Result and Discussion

3.1. Overview of Research Findings

After conducting a thematic analysis of the content and substance of the 39 selected articles, this study identified four focus areas in the development of Eco-Industrial Parks (EIPs) within the palm oil industry. These focus areas include Biomass Utilization in the Palm Oil Industry, Circular Economy Applications, and Conceptualization and Implementation of Eco-Industrial Parks. The results are summarized in Table 1.

Table 1. Overview of Research Findings on Eco-Industrial Parks (EIPs) in the Palm Oil Industry

Reference	Focus Area	Finding
Welo U et al, 2024 [4]	Circular Economy practices applied within the palm oil sector.	The role of Circular Economy (CE) in fostering a more sustainable and economically viable palm oil industry is clearly evident.
Suksaroj C et al, 2023 [5]	Implementation of Circular Economy principles in palm oil operations by utilizing biogas codigestion.	Methane yield and COD removal increased with EFB wastewater
Yuslaini N et al, 2023 [6]	Palm oil industry and investment development	Investment levels within the palm oil sector remained inconsistent, leading to a volatile and uncertain investment environment.
Amran M et al, 2021 [7]	POFA Utilization in Concrete	POFA enhances concrete strength, durability, and reduces cement dependency.
Purnomo H et al, 2020 [8]	Oil Palm & Value Chain	Integrated value chain model support both economic growth and conversation goals.
Ginting A et al, 2024 [9]	Goal programming model for palm oil	Model optimized material flows and enabled full waste utilization.
Bejarano P et al, 2022 [10]	CE indicators for palm oil waste	Developed indicators shoeing potential for better waste reuse and lower emissions.
Pranoto B et al, 2023 [11]	Palm trunk biomass estimation	Identified biomass potential for co firing.

Reference	Focus Area	Finding
Hassan S et al, 2021 [12]	Palm oil residues for bioenergy	Residues show potential for biofuel but need sustainable practices.
Sutomo B et al, 2022 [13]	Circular Economy	Reduced fertilizer costs and increased palm yields.
Haryani E et al, 2025 [14]	Green Productivity in Palm oil	Adoption of GP depends on education and support.
Anizar A et al, 2022 [15]	Technical support & communicaton in palm oil mills	Communication and support improve programs.
Baruji T et al, 2023 [16]	Pretreatment for biogas	Pretreatment boots lignin removal and methane
Ningsih E et al, 2020 [17]	Coconut shell catalyst for biodiesel	Catalyst improved biodiesel field and quality.
Sri Sudiarti et al, 2023 [18]	Palm oil industry in industrial revolution 4.0	Development strategy palm oil industry 4.0
Mohammad S et al, 2021 [19]	POME treatment processes	The main influencing factors for IAAB POME.
Sugeng Rahayu Widodo T et al, 2024 [20]	Clean Production for palm oil industry	Effective housekeeping programmed as the main strategy
Sanjaya A et al, 2024 [21]	POME treatment technology using SBR	The trend of ORP value.
Satriadi Yet al, 2025 [22]	Circular economy in supporting factor of POME.	Liquid waste management by palm oil mills still dominated by traditional systems.
Arista N et al, 2024 [23]	Circular Economy in palm plantation.	Potency of economy circular from cultivation to palm oil industry.
Annisa I, 2025 [24]	Transformative potential of CE principles.	Importance of integrating traditional agricultural technology.
Nadhifah R et al, 2024 [25]	Palm oil waste.	Develop strategies for the sustainability of palm oil in Indonesia.
Lok X et all, 2020 [26]	POME treatment facilities integrated with biogas production	Indicate that each ton of processed POME can generate about 29 m^3 of biogas, achieving roughly 92% COD reduction efficiency.
Asyifa S et al, 2025 [27]	Integration of the Circular Economy Concept	Sustainable strategies base in Bio-Economy base on agricultural waste.

Reference	Focus Area	Finding
Nasution M et al, 2024 [28]	Co-Industrial Park (EIP) Development in Asahan Regency	The industrial area includes waterfront tourism, commercial trade zones and supporting facilities.
Martial T et al, 2024 [29]	Impact of using Palm oil Mill (PKS) waste	PKS waste application significantly enhances plantation management efficiency
Mustapa H et al, 2021 [30]	Industrial Park and Foreign Investments for Sustainable Development	Process of increasing foreign investment for sustainability development in Indonesia.
Rau H et al, 2022 [31]	Factors affecting the palm oil industry' supply chain	Identified that the key factors in implementing a circular economy
Kawai H et al, 2021 [32]	Utilization of renewable and conventional energy in Indonesia	In 2020, the palm oil industry consumed an estimated 602,540 tons of oil equivalent (ToE) in conventional energy.
Ronauly I et al, 2024 [33]	Sustainable Palm oil plantation	A key factor that supports the adoption of sustainable practices within Indonesia's palm oil plantation sector.
Haryanto A et al, 2021 [34]	Opportunities and limitations associated with using OPEFB pellets as a biomass-based energy source.	The elevated ash and mineral levels present major issues that must be resolved to ensure safe utilization.
Rahmawati R et al, 2023 [35]	A green economic framework for the palm oil industry developed through an Islamic economic viewpoint.	The application of green economy principles is consistent with the seven core standards outlined in the ISPO guidelines.
Wan Y et al, 2023 [36]	Enhancing the design and operation of Eco-Industrial Parks tailored to the palm oil sector.	Integrating water and wastewater treatment systems with energy-generation facilities provides the most effective configuration.
Sawit S, 2023 [37]	Sustainable Utilization of Various Economic-Based Wastes	Palm oil industry waste and Biomass waste
Majesty K et al, 2024 [38]	Palm Oil Waste Management	Indicate that less than 16% of ISH farmers actively engage in palm oil waste management practices that incorporate local wisdom as a source of livelihood.
Reich C et al, 2025 [39]	Smallholder-managed oil palm plantations	Smallholder farmers show greater willingness to pursue

Reference	Focus Area	Finding
		certification when they receive more training in farm management and are offered monetary incentives.
Kulsum U et al, 2023 [40]	Smart eco-industrial park development	Ultrafiltration (UF) membrane systems have proven to be more effective than traditional methods for separating and recovering oil and water.
Djarot I et al, 2023 [41]	Evaluation of the social life-cycle impacts associated with oil palm plantation operations.	Many smallholder-operated palm oil plantations continue to fall short of providing workers with the legally required minimum wage.
Abidin J, 2023 [42]	Sustainable palm oil industry assessment	Industrial Palm oil can be a solution in supporting energy security both nationally and globally.

3.2. Biomass Utilization in the Palm Oil Industry

As shown in Fig. 3, all parts of the oil palm tree generate various products, and biomass wastes through harvesting and milling processes. The primary output of palm oil processing is crude palm oil (CPO), whereas the resulting by-products consist of various biomass materials such as oil palm fronds (OPF), oil palm trunks (OPT), empty fruit bunches (EFB), palm kernel shells (PKS), palm mesocarp fiber (PMF), and liquid waste known as palm oil mill effluent (POME).[43].

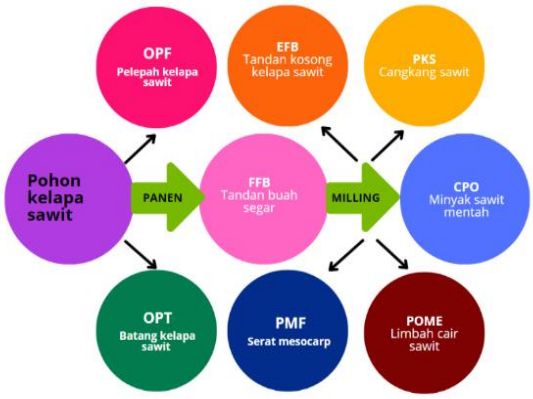

Fig. 3. Main biomass from the palm oil industry [43]

Large commercial plantations typically obtain higher extraction rates, producing up to 24% crude palm oil (CPO) from each batch of fresh fruit bunches (FFB). In contrast, smallholder farms often generate lower outputs due to the poorer quality of harvested fruit. On average, CPO recovery from FFB is about 22%, which indicates that close to 80% of the material becomes residual biomass and effluent. For every ton of FFB processed, the waste stream generally includes around 22% empty fruit bunches, 13% mesocarp fiber, 6% shells, and between 0.6 and 0.8 cubic meters of POME. Altogether, roughly 40% of the fruit mass persists as solid biomass components such as OPEFB, fibers, and shells.[34] These biomass wastes hold significant potential for reuse, thus supporting the circular economy concept in the palm oil industry.

One significant by product is the Oil Palm Empty Fruit Bunch (OPEFB), produced mainly after oil extraction [34]. Due to its high organic matter content, OPEFB has the potential to be utilized as a feedstock for biogas production. To prepare it for use in biogas production, a pretreatment needs to be done to remove the lignin, which serves a barrier for microorganisms in the process of converting Chemical Oxygen Demand [16]. Biogas typically consists of 50–75% methane (CH_4) and 25–45% carbon dioxide (CO_2). Unless handled, emissions of these gases have the potential to contribute significantly to greenhouse gas (GHG) emissions [26].

3.3. Circular Economy Applications

The circular economy framework offers a modern approach to directly addressing these issues. By encouraging resource reduction, reuse, recycling, and regeneration, it seeks to decouple economic growth from the depletion of natural resources and the environmental impacts that typically follow. [4]. The main characteristic of the Circular Economy refers to the use of the utilization of production materials to equilibrate economic expansion through progress of the surroundings and natural assets [13].

Fig. 4 illustrates a closed-loop system in which the palm oil industry reintroduces all generated waste back into production as secondary raw materials. This concept aligns closely with Eco-Industrial Park (EIP) principles, where waste streams are processed and repurposed within the industrial ecosystem. For instance, coconut shells and wet decanter solids can be converted into fuel, while empty fruit bunches and coconut husks can be composted and returned to plantations as organic fertilizer. PTPN III, which manages 24,000–30,000 tons of annual palm oil cultivation to support a mill capacity of 45 tons per hour, demonstrates the potential for utilizing these waste resources effectively.[9].

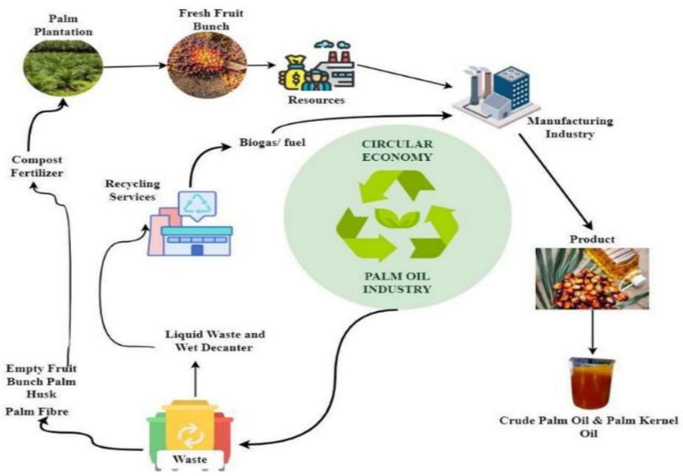

Fig. 4. Circular economy of the palm oil industry [9]

3.4. Conceptualization and Implementation of Eco-Industrial Parks

Eco-Industrial Park (EIP) is one of the most adopted concepts in the development of industrial zones. EIP, or *Kawasan Industri Berwawasan Lingkungan* in Indonesian, can be defined as a cluster of factories or service-oriented businesses located within a designated area that aims to enhance environmental, economic, and social performance. EIP reflects a holistic approach to industrial zone development, in which sustainability serves as the focus [28].

To enable industrial parks' development within industrial estates precisely, to encourage green and sustainable operations six key factors have been identified as having very significant influence upon overall system performance. These include: (1) imposing sanctions on non-environmentally friendly industries; (2) providing green open spaces; (3) ensuring the availability of affordable housing (at least 30% of the area used by each industry); (4) enforcing strict legal regulations; (5) maintaining water catchment areas to secure industrial water supply; and (6) establishing a dedicated institution to manage and direct the transformation toward green industrial parks. In addition, the construction of an integrated wastewater treatment plant (WWTP), while representing lower system dependency, is nonetheless an extremely determinant supporting influence [40].

As illustrated in Fig. 5, the application of the EIP concept entails the involvement of several supporting actors. For it to be used in the Indonesian context, successful EIP implementation requires the participation of six key groups: (1) government agencies, (2) investors or financial stakeholders, (3) industrial operators and company management, (4) local communities residing around industrial zones, (5) academic and research institutions, and (6) environmental non-governmental organizations. [40].

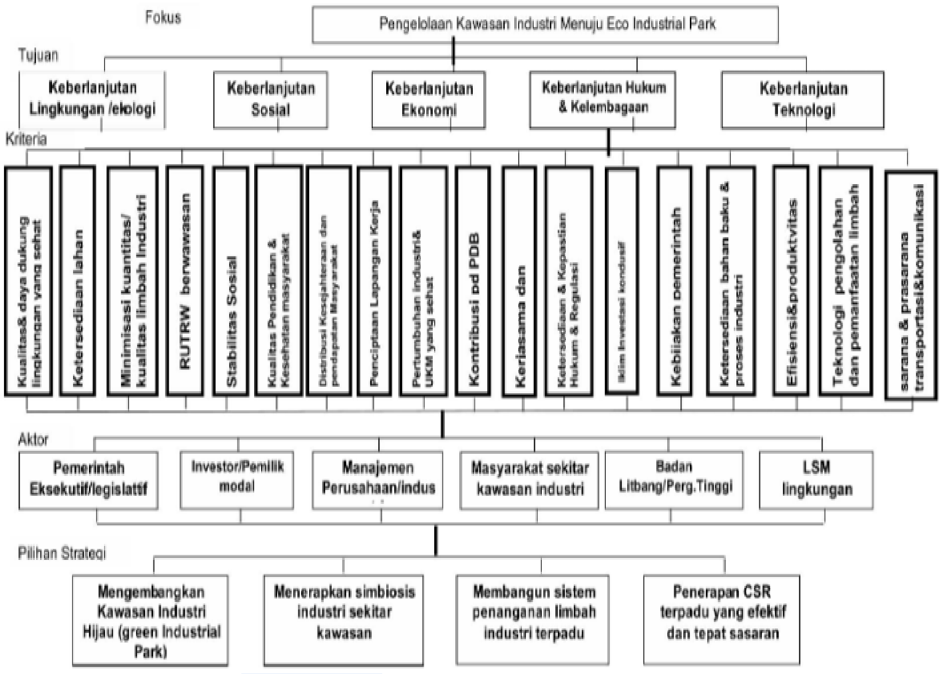

Fig. 5. Industrial area management hierarchy Towards an eco-industrial park [44]

To overcome such constraints, the implementation of the Eco-Industrial Park (EIP) model is proposed, wherein resource conservation and utility exchange among principal stakeholders can be optimized. The shared scheme is expected to ensure equitable access to basic services in rural industrial clusters while, simultaneously, increase environmental and economic sustainability [45].

4. Conclusion

This study offers a systematic literature review related to the application of circular economy principles and utilization of the Eco-Industrial Park (EIP) concept in Indonesia's palm oil industry. Three dominant themes are determined by the analysis as biomass utilization, applying circular economy, and EIP conceptualization. The findings indicate that various biomass streams specifically POME, empty fruit bunches, and palm kernel shells can be effectively converted into renewable energy sources or value-added products like compost and construction materials.

This study also finds that circular economy strategies for the Indonesian palm oil industry involve energy recovery (e.g., biogas), material recycling, and process and stakeholder integration in the frame of sustainable industrial parks. Moreover, the preconditions to execute EIP are discovered to include an effective regulatory condition for environment, water resource management, institutional governance, and multi-stakeholder engagement, such as government, industry, university, and NGOs.

Thus, it can be asserted that although EIP's implementation in Indonesia's palm oil sector is currently in its infancy, there exists large potential to integrate circular economy principles through the use of the EIP system. For this objective to be realized effectively, quantifiable CE performance indicators, improved inter-institutional coordination, and applying the best available technologies that have been made local are essential. The study recommends that future research should be focused on measuring CE maturity levels and developing contextual blueprints for EIP in Indonesian palm oil clusters.

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