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Research article

Integrating life cycle assessment and multi criteria decision making analysis towards sustainable cocoa production system in Indonesia: An environmental, economic, and social impact perspective

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A B S T R A C T

Sustainable Cocoa production practices should be investigated comprehensively to address sustainability requirements and mitigate Cocoa production issues in Indonesia. This study aims to identify the sustainable Cocoa production system considering the environmental, economic, and social impacts. Life cycle framework and multicriteria decision-making (MCDM) were integrated to obtain the study's objectives by comparing Cocoa monocropping system (CM) and Cocoa intercropping systems (IC). The result indicated that in the environmental sustainability aspect, the monocropping system (CM) showed higher performance as indicated by the lower environmental impact in all indicators; for example, CM emitted a lower Global Warming Potential (GWP) that has a lower margin of 34.5–55.9 % compared to the intercropping system (IC-I and IC-II). In the economic aspect, both on the short-term and long-term analysis, the Cocoa intercropping system (IC-II) generated higher value-added and economic feasibility, with a higher profit margin of 150–205 % compared to CM and IC-1. Along with the increase of economic benefits in IC II, this system also significantly provides social benefits, as presented by the higher social index margin of 4.9–23.7 % compared to other systems. Furthermore, by applying decision-making analysis, the result determines the highest index on the Cocoa intercropping system II (IC-II). These findings highlight that applying the intercropping system II is recommended to overcome the cocoa issue at the farmer and decision-maker levels. Additionally, the proposed method that combined LCA-MCDM can be applied to another agricultural commodity to achieve sustainable agriculture production.

1. Introduction

Cocoa is a strategic agriculture commodity in the global market. The demand for Cocoa has increased over the past years following the growth of Cocoa-based products linked to the increased in living standards in highly populated countries [1]. As the Cocoa supplier to the global market, Indonesia can significantly supply Cocoa to the global market with an average contribution of 678,0000 tons per year. According to the FAO, Indonesia was listed as the third largest Cocoa plantation area, contributing 14 % to the total Cocoa plantation area in the world from 2018 to 2020 [2]. In the land management ownership aspect, the Cocoa plantation in Indonesia is managed by three actors: small-sized Cocoa farmers, private companies, and the government. The small-sized Cocoa farmers manage

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98.29 % of Cocoa plantations from the total Cocoa plantation area in Indonesia [2]. Cocoa production in Indonesia is concentrated among small-size farmers with an average land ownership of <5 ha.

Cocoa in Indonesia is challenged by some issues related to the cocoa production trend and the environmental impact. The trend of cocoa production has shown a gradual decrease, with an average of 0.16 % per year [2]. At the farmer level, the decreasing trend is affected by the low economic benefit obtained by Cocoa farmers. The Cocoa production activity at the farm level can not generate significant economic benefits for the farmer. One reason is that the production capacity per hectare is still low. According to the data released by Indonesia Agriculture Ministry, the average Cocoa production per hectare in Indonesia was 733 kg. Compared with other Cocoa producers, the level of Cocoa productivity in Indonesia is still lower. Furthermore, the lower productivity will be followed by the lower revenue and the lower net economic profit at the same cost level. Moreover, the economic impact will affect its social condition [3]. On the other hand, Cocoa production is challenged by international trading and market preference related to environmental sustainability aspects, such as the ecolabelling, carbon footprint, global warming potential, and human health from agricultural products [4]. Therefore, these two issues related to socio-economic benefit impact and environmental aspect requirement encourage on exploring the sustainable Cocoa cultivation in these two aspects to promote the Cocoa cultivation practice.

Currently, Cocoa is being planted using methods such as monocropping and intercropping. In the monocropping system, a Cocoa tree is planted in a single commodity in the area. Many farmers have been practicing this method during the Cocoa cultivation. Meanwhile, the intercropping system that plants Cocoa combined with another agricultural commodity in the plantation area is still limited. However, connecting to the cocoa issue in Indonesia both on the economic and environmental aspects and evaluating some cocoa cultivation methods will help to find the most beneficial cocoa cultivation system in the economic, social, and environmental aspects.

In sustainability evaluation, the life cycle framework was massively used in the environmental, economic, and social impact assessment [5]. The life cycle framework is an approach that considers the whole life of a product and service [6]. In the environmental aspect, life cycle assessment (LCA) is a comprehensive approach to evaluating the environmental impact of a product and service that considers the whole life of its product and service according to different impact categories [7,8]. The LCA study aims to compare alternative products, processes, or services or to identify life cycle steps where the most significant improvements can be made [9]. Initially, LCA was developed primarily for industrial production systems, but in these two decades, LCA methodology has been widely used in many sectors, including the agriculture and food sectors [10,11]. The recent studies that specifically performed LCA in agriculture production at the farm level have been widely conducted, such as the LCA study on coffee related to the cropping system and fertilizer management [3,7,12,11]; the LCA study on cocoa fertilizer management and agroforestry system [12,13]; the LCA study on cocoa production and its biomass utilization [13,14], and the LCA in other agriculture commodities production system [13–20]. According to the previous LCA study in agriculture, the LCA approach can capture the comprehensive environmental impact. In the economic evaluation aspect, life cycle cost (LCC) was used to identify the economic performance that involves all economic aspects in the life span of a product [16]. Many studies in the agriculture sector used the LCC to evaluate their economic sustainability [8,21]. In Social aspect, the social life cycle assessment (SLCA) is the method used to identify the social impact of a product, service, method, technology, and organization. Some study in agro-industrial sector was also used SLCA to assess the social sustainability of their product or service, such as the SLCA study on coffee [18], biodiesel [19], bamboo [20], pulp [22]and bioethanol [6].

The multicriteria decision-making analysis is currently introduced and regarded as the best solution for dealing with sustainability conflict at both micro and macro levels for further improvement [21]. Multicriteria decision-making (MCDM) techniques have been employed widely in various areas, such as in boxboard production [21], carbonaceous adsorbents [23], and waste management [24]. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is one of the MCDM techniques. It has been frequently used in agriculture studies, such as in wastewater treatment and biomass-based products [23], energy siystem [25], and Brazilian beef [26]. Moreover, LCA and TOPSIS procedures were combined in environmental studies, such as in boxboard production, where the environmental and economic aspects become the criteria for decision-making analysis [23]. In TOPSIS, the selection procedure occurs, and the alternative is close to the ideal state. The previous study proved that TOPSIS can provide the best alternative for comparative study. According to this study, the possibility of exploring the best solution for the Cocoa production alternative can be identified by the life cycle approach and TOPSIS combination.

Some recent cocoa sustainability studies used the life cycle approach to evaluate the environmental impact of cocoa production and its supply chain in various system boundaries at upstream and downstream levels Some recent cocoa sustainability studies used the life cycle approach to evaluate the environmental impact of cocoa production and its supply chain in various system boundaries at upstream and downstream levels [5,13,25,26]. The specific study on evaluating cocoa production at the farm level that focuses on investigating the more beneficial cocoa cultivation system considering all sustainability aspects: environmental, economic, and social, and continuously integrating the decision-making analysis still needs to be completed. Due to the lack of studies on this area, specifically on exploring the type of cocoa cultivation system that is more sustainable, studying this subject and area is essential.

Combining the decision-making analysis with the LCA study is attractive for assessing agriculture production sustainability since it involves various indicators, such as economic, environmental, and social at different scales and uncertainty levels [27]. Therefore, integrating these two methods, LCA and multicriteria decision-making analysis, while exploring more sustainable Cocoa production will provide a valuable result. Considering the Cocoa production issue in Indonesia and the sustainability requirement in the global Cocoa market, this study aims to investigate the best solution of sustainable cocoa cultivation system that considers the comprehensive sustainability evaluation in environmental, economic, and social aspects using LCA and multicriteria decision-making analysis. This study captures the sustainability status of some cocoa cultivation systems and provides suggested solutions to address the cocoa production issue in Indonesia. This study is the first work on identifying the most sustainable cocoa cultivation system associated with environmental, economic, and social factors by combining the life cycle approach and multicriteria decision-making analysis to solve the cocoa issue in Indonesia.

2. Materials and methods

To achieve the best solution for sustainable Cocoa production system, this study combined the LCA with multi-criteria decision-making (MCDM) that specifically used Techniques for Others Preferences by Similarity to the Ideal Solution (TOPSIS) as the method. This study following the research stage as presented in Fig. 1. As indicated in Fig. I, this study consist of two main procedure: (1) Sustainability evaluation in three aspects: environmental, economic, and social; and (2) Multicriteria decision making analysis.

2.1. Sustainability assessment of cocoa production at farm level

This study used the life cycle framework to evaluate all sustainability impacts. Life cycle approach is the comprehensive eavaluation that evaluate the potential environment impact of a product system throughout a life cycle [14]. LCA was used to evaluate the environmental impact; LCC and economic feasibility analysis were employed to evaluate the economic performance; and SLCA was performed to assess social impact. The life cycle approach has four main stages, namely, (1) goal and scope definition, (2) functional unit definition and Inventory data, (3) impact assessment that consist of the impact evaluation on environmental, economic, and social, and (4) interpretation of the result.

2.1.1. Goal and scope of the study

This study aimed to comprehensively identify the sustainable Cocoa production associated with the potential environmental, economic, and social impacts at the farm level. The scope of this LCA study involved all processes in the Cocoa production system at the farm level. Three Cocoa cultivation systems will be compared and evaluated. Detailed information of three Cocoa cultivations are presented in Fig. 2. According to Fig. 2, the three cocoa cultivation system is: monocropping system (Fig. 2a), intercropping system I, which combines with the horticulture commodity (Cabbage) (Fig. 2b), and the intercropping system II, which combines with the horticulture commodity (Corn) (Fig. 2c).

The boundary was determined from a cradle-to-farm gate approach, including all Cocoa cultivation stages: Seeding and Nursery, Land preparation and Planting, Maintenance I, Maintenance II, and Harvesting. Detailed research boundary is expressed in Fig. 3. According to Fig. 3, this study counted all the phases in the cocoa lifespan, it considers two maintenance stage categories: maintenance – I and maintenance II. Maintenance -I represent the maintenance in a pre-productive stage that is usually counted two years after planting until the first harvesting period. Meanwhile, maintenance II defines the maintenance activity in a productive stage that considers all maintenance activities after the first year of the harvesting period. The Cocoa plantation in this study has been practiced in the five-year production. Therefore, this study considers five years of production activities that follow the boundaries of this system.

2.1.2. Functional unit definition

Determining the functional unit is important in the LCA procedure before collecting data. The functional unit defines the standard

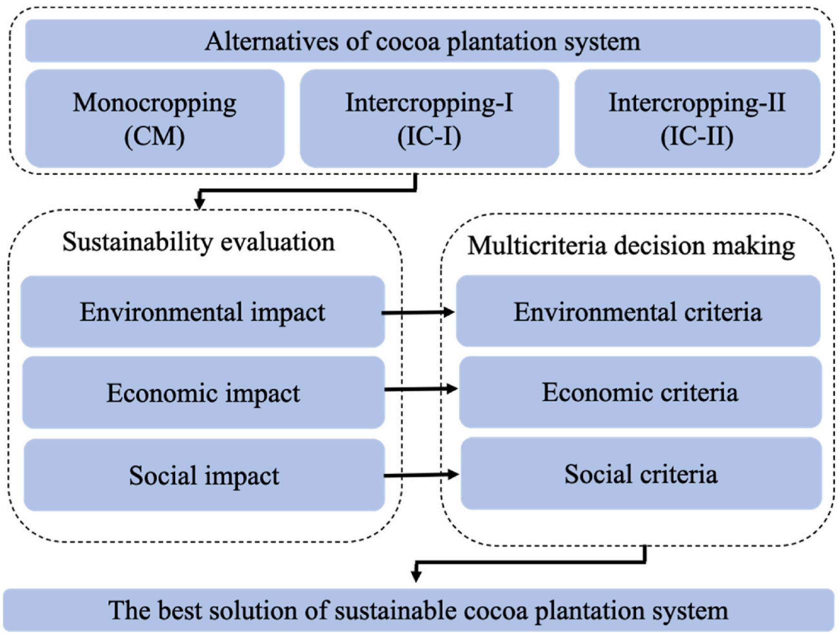

Fig. 1. Research procedure.

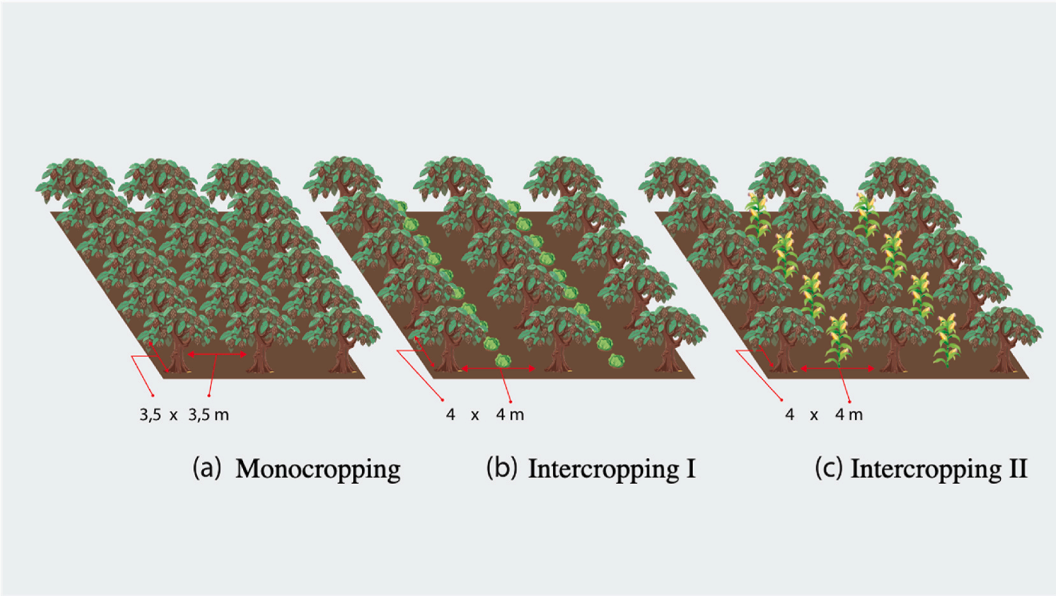

Fig. 2. The three cultivations system.

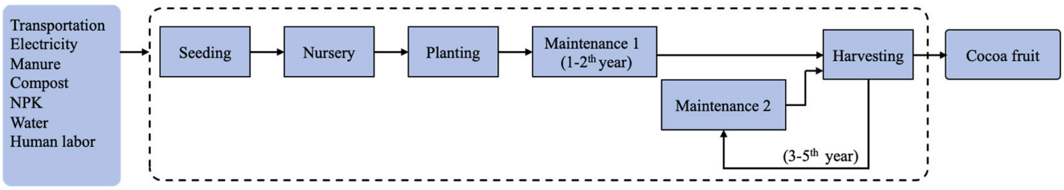

Fig. 3. System boundary.

data collection measurement [1]. This study used 1 kg of cocoa production at the farm level as the functional unit. However, during the data collection, the data is collected using 1 ha of cocoa plantation, then converted to a 1 kg product system in inventory data analysis.

2.1.3. Data collection and inventory data

The data was collected by using field observation and deep interview with a cocoa farmer group that practiced the three types of cocoa cultivation in Garut, West Java. The farmer group was chosen for several reasons. Firstly, the farmer group is located at the center of cocoa production in this regency and dominantly supplies the cocoa industry. Secondly, the farmer group is practicing all Cocoa cultivation systems in a similar area for all types of Cocoa production. Lastly, the farmer group organizes all Cocoa farmers in this area during cultivation. According to the farmer group being studied, it represents enough of the Cocoa production system in Garut Regency, west Java. The specific study location is presented in Fig. 4.

The inventory analysis was the second phase of LCA procedures. This phase is an input and output data inventory according to the studied system [28]. The inventory data present the input-output material and energy as presented in Table 1. Inventory data is essential for the calculation of environmental and economic impact. The additional information regarding the price and cost were used during the economic impact evaluation. The data collection items in social impact evaluation differ from the environmental and economic impact assessment that followed the guidelines from UNEP/SETAC [29].

The following are the rules for collecting the data.

- The input of material and energy used at the farm level includes synthetic and organic fertilizer and pesticide application for 1-ha Cocoa plantations.
- The electricity used is associated with the energy resource for watering activity.
- Gasoline is associated with labor and material transport to the field. The average distance to transport the material and labor is 2 km.
- This study used five years of Cocoa production, with two years of the vegetative phase and three years of the generative period.
- The Cocoa production used is the Cocoa fruit that is produced for five years of Cocoa cultivation.

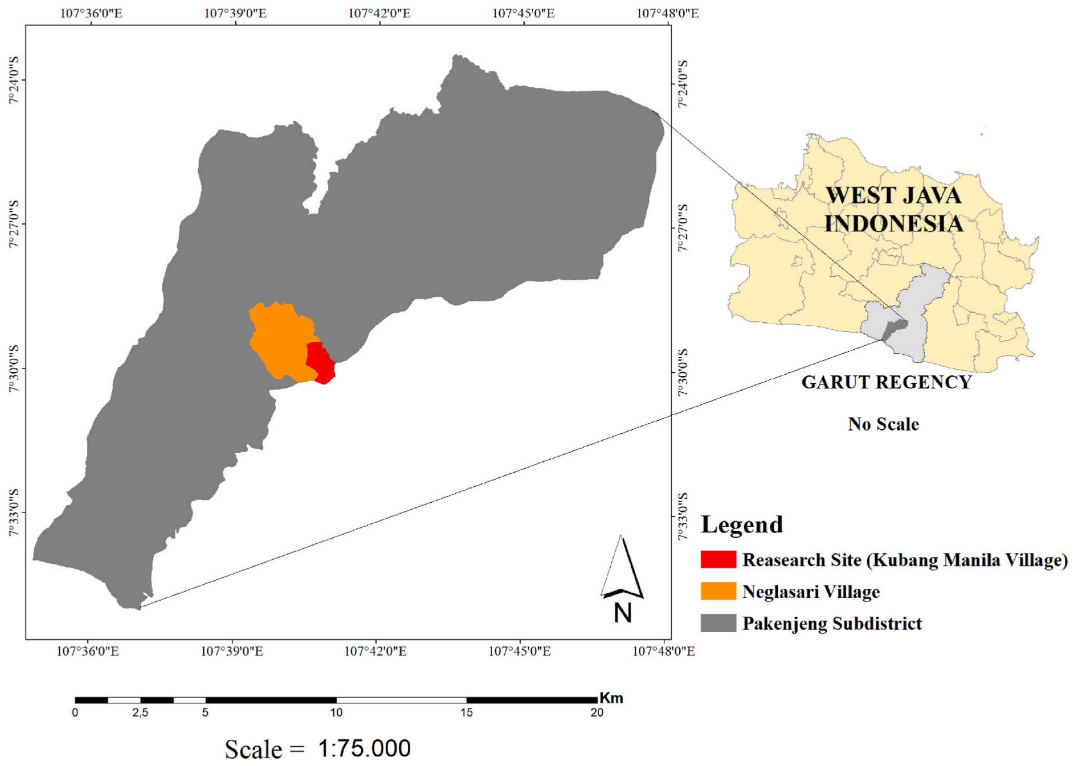

Fig. 4. Study location.

2.1.4. Life cycle impact assessment

2.1.4.1. Environmental impact assessment. The LCA approach was employed to calculate the environmental burden associated with the Cocoa production activity. The LCA is widely applied to assess the potential environmental impact associated with agriculture production [23]. During the environmental impact assessment, this study followed the IPCC refinement 2019 and used Recipe 2016 as the method. This study analyses the eighteen environmental impact indicators by using Simapro, namely global warming potential, stratospheric ozone depletion, ionizing radiation, ozone formation (human health), fine particulate matter formation, ozone formation (terrestrial ecosystem), terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity, human non-carcinogenic toxicity, land use, mineral resource scarcity, fossil resource scarcity, water consumption. The impact calculation is determined by **Equation (1)**.

$$EI = \sum_{k=1}^{n} (\text{Emission factor}_k \times \text{data activity of material and energy input}_k) \tag{1}$$

Equation (1) is the general formula to calculate all environmental impact indicators. During the GWP calculation, this study also considers the field emissions from the material application during production, including the direct and indirect emissions resulting from N additions, deposition, and leaching [8].

Equation (2) is applied to calculate the total GWP impact of agriculture production at the farm level.

$$GWP_{total} = GWP_{ip} + GWP_{field} \tag{2}$$

Equation (2) expressed the total of GWP is determined by the additional of emission from input production (GWP_{ip}) and the field emission (GWP_{field}). GWP_{ip} is the CO_2 emission from input production such as electricity, gasoline, fertilizer, pesticide, and other inputs applied during the Cocoa production, multiplied by its emission factor. As mentioned before, the LCA for agriculture production should also consider the field emission in their assessment [8,30]. The field emission consists of the direct and indirect emissions resulting from N additions, deposition, and leaching [31]. This study followed the 2019 refinement of IPCC guidelines for national GHG emissions to calculate the direct and indirect emissions resulting from N additions, deposition, and leaching (N_2O) [30]. The calculation follows the IPCC tier 1 default value of 1 % for N inputs from all fertilizer applications. In this study, the emission from the field was represented by GWP_{field}.

2.1.4.2. Economic performance evaluation. Some studies in LCA also performed the economic performance evaluation [6,23,32,30]. This study performs three indicators in economic performance evaluation: life cycle cost, value-added, and feasibility analysis.

Table 1
Inventory data for 1 kg Cocoa production.

Stage	Input	Unit	Plantation system		
			Monocropping	Intercropping 1	Intercropping 2
Seeding and Nursery					
	Gasoline	liter	0	0	0
	Electricity	KWH	0.00004	0.00003	0.00003
	NPK	kg	0.00067	0.00333	0.00385
	Water	liter	0.50000	0.11111	0.12821
	Human labor	hr	0.00053	0.00036	0.00041
	compost	kg	0.00333	0.00222	0.00256
	Pesticide	kg	0.00002	0.00001	0.00002
Land Preparation and planting					
	Human labor	hr	0.00427	0.00284	0.00328
	Manure	kg	0.00333	0.01111	0.01282
	Gasoline	liter	0.00107	0.00071	0.00082
	Water	liter	0.16667	0.11111	0.12821
	electricity	kwh	0.000003	0.000002	0.000002
Manitenance I (Before first harvesting)					
	Human labor	hour	0.00711	0.05689	0.02626
	Manure	kg	1.00000	0.66667	0.76923
	NPK	kg	0.05000	0.08889	0.00000
	Pesticide	liter	0.00009	0.00028	0.00008
	electricity		0.00000	0.00015	0.00007
	Water	liter	0.00000	1.77778	0.82051
	Gasoline	liter	0.00124	0.01422	0.00656
Maintenance II (After first harvesting)					
	Human labor	hour	0.00747	0.08533	0.03938
	Manure	kg/tree	1.50000	1.00000	1.15385
	NPK	kg/tree	0.07500	0.13333	0.10256
	Pesticide	liter	0.00013	0.00043	0.00012
	Electricity		0.00000	0.00022	0.00010
	Water	liter	0.00000	2.66667	1.23077
	Gasoline	liter	0.00187	0.02133	0.00985
Harvesting	Human labor	hr	0.00960	0.00924	0.01231
	Gasoline	liter	0.00200	0.00347	0.00349

2.1.4.3. Life cycle cost (LCC) analysis. LCC of a product or system is an economic analysis tool that commonly used to evaluate project investment. It considers all real-life costs, including the acquisition, operation, maintenance, and ultimate disposal [23,33]. In agriculture production, specifically at the farm level, LCC counted all the variable costs, such as the cost of material, labor, packaging, and transportation, according to the goal and boundary [4]. The goal and boundaries of an LCC are similar to those of an LCA [34]. The LCC method employed in this study is based on the general life cycle cost model [35]. To determine the LCC, this study used **Equation (3)**.

$$LCC = RC + NRC \tag{3}$$

In **Equation (3)**, LCC represents the life cycle cost of Cocoa production at the farm level, RC stands for recurring expenses (all the input during the operation process), and NRC stands for nonrecurring costs (Installation, support, research, capital investment). Following the usual LCC practice, the capital goods costs are not considered [27,34]. The total cost of each scenario was calculated according to one functional unit (1-ha Cocoa plantation) by considering all the items in the LCA inventory, such as the cost of utilizing fertilizer, pesticide, labor, water, electricity, and gasoline.

2.1.4.4. Value-added analysis (VA). The value-added (VA) analysis is defined as the short term of economic performance that defines the net profit, which is calculated by the revenue (R) minus the costs of the life cycle of the product), reflecting the increase in economic value due to the production of the final goods [27]. In this study, the VA was estimated by considering the cycle cost and revenue incurred from the cradle to gate by using **Equation (4)**.

$$VA = R - LCC \tag{4}$$

All economic unit are based on present value (March 3, 2024, exchange rate of USD 1.00 = IDR 15,793).

2.1.4.5. Economic feasibility study. The economic feasibility analysis was the method that analyzed the long-term economic performance of a product, service, method, and business organization [36]. There are several indicators of economic feasibility analysis. However, this study only consider three aspect, namely: net present value (NPV), return of investment (ROI), benefit and cost ratio analysis (B/C Ratio) [37].

- Net Present Value (NPV)

NPV is expressed as the present economic value of future expenses and revenue, which uses a discount or interest rate on payments and revenues during the analyzed period. NPV is determined by using Equation (5) [36,38].

$$NPV_{t0} = \left(VB_{t0} + \left(\sum \frac{FVB_{tn}}{(1+i)^n}\right)\right) - \left(VC_{t0} + \left(\sum \frac{FVC_{tn}}{(1+i)^n}\right)\right) \tag{5}$$

where NPV_{t0} is the net present value at the initial time; VB_{t0} is the value of benefit at the initial time; FVB_{tn} is the future value of the benefit; n is the total period; VC_{t0} is the value of the production cost at the initial time; FVC_{tn} is the future value of the production cost; and i is the discount rate representing opportunity cost. In Indonesia, the average discount or interest rate for agricultural payments is 6%–7%. The present study considered a discount rate of 6 % for all economic investment calculations.

- Return of Investment (ROI)

ROI is the percentage of the possibility of returning the investment. An ROI above the discount rate used indicates that the project is economically viable [6]. ROI was calculated using Equation (6).

$$ROI = \sum_{t=1}^{n} \frac{FVB_t - FVC_t}{FVC_t} \tag{6}$$

According to Equation (6), FVB_t indicates the future value of the benefit, n is the total period, and $_t$ is the future value of the production cost. However, the feasible of ROI should be more than 0.6.

- Benefit – Cost Ratio Analysis

The benefit and cost ratio (B/C ratio) is the ratio of economic profit to the total production cost of a project [39]. The value should be more than 1 to be categorized economic feasible. To calculate B/C Ratio, this study used Equation (7).

$$B \Big/ C\ Ratio = \frac{\sum_{t=1}^{n} FBV_t}{\sum_{t=1}^{n} FcV_t} \tag{7}$$

As presented by Equation (7), FVB_t expresses the future value of benefit, n is the total period, *and* $_t$ is the future value of the production cost.

2.1.4.6. Eco efficiency index. Eco-efficiency connects the environmental impact and economic performance by ratio [40]. Eco-efficiency can be calculated from two perspectives: (1) focus on the economic value perspective and (2) focus on the environmental improvement perspective [41]. From an environmental intensity perspective, eco-efficiency will have an environmental impact due to economic activity [40]. Our eco-efficiency analysis follows the environmental intensity perspective and is expressed by equation (8).

$$Eco-efficiency = \frac{EI}{EP} \tag{8}$$

Where *EI* is environmental impact, expressed by all environmental impact indicators per hectare of the Cocoa plantation, *EP* is an economic performance, expressed by net profit per hectare.

2.1.4.7. Social impact evaluation. In the current context of sustainable production and consumption, it is necessary to consider the environmental, economic, and social aspects during the production activity [19,34]. As part of the Life Cycle Sustainability Assessment (LCSA), the Social Life Cycle Assessment (SLCA) provides the most effective method to evaluate the social impact of a product or service throughout its life cycle. This study performed the SLCA to evaluate the Cocoa production system. During the SLCA procedure, this study adapted UNEP/SETAC S-LCA guidelines [29].

The social impact categories, sub-categories, and characterization models shall be chosen according to the goal and scope of the study [29,42]. This study considers the following stakeholders and indicators according to UNEP/SETAC and expert view.

- Workers: Working hours, fair salary, social benefit
- Community and society: community engagement, local employment, contribution to economic development
- Supply chain: Promoting social responsibility, maximizing on creating value added.

The social sustainability index (SSI) represents the indicator of the social aspect. Some previous study uses the SSI to represent the social impact of a product, service, or organization [18,43]. The net score of subcategory calculation is determined using Equation (9).

$$IS_x = \frac{\left[\sum_{n=i}^{I} I_i \times CI\right]}{I_n} \tag{9}$$

where:

IS_x = net score of subcategory "x"

I_i = indicator "i"

I_n = number of indicators of subcategory "x"

CI = coefficient of indicator "i"

The normalization of the net score for each endpoint indicator was calculated by using **Equation (10)**.

$$\boldsymbol{CS_x} = \frac{\sum_{n=i}^{S_c} \boldsymbol{IS_x}}{\sum_{n=i}^{S_c} \boldsymbol{CI}} \tag{10}$$

where:

CS_x = net score of endpoint category "x"

S_c = subcategory

IS_x = sum of the total score of subcategory "x"

CI = sum of the total coefficient of endpoint indicator "x"

The social sustainability index calculation by using **Equation (11):**

$$\boldsymbol{SS_x} = \frac{\sum_{n=i}^{S_c} \boldsymbol{CS_x}}{\sum_{n=i}^{S_c} \boldsymbol{I_a} \times \boldsymbol{W_f}} \tag{11}$$

where:

CS_x = net score of endpoint category "x"

I_a = endpoint category (score 0–1, following Table 2)

W_f = sum of the total score of subcategory "x" (using 1 for all categories)

Lastly, the endpoint score is converted into the social sustainability status as presented in Table 2.

2.2. Multicriteria decision making analysis for sustainable cocoa production

TOPSIS is one of the MCDM methods that provides the methodological approach to select the best alternative based on the concepts of the compromise solution [23]. TOPSIS was widely used as a decision-making study in many sectors. Some studies reported the integrated LCA and TOPSIS during the absorbent production from biomass selection [23]. Accordingly, the best-preferred alternative for Cocoa cultivation will be shown by the shortest Euclidean distance from the positive ideal solution (PIS) and the longest Euclidean distance from the harmful ideal solution (NIS). In this paper, there are three alternatives Cocoa cultivation systems: Cocoa monocropping system (CM), Cocoa intercropping system combined with cabbage (IC-I), and Cocoa intercropping system combined with corn (IC-II), while the five selected criteria from environmental, economic, and social perspectives were chosen, including environmental impact aspect (GWP), economic performance aspect (LCC and economic value added), environmental-economic aspect (ecoefficiency index), and social impact aspect (social sustainability index). Therefore, this study has three alternatives (A1, A2, and A3) and five criteria (C1, …,C5). The matrix of criteria and alternatives is presented in Fig. 5. Each alternative will be compared according to the five criteria.

The procedure of TOPSIS method is calculated by using **Equation (12)–(18)**.

1. Compute a normalize decision matrix:

Table 2
Sosial sustainability index of scoring system.

Sustainability Index	Grade	Level of Sustainability	Significance
0.81–1.00	A	Highly sustainable	Strongly positive
0.61–0.80	B	Sustainable	Positive
0.41–0.60	C	Neutral	Moderate/satisfied
0.21–0.40	D	Unsustainable	Negative
0.00–0.20	E	Highly unsustainable	Strongly negative

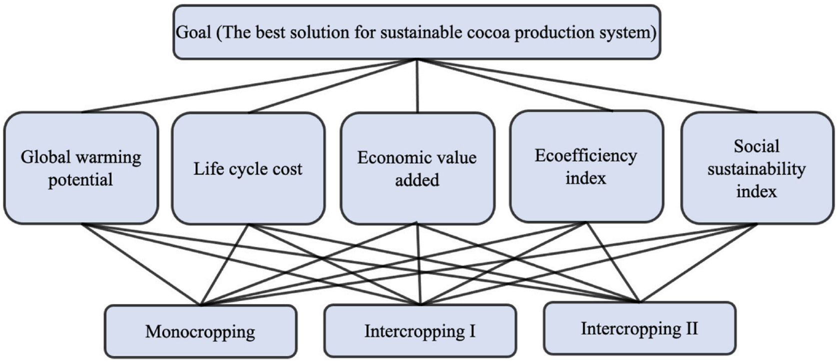

Fig. 5. Matrix of Indicators and alternatives for TOPSIS.

$$r_{ij}(x) = \frac{x_{ij}}{\sqrt{\sum_{k=I}^{9} x^2{}_{ij}}}, i,j = 1, \ldots, 9 \quad (12)$$

2. Calculate the weighted normalized decision matrix:

$$v_{ij}(x) = w_j r_{ij}(x), i,j = 1, \ldots, \overbrace{9 = r_{ij}}^{w=I}(x) \quad (13)$$

3. Determine the PIS and NIS

$$PIS = A^+ = \{v_I^+(x), \ldots, v_9^+(x)\} = \left\{ \left(\frac{max\ v_{ij}}{i}(x) \middle| j \in J_1\right), \left(\frac{min\ v_{ij}}{i}(x) \middle| j \in J_2\right) \right\} \quad (14)$$

$$NIS = A^- = \{v_I^-(x), \ldots, v_9^-(x)\} = \left\{ \left(\frac{min\ v_{ij}}{i}(x) \middle| j \in J_1\right), \left(\frac{max\ v_{ij}}{i}(x) \middle| j \in J_2\right) \right\} \quad (15)$$

where J_1 are the sets of benefit criteria and J_2 are the sets of cost criteria.

4. Calculate the Euclidean distance of each alternative (adsorbent) from the PIS and NIS:

$$D_k^+ = \sqrt{\sum_{i=1}^{9} \left[v_{ij}(x) - v_i^+(x)\right]^2} \quad (16)$$

$$D_k^- = \sqrt{\sum_{i=1}^{9} \left[v_{ij}(x) - v_i^-(x)\right]^2} \quad (17)$$

5. The similarities to the PIS can be derived as:

$$C_k^+ = \frac{D_k^-}{D_k^- + D_k^+}, k = 1, \ldots, 9 \quad (18)$$

Where, $C_k^* \in [0, 1]$. Finally, to choose the best Cocoa production, the preferred orders were obtained by the similarities to the C_k^* in descending order. This study used five indicators considered during the decission making analysis to provide the best suggestion of Cocoa production system, namely: Global warming potential (GWP), Life Cycle Cost, Economic Value added, Ecoefficiency index, and Social Sustainability Index.

3. Results and discussion

3.1. Sustainability evaluation of cocoa production

3.1.1. Environmental impact of three cocoa production

This study evaluated the eighteen environmental impacts of three Cocoa production systems. The result is presented in Tables 3 and 4. Table 3 explicitly shows the GWP calculation on both the field emission and input production emission. The comprehensive environmental impact is displayed in Table 4. According to Tables 4 and in all environmental impact categories, intercropping system-I has the most significant environmental damage on the Cocoa cultivation system. A detailed explanation of each environmental impact category is presented in the following subsection.

3.1.1.1. •Global warming potential (GWP). According to Table 4, the Intercropping-I (IC-I) emitted the dominant GWP impact on 1 kg Cocoa fruit production at the farm level. The GWP was 0.22 kg CO_2 eq for monocropping, 0.34 kg CO_2 eq for intercropping-I, and 0.26 kg CO_2 eq for intercropping-II. The GWP impact is contributed by the emission from the field and emission from the input production. According to Table 3, the GWP impact from input production was 0.163 kg CO_2 for monocropping, 0.29 kg CO_2 for intrcropping-I, and 0.26 kg CO_2 for intercropping-II. Moreover, the contribution of GWP from input production is significantly contributed by the use of NPK, with 77 % in CM and IC-I and 82 % contribution in IC-II. However, the emission from transport activity is the second largest factor, making 17–21 % of the contribution. Detailed contribution factor is presented in Table 5. According to several studies evaluating global warming potential in agriculture production, chemical fertilizer was the hotspot of emission that predominantly contributed to GWP [8,15,44,45]. According to the GWP impact evaluation in this study, the contributor factor to GWP impact in Cocoa production shows the similar contribution.

3.1.1.2. •Stratospheric ozone depletion. The impact of Cocoa production on stratospheric ozone depletion was dominantly contributed by practicing Intercropping 1 (IC-I) with 3.4×10^{-6} kg $CFC11_{eq}$ impact per kg of Cocoa. ccording to Table 5, NPK was the most contributing factor to stratospheric ozone depletion, with 98–99 % of the contribution. At the IC-II, the percentage contribution factors of NPK to Stratospheric ozone depletion was the highest. It is caused by the highest NPK utilization during the management of cocoa plantations by IC-II.

3.1.1.3. •Ionizing radiation. The highest impact of ionizing radiation was emitted by practicing Intercropping I (IC-I) with 1.2×10^{-3} kBq $Co\text{-}60_{eq}$ impact per kg of Cocoa. Meanwhile, CM impacted to 5.9×10^{-3} kBq $Co\text{-}60_{eq}$ or 53 % lower than IC-I. n CM, 61 % of the impact of ionizing radiation was contributed by NPK, while Pesticides contributed 39 %. According to Table 5, a similar contribution factor is also shown in IC-I and IC-II, that NPK and Pesticides predominantly contribute to Ionizing Radiation. The highest contribution of NPK was in IC-I, which contributed 79 %.

3.1.1.4. •Fine particulate matter formation. The Intercropping system I (IC-I) emitted the highest impact on fine particulate matter formation with the impact of 2.66×10^{-4} kg $PM_{2.5eq}$. The lowest impact is emitted by monocropping system (CM) with 1.43×10^{-4} kg $PM_{2.5eq}$ or 46 % lower than IC-I and 21.4 % lower than IC-II. NPK still dominantly contributes to fine particulate matter formation with 59–67 % of the contribution. The second largest contribution factor was the transportation activity, which contributed 27–33 %. However, Electricity was the lowest contributor factor with only 1–3% of the contribution.

3.1.1.5. •Ozone formation, terrestrial formation. The Interropping I (IC-I) has the highest impact to ozone formation, terrestrial formation with Intercropping I (IC-I) has the highest impact on ozone formation and terrestrial formation withh 6.41×10^{-4} kg $NO_{x\ eq}$ impact per kg of Cocoa. The Lowest impact was the Monocropping system (CM), with 8–39 % lower impact than IC-I and IC-II. According to the contribution factor analysis result, as presented in Table 5, the significant contributor factor was the transport activity, which contributed approximately 60–68 % of the contribution. However, NPK was the second most significant factor, with 20–38 % of the contribution. Meanwhile, pesticides were the lowest, with a 2–3% impact on the ozon formation. According to this result, NPK does not significantly impact ozone formation. Inversely, in other environmental impact indicators, NPK was the dominant factor.

3.1.1.6. •Terrestrial acidification. The impact of cocoa production on terrestrial acidification is dominantly contributed by the

Table 3
Total GWP calculation from the field and input production.

	Unit	CM	CI-I	CI-II
Emission from managed soil	Kg CO2 eq/ha	930.72	1011	971.34
Volatilization	Kg CO2 eq/ha	191.01	200.27	195.95
Leaching	Kg CO2 eq/ha	223.37	242.55	233.12
CO2 emission from input production	Kg CO2 eq/ha	3690	9990	6289
Total emission per hectare	Kg CO2 eq/ha	5035.10	11,443	7689
Total Cocoa fruit production	Kg	22,500	33,750	29,250
Total emission per kg Cocoa fruit	Kg CO2 eq/kg	0.22	0.34	0.26

Table 4
Environmental impact assessment result for all indicators per kg of Cocoa.

Impact category	Unit	MC	CI-I	CI-II
Global warming	kg CO2 eq	0.22	0.34	0.26
Stratospheric ozone depletion	kg CFC11 eq	0.000002	0.0000034	0.0000026
Ionizing radiation	kBq Co-60 eq	0.000599	0.001275	0.000752
Ozone formation, Human health	kg NOx eq	0.000385	0.000633	0.000419
Fine particulate matter formation	kg PM2.5 eq	0.000143	0.000266	0.000182
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.000390	0.000641	0.000425
Terrestrial acidification	kg SO2 eq	0.000710	0.001274	0.000919
Freshwater eutrophication	kg P eq	0.000004	0.000010	0.000006
Marine eutrophication	kg N eq	0.000001	0.000003	0.000001
Terrestrial ecotoxicity	kg 1,4-DCB	0.020939	0.052316	0.023295
Freshwater ecotoxicity	kg 1,4-DCB	0.000392	0.000957	0.000402
Marine ecotoxicity	kg 1,4-DCB	0.000505	0.001191	0.000532
Human carcinogenic toxicity	kg 1,4-DCB	0.000146	0.000407	0.000161
Human non-carcinogenic toxicity	kg 1,4-DCB	0.013916	0.029180	0.014849
Land use	m2a crop eq	0.000394	0.001161	0.000373
Mineral resource scarcity	kg Cu eq	0.001510	0.002804	0.002061
Fossil resource scarcity	kg oil eq	0.044194	0.080057	0.057496
Water consumption	m3	0.000115	0.000220	0.000156

intercropping system I (IC-I) with 1.274×10^{-3} kg $SO_{2.eq}$ per kg of Cocoa production. Meanwhile, the monocropping system (CM) emitted the lowest impact with 7.1×10^{-4} kg $SO_{2.eq}$. For this impact, NPK, as the highest contribution factor to Terrestrial Acidification, gives 75–81 % of the contribution. Transport activity contributes 17–20 %, and pesticide contributes 2–5%.

3.1.1.7. •*Freshwater eutrophication.* Intercropping-I was the consistent cocoa cultivation system with a lower environmental impact, including the freshwater eutrophication impact with 4×10^{-6} kg P_{eq} impact per kg of cocoa production. However, the highest impact on Freshwater Eutrophication was attributed to Intercropping I (IC-I) with 1×10^{-5} kg P_{eq} of emission. According to Table 5, NPK was the highest contribution factor in CM, IC-I, and IC-II, with 65 %, 50 %, and 75 % of the contribution to Freshwater eutrophication. At the same time, the lowest contributor factor was electricity, with 2–8% of the contribution.

3.1.1.8. •*Marine eutrophication.* The impact of the cocoa production system on marine eutrophication was 1×10^{-6} kg N_{eq} from monocropping system (CM), 3×10^{-6} kg N_{eq} from Intercropping I (IC-I), and 1×10^{-6} kg N_{eq} from Intercropping II (IC-II). According to this result, IC-I still has the dominant impact on marine eutrophication, with pesticides as the most contributing factor. Pesticide contributes 80 %, 11 % from transport, 8 % from NPK, and 1 % from Electricity, respectively. Similar to the contribution factor in IC-I, pesticide was the dominant contributor factor in the CM and IC-II.

3.1.1.9. •*Terrestrial ecotoxicity.* Table 4 indicates that IC-I predominantly impacted the terrestrial ecotoxicity with 5.2×10^{-2} kg 1,4-DCB. Meanwhile CM has the lowest impact on the terrestrial ecotoxicity with 2.09×10^{-2} kg 1,4-DCB. According to Table 5, the main contributor factor to terrestrial ecotoxicity was Pesticides in all Cocoa production systems, with a percentage contribution of 58 % from CM, 69 % from IC-I, and 48 % from IC-II, respectively. However, there is the same proportion of contribution between two factors in IC-II, namely pesticide and NPK, with 48 % of the contribution.

3.1.1.10. •*Freshwater ecotoxicity.* The dominant impact of IC-I on the environment was also shown in the freshwater ecotoxicity impact that emits 9.5×10^{-4} kg 1,4DCB. Meanwhile, the lowest impact was attributed to the CM, which was 3.9×10^{-4} kg 1,4DCB. As shown in Table 5, pesticide was the most significant contributor factor in all cocoa plantations with contributions 2×10^{-4} kg 1,4DCB in CM, 5.9×10^{-4} kg 1,4DCB in IC-I, and 1.8×10^{-4} kg 1,4DCB in IC-II.

3.1.1.11. •*Marine ecotoxicity.* In marine ecotoxicity, the lowest impact was attributed to CM with 5×10^{-4} kg 1,4DCB. Meanwhile, the IC-I emitted the most significant impact, with 1×10^{-3} kg 1,4DCB. There is a difference in the dominant contribution factor of the three Cocoa plantation systems. Transport significantly impacts marine ecotoxicity in CM and IC-II, with a 49 % contribution in CM and 50 % in IC-II, followed by pesticides with a 44 % contribution in CM and 38 % in IC-II. Meanwhile, in IC-I, pesticides become the most significant factor contributing 55 % to freshwater ecotoxicity, while transport gives 37 %, respectively.

3.1.1.12. •*Human carcinogenic toxicity.* According to Table 4, IC-I has the highest impact on human carcinogenic toxicity with 4×10^{-4} kg 1,4DCB. Meanwhile, the lowest impact isattributed to CM with 1.46×10^{-4} kg 1,4DCB. As presented in Table 5, pesticides predominantly contributed to this impact in all cocoa production systems. Pesticide contributes 68 % in CM, 73 % in IC-I, and 56 % in IC-II. Transportation is the second largest contributor to human carcinogenic toxicity, with 18 % contribution in CM, 11 % in IC-I, and 17 % in IC-II. However, in this impact, NPK is the lower contribution, with 11 % in CM, 7 % in IC-I, and 14 % in IC-II. According to this study, pesticides cause the most significant damage to human health.

Table 5
Contribution factor of environmental impact.

Impact category	Cocoa plantation	NPK	Pesticide	Transport	Electricity
GWP	CM	0.126661	0.002589	0.03432303	0.0000518
	IC-I	0.227341	0.007687	0.06008465	0.0004660
	IC-II	0.176170	0.002353	0.03653812	0.0002589
Stratospheric Ozone depletion	CM	0.000002	0.000000	0.00000002	0.00000000002
	IC-I	0.000003	0.000000	0.00000003	0.0000000001
	IC-II	0.000003	0.000000	0.00000002	0.00000000008
Ionizing Radiation	CM	0.000771	0.000503	0	0.00000164
	IC-I	0.000597	0.000154	0	0.00000091
	IC-II	0.000430	0.000169	0	0.00000018
Ozon formation, human health	CM	0.000087	0.000007	0.000048	0.00000103
	IC-I	0.000205	0.000021	0.000406	0.00000120
	IC-II	0.000159	0.000006	0.000253	0.00000067
Fine particulate	CM	0.000087	0.000007	0.000048	0.00000103
	IC-I	0.000156	0.000022	0.000079	0.00000931
	IC-II	0.000121	0.000007	0.000049	0.00000517
Ozon Formation, Terrestrial Ecosystem	CM	0.000116	0.000007	0.000266	0.00000013
	IC-I	0.000208	0.000022	0.000410	0.00000121
	IC-II	0.000161	0.000007	0.000256	0.00000067
Terrestrial Acidification	CM	0.000535	0.000019	0.000156	0.00000018
	IC-I	0.000960	0.000058	0.000255	0.00000162
	IC-II	0.000744	0.000018	0.000157	0.00000090
Freshwater eutrophication	CM	0.000003	0.000001	0	0.00000008
	IC-I	0.000005	0.000004	0	0.00000073
	IC-II	0.000004	0.000001	0	0.00000041
Marine eutrophication	CM	0.0000001	0.000001	0.0000002	0.000000005
	IC-I	0.0000002	0.000002	0.0000003	0.00000004
	IC-II	0.0000002	0.000001	0.0000002	0.00000002
Terrestrial ecotoxicity	CM	0.008098	0.012169	0.0006086	0.0000638
	IC-I	0.014535	0.036137	0.0010705	0.0005739
	IC-II	0.011264	0.011062	0.0006504	0.0003188
Freswater ecotoxicity	CM	0.000003	0.000200	0.0001851	0.0000036
	IC-I	0.000005	0.000594	0.0003255	0.0000321
	IC-II	0.000004	0.000182	0.0001978	0.0000178
Marine ecotoxicity	CM	0.000030	0.000221	0.0002494	0.0000047
	IC-I	0.000054	0.000656	0.0004387	0.0000421
	IC-II	0.000042	0.000201	0.0002665	0.0000234
Human Carcinogenic	CM	0.000016	0.000099	0.0000257	0.0000041
	IC-I	0.000029	0.000295	0.0000452	0.0000371
	IC-II	0.000023	0.000090	0.0000275	0.0000206
Human non carcinogenic	CM	0.000513	0.003342	0.0099734	0.0000879
	IC-I	0.000920	0.009925	0.0175435	0.0007909
	IC-II	0.000713	0.003038	0.0106584	0.0004394
Land use	CM	0.000016	0.000376	0	0.0000018
	IC-I	0.000029	0.001116	0	0.0000161
	IC-II	0.000022	0.000342	0	0.0000089
Mineral resource	CM	0.001429	0.000080	0	0.00000003
	IC-I	0.002566	0.000238	0	0.0000003
	IC-II	0.001988	0.000073	0	0.0000001
Fossil resource scarcity	CM	0.032142	0.000884	0.0111555	0.0000132
	IC-I	0.057691	0.002624	0.0196228	0.0001188
	IC-II	0.044705	0.000803	0.0119217	0.0000660
Water consumption	CM	0.000105	0.000010	0	0.0000002
	IC-I	0.000188	0.000030	0	0.0000021
	IC-II	0.000146	0.000009	0	0.0000012

3.1.1.13. •*Human non-carcinogenic toxicity.* The impact of Cocoa production activity at the farm level on human noncarcinogenic toxicity is predominantly attributed to cocoa intercropping-I (IC-I) with 2.91×10^{-2} kg 1,4DCB. The Cocoa Monocropping system (CM) has the lowest impact, with 1.39×10^{-2} kg 1,4DCB. Transport activity contributed to the impact with 60–72 % of the contribution. Meanwhile, pesticides account for 20–34 % of the contribution. The use of NPK and electricity only contributes 3–4% to the impact of human noncarcinogenic toxicity.

3.1.1.14. •*Mineral resource scarcity.* The material and energy used during the Cocoa production system impacted the mineral resource scarcity. This study indicates that practicing the Cocoa intercropping system-I(IC-I) impacted the mineral resource scarcity at 2.8×10^{-3} kg Cu_{eq}. g CM gave the lowest impact with 1.5×10^{-3} kg Cu_{eq}, Meanwhile, IC-II caused 2.06×10^{-3} kg Cu_{eq}. According to Table 5, the significant factors contributing to the impact of the mineral resource scarcity were NPK and pesticides. NPK predominantly contributed 92–96 % of the contributions. Whereas pesticide shares 4–8%.

3.1.1.15. •Fossil resource scarcity. IC-I had the highest impact on fossil resource scarcity with 8×10^{-2} kg oil $_{eq}$. The lowest impact was emitted by CM, with 1.3×10^{-2} kg oil $_{eq}$. According to Table 5, three material and energy inputs contributed to fossil resource scarcity: NPK, transport, and pesticide. The most significant factor contributing to fossil resource scarcity was NPK with 72–78 % of contribution. Meanwhile, transport gives 21–25 % of contribution, and pesticide shares 1–3 %. In this impact, the impact of transport was considered as the contributing factor since gasoline or solar energy was considered for transportation.

Practicing Cocoa production with intercropping-I (IC-I) emitted the highest impact on environmental damage in air, water, land, human, and natural resources. A previous study revealed that agriculture production impacted the environmental burdens, such as greenhouse gas emissions [46], and finally will impact the natural depletion [47]. The factors influencing the environmental issues in agriculture production were observed. Some studies revealed that the massive use of chemical content input during the production activity was the most significant factor contributing to environmental damage, contributing 44–79 % [48]. According to this study, NPK predominantly contributed to 10 environmental impact indicators, namely global warming potential (GWP), stratospheric ozone depletion, Ionizing radiation, ozone formation, fine particulate matter formation, terrestrial acidification, freshwater eutrophication, mineral resource scarcity, fossil resource scarcity, and water consumption. This result indicated that using NPK (chemical fertilizer) impacted environmental damage significantly. The previous LCA study in agriculture production, such as in Coffee, indicated a similar result [4,44], that chemical fertilizer application is the highest contributor to environmental damage impact at the farm level.

Another chemical content input in Cocoa production that contributed to environmental damage was pesticides. There were seven environmental impacts significantly attributed to pesticides: marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity, human noncarcinogenic toxicity, and land use. According to this result, pesticides have a dominant impact on water and human health. Some research revealed the impact of pesticides on the environment and human health. Moreover, acute and chronic health issues that are caused by agricultural pesticides are serious public health concerns [49]. For human, the pesticide can be a carcinogenic, cytotoxic, and mutagenic [50].

3.1.2. Economic performance of cocoa production system

*3.1.2.1. •Value **added analysis.*** The evaluation of economic value added will inform the short term of economic impact of cocoa production. Since the economic aspect become the primarily issue at cocoa farmer lavel, this evaluation will provide a brief economic impact aspect. Value added analysis considers cost and revenue on the calculation. According to Table 6, the highest life cycle cost (LCC) is required by intercropping system-I (IC-I), with the total expenses to manage 1-ha Cocoa plantation being 11,340 USD·ha^{-1}. In contrast, the Monocropping system (CM) required the lowest cost with 4187 USD·ha^{-1}. The higher maintenance and input production application during practicing IC-II caused the higher expenses. In agricultural production at the farm level, some studies also report that maintenance specifically for fertilizer application is required at the highest cost [44]. The study on fertilizer-economic preference aspect in rice production revealed that there are the association between fertizer use and economic aspect, where the fertilizer are widely and execively used [51]. In line with the previous study, this study reveals the fertilizer required the highest cost with 82–94 % of the total cost in all Cocoa plantation system.

In general economic aspects, IC-I generated the highest revenue due to its productivity. In comparison, IC-II is placed second, and CM has the lowest income. However, the highest revenue does not represent the highest economic benefit. Therefore, according to the economic value-added analysis that considers LCC and revenue, IC-II is more beneficial economically as it presents the highest net profit at 15,585 USD·ha^{-1}. On the other hand, CM generated the lower economic value added at 2,937 USD·ha^{-1}. The advantage of IC-I and IC-II was that the farmer could generate income from the first year of production activity from horticulture commodity. Meanwhile in CM, farmers started to generate revenue in the third year of the Cocoa plantation. In Indonesia, many farmers practice CM in their Cocoa cultivation system with low economic benefits generated. As mentioned, economic benefits remain the primary issue for the declining number of Cocoa farmers and Cocoa area plantations. This study found an alternative cultivation system that could increase the economic benefit for farmer by practicing IC-II and IC-I.

In developing country, raising the economic value addedd for farmer is become the crucial issue to be solved, since the low average of their land ownerchip effects to their agriculture commodity production and its revenue [52]. Where the increase of land ownership on agriculture production will increase the economic security of household [53]. The government in developing country are interested to increase the economic benefit at farmer level [54]. The increase of economic benefit by increasing land ownership is difficult to be implemented in developing country. Therefore, applying the culvitation management system that economicaly feasible is recommended. Acoording to this study, intercopping system of Cocoa production is recommended to generate the higher economic value added.

Table 6
Economic performance analysis using LCC.

Resume of economic performance per kg of product (kg/USD)				
Economic performance		Monocropping	Intercropping I	Intercropping II
Total expenditure		0.186	0.336	0.256
Income	Cocoa	0.317	0.317	0.317
	Horticulture	0	0.190	0.348
	Total	0.317	0.507	0.665
Net Profit		0.131	0.171	0.409

3.1.2.2. •*Economic* ***feasibility analysis of cocoa production system.*** The economic feasibility study is an economic analysis that identifies the feasibility of a product, method, or technology in a long-term period [39]. This study conducts a feasibility analysis to determine which cocoa cultivation method that is more economically viable. This study performed NPV, ROI, and Cost-Benefit Ratio Analysis as the feasibility indicators. Table 7 indicates that IC-II performed the highest in all feasibility indicators, such as IC-II generating 17,419 USD, while IC-I and CM generated 8,352 USD and 2,262 USD. In Return on Investment (ROI), IC-II performed the highest percentage with 18.8 %, whereas IC-I and CM were 8.6 % and 12.1 %. According to the standard annual rate in Indonesia, this study used 6 % as the standard for the calculation. According to the ROI aspect, all the cocoa plantations are feasible economically.

In the cost-benefit ratio analysis, IC-II still shows the domination of economic feasibility with an index score of 1.7, while IC-I and CM were 0.8 and 0.6. The higher return on investment indicates a higher possibility of return on the financial expenses during the project [55]. According to these three indicators, IC-II is more economically feasible. This study informs the long-term economic evaluation of cocoa production as the consideration for cultivating cocoa from a business perspective.

3.1.3. Social impact performance of cocoa production system

This study used the social sustainability index as the leading indicator of social impact. The SLCA assessment method is still in progress in finding the standard model evaluation [56,57]. Previous social impact studies have proposed methods to evaluate the SLCA in many sectors [12,18,19,58,59]. This study considers the social indicators and methods provided by UNEP/SETAC [29]. A weighting and scoring system was also conducted to identify social sustainability, following some previous SLCA studies on agricultural commodities [60]. The result in Table 8 showed that IC-II practicing the Cocoa intercropping system combined with corn resulted in the highest social sustainability index (SSI) with the final index score of 0.794, while the SSI of IC-I at 0.755, and SSI for CM had the lowest score with 0.60. The highest social impact index in IC-II is contributed by the higher impact score in the three endpoint indicators: Socioeconomic value added for the worker (Worker) at 0.9, Community and Societal Development (Community and Society) at 0.86, and Socioeconomic value added for supply chain actor (Supply chain actor) at 0.78. However, the Cocoa cultivation system does not have impact to the Consumer actors in terms of consumer satisfaction.

According the proposed SLCA method [18,43], the highest SSI value indicates the more sustainable of its product, method, technology, or service [43]. As shown by the SSI result, IC-II is more sustainable in terms of social impact on workers, community and society, and supply chain actors. However, the social impact evaluation should be taken into account in sustainability analysis [61]. According to this study result, practicing intercropping (IC-I and IC-II) provides a higher social impact in social aspect than the monocropping system (CM). Since the economic benefit in intercropping system was higher than in monocropping system, it seems that there is a connection between the economic benefit and social impact [62]. Some study also reveal that the social benefit has a positive impact on farmer' participation in agriculture production [63]. Therefore, it is possible to attract the farmer's intention to continue their cocoa production, if the social impact has increased. According to the current cocoa issue regarding the decreased of cocoa production due to the reduction of the number of cocoa farmer, this study result provide a consideration for government to promote the Cocoa cultivation system that provide the higher of social impact to attract the farmer attention.

3.1.4. EcoEficiency index of cocoa production system

Eco-efficiency was evaluated by considering the economic value added and total emission per hectare Cocoa plantation. The higher eco-efficiency index indicates a higher impact to the environment in an environmental perspective [64,65]. Table 9 expresses the eco-efficiency index for all environmental impact categories. According to Table 9, practicing IC-II obtained the lowest ecoefficiency index in all categories. For example, IC-II resulted in a 0.62 ecoefficiency index in GWP impact. This result represents that per unit of economic benefit generated by practicing IC-II will emmit 0.62 kg CO_2 eq. In contrast, IC-I obtained the highest ecoefficiency index of all impact indicators. It indicated that per unit economic value added on IC-I has the highest environmental impact in all indicators. Therefore, according to this study, practicing IC-II is more beneficial in the environmental-economic combination aspect, as shown by the lowest ecoefficiency index in all categories.

3.2. Multicriteria decision making analysis of sustainable cocoa production

Standardizing the sustainability status in product and service systems is still in progress. Due to the uncertainty and multicriteria aspect of sustainability consideration, integrating the LCA method and multicriteria decision analysis is predicted will provide a more realistic result to identify the more sustainable alternatives of products and services [23,66].

This study considers many aspects of obtaining the best solution for the Cocoa cultivation system, such as Environmental impact (GWP), Economic performance (LCC and economic value added), Environmental-Economic (Ecoefficiency index), and Social Impact (Social Sustainability index). Using TOPSIS, the best solution for sustainable Cocoa production system practice considering the comprehensive sustainability aspect will be obtained. The results indicated IC-II that practicing Cocoa cultivation combined with corn presented a high value on TOPSIS result, with score of 0.75. It indicates that by considering the five indicators in environmental, economic, and social sustainability aspects, combining Cocoa cultivation with corn is more sustainable and suggested to be applied. The second recommended method for Cocoa cultivation is practicing the Cocoa monoculture system (CM) with a total TOPSIS score of 0.44. The last recommendation for Cocoa cultivation combines Cocoa trees and cabbage with a TOPSIS score of 0.2.

According to the TOPSIS result that recommend IC II as the best Cocoa production system at farm level, the single economic aspect consideration will not represent the overall of economic benefit for IC II. It was indicated by single economic aspect in IC II (revenue or cost) does not performing the best economic performance. However, by integrating the two of economic aspects: revenue and cost by the economic value added aspects, IC-II dominantly generates the highest value. Therefore, using the economic value added (EVA) as

Table 7
Economic feasibility analysis.

Economic Indicators	Unit	Monocropping (CM)	Intercropping-I (IC-I)	Intercropping-II (IC-II)
Economic value added/kg	USD/kg	1.01	2.47	3.57
Net Present Value (NPV)	USD/ha	2262	8352	17,419
Return of Investment (ROI)	%	12.1	8.6	18.8
Benefit-Cost Ratio	–	0.6	0.8	1.7

Table 8
Social sustainability index.

Cocoa production system	Social Sustainability Index
Monocropping (CM)	0.6057
Intercropping 1 (IC-I)	0.7556
Intercropping II (IC-II)	0.7947

Table 9
Eco-Efficiency Index per kg Cocoa production at farm level.

Impact category	Unit	Ecoefficiency		
		CM	CI-I	CI-II
Global warming	kg CO2 eq	1.25355	1.73295	0.52665
Stratospheric ozone depletion	kg CFC11 eq	0.00001	0.00002	0.00001
Ionizing radiation	kBq Co-60 eq	0.00459	0.00748	0.00184
Ozone formation, Human health	kg NOx eq	0.00295	0.00371	0.00102
Fine particulate matter formation	kg PM2.5 eq	0.00110	0.00156	0.00044
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.00299	0.00376	0.00104
Terrestrial acidification	kg SO2 eq	0.00544	0.00747	0.00225
Freshwater eutrophication	kg P eq	0.00003	0.00006	0.00001
Marine eutrophication	kg N eq	0.00001	0.00002	0.00000
Terrestrial ecotoxicity	kg 1,4-DCB	0.16042	0.30673	0.05698
Freshwater ecotoxicity	kg 1,4-DCB	0.00300	0.00561	0.00098
Marine ecotoxicity	kg 1,4-DCB	0.00387	0.00698	0.00130
Human carcinogenic toxicity	kg 1,4-DCB	0.00112	0.00239	0.00039
Human non-carcinogenic toxicity	kg 1,4-DCB	0.10661	0.17108	0.03632
Land use	m2a crop eq	0.00302	0.00681	0.00091
Mineral resource scarcity	kg Cu eq	0.01157	0.01644	0.00504
Fossil resource scarcity	kg oil eq	0.33858	0.46937	0.14063
Water consumption	m3	0.00088	0.00129	0.00038

the consideration aspect will represent the best alternatif of Cocoa production system in economic aspect. In real situation, farmers sometime only focusing on a single economic aspect consideration on managing their Cocoa plantation, such as the lower cost, or the higher revenue. Therefore, this study proved that in by comprehensive evaluation in economic aspect using economic value added analysis will represent the best alternative of Cocoa production. Furthermore, this study also showed that by combining comprehensive economic value added with environmental and socioeconomic, the IC-11 is recommended as the highes TOPSIS value. Detailed result is provided in Table 10. This result provide the contribution on practical of Cocoa cultivation in farm level.

4. Conclusion

Integrating LCA and TOPSIS to determine the sustainable Cocoa production system with considering all sustainability aspects were performed. Some points highlighted according to the study result. In the environmental aspect, practicing the Cocoa monocropping system (CM) emitted the lowest environmental impact in 18 categories, followed by the intercropping-II (IC-II), and the highest environmental impact was emitted by intercropping-I (IC-I). In the economic aspect both on the short term and long-term perspectives, the Cocoa intercropping system (IC-II) generated higher value added and higher economic feasibility. Moreover, combining economic

Table 10
TOPSIS result.

Alternatives	Score of Preference	Rank
Monocropping (CM)	0.449308151	2
Intercropping 1 (IC-I)	0.220209336	3
Intercropping II (IC-II)	0.755143232	1

and environmental aspects through the eco-efficiency index showed that Cocoa intercropping system II (IC-II) obtained a high performance as indicated by the lower ecoefficiency index which indicates the lower environmental damage impact per unit of economic benefit generated. In the social aspect, Intercropping I and II performed the highest impact, while monocropping performed the lowest score. According to this result, each indicator suggests a different result of recommended cocoa cultivation in the partial aspect of sustainability evaluation. Using TOPSIS as one of the MCDM tools that consider five aspects of the calculation: Environmental impact (GWP), Economic performance (LCC and economic value added), Environmental-Economic (Ecoefficiency index), Social Impact (Social Sustainability index), determined the best alternative solution of Cocoa production system. The result shows that the Cocoa intercropping system II (IC-II) performed the highest value, followed by the monocropping system, and the last suggestion is Cocoa intercropping system II. This study contributed to some aspects. In the future study of sustainable agriculture development, this study provides a benchmark for obtaining the comprehensive decision-making at the farm level to achieve sustainable agriculture production. In a practical aspect, this study provides scientific information and suggestions for farmers to apply the sustainable Cocoa cultivation system. For the decision maker, this study provides scientific information as the primary consideration of regulation to solve the national Cocoa issue associated with the decreasing trend of Cocoa production at the farm level.

Data availability

No. Data included in article/supplementary material/referenced material.

CRediT authorship contribution statement

Devi Maulida Rahmah: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Januardi:** Writing – review & editing, Visualization, Investigation, Formal analysis. **Puspita Nurlilasari:** Visualization, Project administration, Investigation, Formal analysis, Data curation. **Efri Mardawati:** Writing – original draft, Methodology, Formal analysis, Conceptualization. **Roni Kastaman:** Validation, Supervision, Methodology, Conceptualization. **Koko Iwan Agus Kurniawan:** Writing – review & editing, Software, Validation, Formal analysis. **Neng Tanty Sofyana:** Visualization, Resources, Project administration, Formal analysis, Data curation. **Ryozo Noguchi:** Validation, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Devi Maulida Rahmah reports financial support was provided by Padjadjaran University. Devi Maulida Rahmah reports a relationship with Padjadjaran University that includes: employment and funding grants. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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