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CASE STUDY

Life cycle assessment of cocoa farming sustainability by implementing compound fertilizer

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ABSTRACT

BACKGROUND AND OBJECTIVES: The global competitiveness of the cocoa processing industry is enhanced through the implementation of technical policies as a sustainable economic sector. The effort is motivated by the potential of large cocoa production and the international market demands for the industry to apply innovative, effective technology and comply with sustainability standards (environment, social, and economic). Therefore, this study aimed to analyze the environmental impact assessment of cocoa production from upstream to downstream processes in North Luwu Regency, South Sulawesi.
METHODS: Data were collected from 321 respondents actively working and had at least 8 years of experience in cocoa cultivation and production. Respondents included staff of the Masagena Farmers' Cooperative from Chalodo Sibali Resoe Industry, Masamba City, and North Luwu Regency, and the secondary data were obtained from a literature review. In addition, the environmental impact was determined using the Midpoint Recipe method and the ecoinvent 3.8 database. This was conducted based on the International Standard Organization of life cycle assessment 14040 and 14044 with a function unit of 1 kilogram chocodate cashew production.
FINDINGS: The results showed that reducing chemical fertilizer was environmentally preferable to decreasing all the impact categories assessed since the total potential global warming impact from chocodate cashew production was 2.092 kilogram carbon dioxide equivalent. In this context, electricity and fertilizer were the main contributors to environmental pollution, accounting for 0.438 kilogram carbon dioxide equivalent and 0.215 kilogram carbon dioxide equivalent at 20.97 percent and 10.27 percent, respectively.
CONCLUSION: The reduction in the use of inorganic nitrogen, phosphate, potassium fertilizer, from 3.75 to 1.25 kilogram perkilogram cocoa, or the adoption of bio-based nitrogen, phosphate, potassium fertilizer at a rate of 2.5/ kilogram, could substantially mitigate the environmental impact. This mitigation resulted in a 16 percent decrease in global warming potential, reducing from 2.092 to 1.745 kilogram carbon dioxide equivalent. In addition, valuable insights were provided into the scope of life cycle assessment studies and contributed to the selection of sustainable cacao farming systems. These results could be relevant to life cycle assessment practitioners, stakeholders, and governments in offering valuable insights for the formulation of policies and programs for developing cacao farming in the future.

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INTRODUCTION

Indonesia is the world's largest processed cocoa producer, accounting for approximately 15 percent (%) of global chocodate consumption, and the fifth producer after Ivory Coast, Ghana, Nigeria, and Cameroon (Beg *et al.,* 2017). Cocoa bean production was 220,000 tonnes and 231,000 tonnes in 2019 and 2020, respectively. Cocoa represents a strategically important export commodity with the potential to yield substantial profits as an export commodity. In addition, it is a leading commodity in international trade, along with rubber, palm oil, and coffee. The large production capacity contributes as one of cocoa planting hearts, reaching 61.4% of the national cocoa area to the economy in all circumstances. Despite the impact of the coronavirus outbreak, cocoa processing industry continued to contribute to foreign exchange. This was evident in the export value of domestically processed cocoa products in 2020, which amounted to approximately 1.12 billion United States dollars (USD), marking an increase of 12% compared to the previous year (Parra-Paitan and Verburg, 2022). In addition to high production capacity, the products have a distinctive taste that increases their competitiveness in the global trade market. Processed cocoa products in the form of liquor, butter, powder, and cake are exported to large international markets including the United States, Netherlands, India, Germany, and China (Harya *et al*., 2018). Despite their high product competitiveness, the added value is still low, due to a relatively slow cocoa processing industry. This is affected by the low quality of production from smallholder plantations, namely 92.34% with a total of 1,400,636 micro, small and medium-sized enterprises (MSMEs) as producers (Tothmihaly *et al*., 2019). Cocoa production from farmers significantly contributes to the global value chain since it is exported to numerous countries. Similar to the exports from the agricultural and plantation sectors, efforts are needed to increase value-added products and maintain product competitiveness in the global trade market. The strategic and technical measures include enhancing crop productivity, elevating the quality of processed cocoa products, maintaining the policy of export duty tariffs for cocoa bean, enhancing infrastructure, and fostering a conducive and productive industry environment. Furthermore, it is important to be in line with the global market preferences, which increasingly demand environmentally friendly cocoa cultivation and processing methods. Compared to other agricultural products, cocoa liquor*,* butter, and powder have relatively low environmental impacts (2–4 kilogram carbon dioxide equivalent (kg CO_2-eq) (Misselbrook *et al*., 2000). Even though cocoa is a plantation crop with a relatively lower impact, it is crucial to address and mitigate its environmental footprint, considering the role as a food crop and staple source of sustenance for the Indonesian population. Beside greenhouse gas (GHG), cocoa production also presents significant emissions of ammonia (NH_3) and methane (CH_4) due to fertilizer use, with NH_3 emissions contributing to acidification (Fardet and Rock, 2020). Nitrous oxide (N_2O) and NH_3 must be addressed to minimize GHG emissions from cocoa production. This impact can be measured through a framework known as life cycle assessment (LCA) which characterizes and depends on the flow of input, output, energy, and emissions in the supply chain. Therefore, physical, social, and economic changes to the environment influence the interpretation of analysis results. Physical environmental impacts include measuring the soil potential of hydrogen (pH), implementing good agricultural practice (GAP), soil and air management technology, and types of plant varieties. In economic terms, farmers' management of essential production inputs, including fertilizer usage (Samimi *et al.,* 2023), the quantity of entries, specifications, labor allocation, and financial record-keeping in the industry, plays an important role. Concurrently, in the social context, the interplay between farmers is of great significance. This comprises their inclusion in group activities, community initiatives, and the pursuit of information regarding cocoa production enhancement through interactions with government agencies, corporations, and other pertinent stakeholders (Idawati *et al*., 2018; Idawati and Ariyanto, 2019; Recanati *et al*., 2018). The International Organization for Standardization (ISO) 14040-14044 provides guidelines for the design and execution of LCA studies. LCA method can identify and mitigate the main causal effects of the use of materials resulting in negative environmental impacts at all stages of the supply chain (Konstantas *et al*., 2018). Therefore, this study aims to investigate the environmental impacts of improved nitrogen fertilizer application in cocoa production, from cradle to grave (Ramos *et al*., 2022). The results may be used to improve the environmental sustainability of market-oriented cocoa production systems. The quantifiable benefits are the direct assessment of cocoa production systems to inform policymakers on regulation and environmental impact mitigation measures, assist farmers in implementing GAP, and educate consumers on the benefits of more sustainably produced goods (Bianchi *et al*., 2021; Santoso *et al*., 2023). The results have the potential to assist entrepreneurs in evaluating the viability of cacao production supply system, with a specific focus on identifying the variables influencing the systems. The analysis includes categorizing the effects of cocoa production on the global warming potential (GWP), freshwater eutrophication potential (FEP), marine eutrophication potential (MEP), and acidification terrestrial potential (ATP) emissions. The objectives are: 1) assess the most significant environmental impacts and identify critical phases and hotspots, 2) compare the environmental performance of various production system modifications, and 3) propose methods to reduce negative environmental impacts and encourage more sustainably produced cocoa using LCA results. This study was carried out at the Masagena Farming Cooperative in Pongo Village and PT Chalodo Sibali Resoe Industry, Limited company (Ltd), Masamba City, North Luwu Regency, South Sulawesi Province, Indonesia, from 2022 to 2023.

MATERIALS AND METHODS

The total area of cocoa plantation in North Luwu Regency was 40,814.56 hectare (ha) and 38,367.04 ha in 2020 and 2021, respectively, operated by

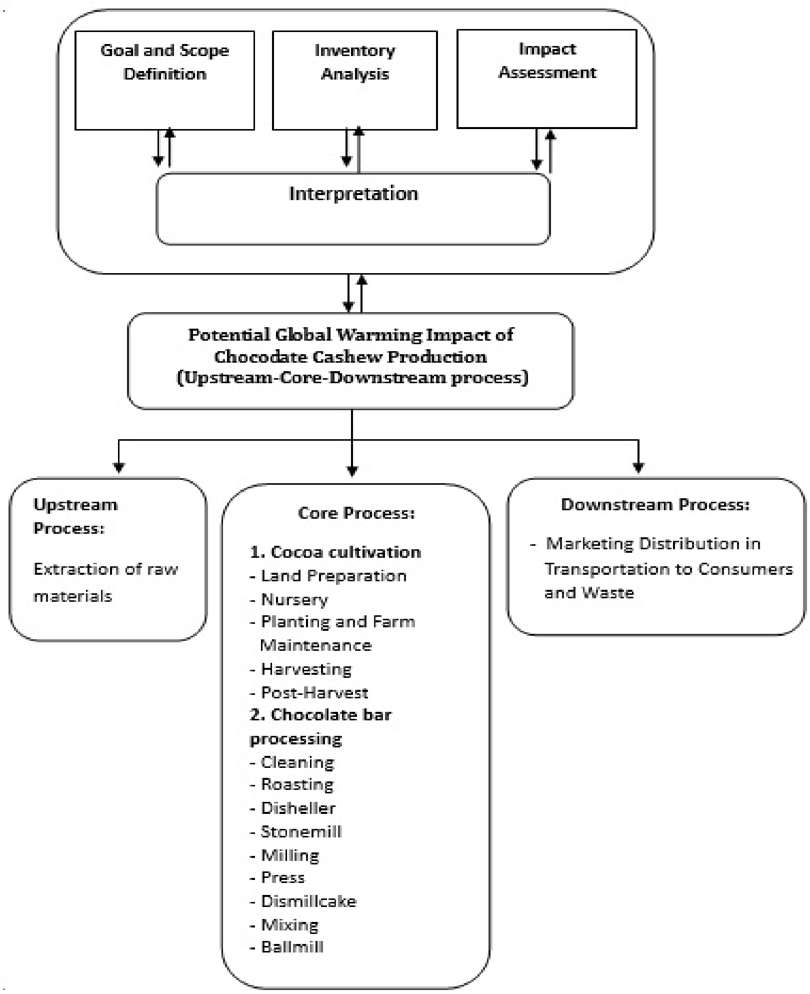

Fig. 1: Framework LCA stages of chocodate cashew production processes

29,481 heads of families and 26,567 farmers, with a production rate of 87.10 tons/ha. The number of farmers in 2021 was 26,567, with a total land area of 38,367.04 Ha. This analysis is a case study of the Masagena Farming Cooperative with a land area of 2,424 ha, owned by 1,616 active farmers. The calculation of the representative sample size from the total population of 1,616 using the Slovin formula is 321 farmers, as shown in Eq. 1 (Sevilla, 2007).

$$n = \frac{N}{1 + N * e^2} \qquad 1$$

Where; n is the number of samples, and N is the total population.

The method used adhered to the ISO 14040:2006 series LCA framework. The initial stage included determining objectives and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretive analysis of the potential global warming impacts of chocodate cashew production. The characterization results in Table 3 are presented based on the cases of (Rahmah *et al*., 2022), as shown in Fig. 1.

Study area

This study was conducted at the Masagena Farmers' Cooperative in the functional unit of 1 kg chocodate cashew from the total production in one harvest season (6 months/production) of Pongo Village and PT Chalodo Sibali Resoe Industry, Ltd., in Masamba City, North Luwu Regency, South Sulawesi Province, Indonesia, from October 2022 to September 2023 Fig. 2.

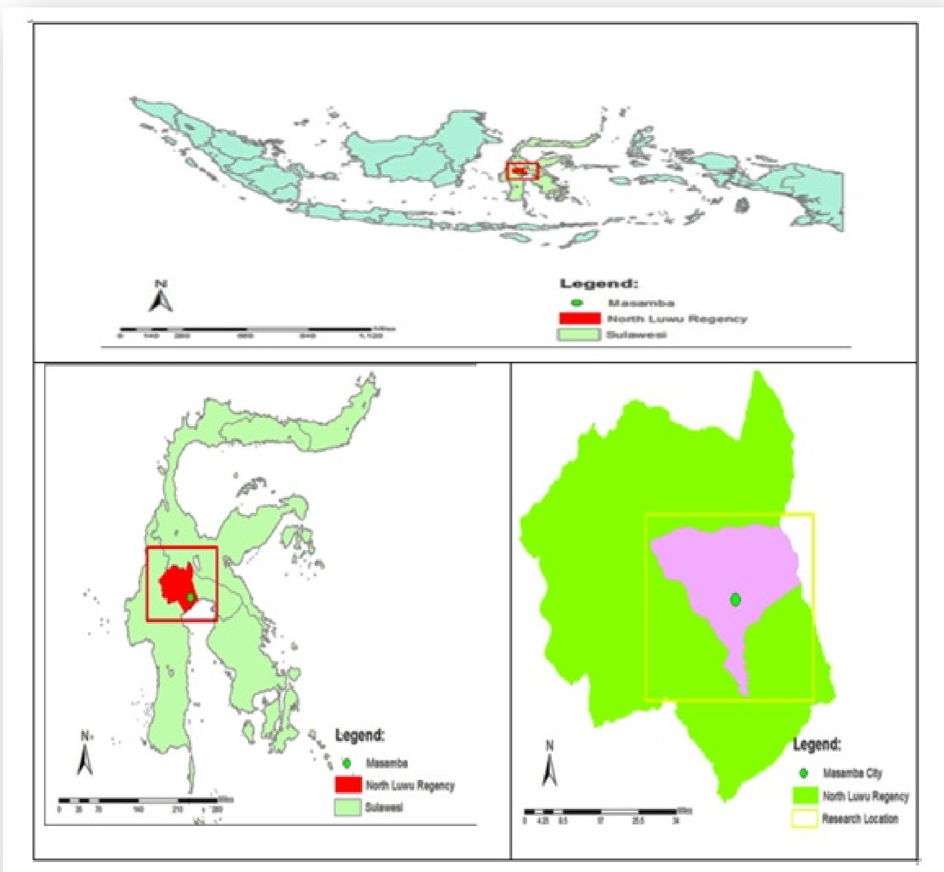

Fig. 2: Geographic location of the study area in Indonesia and detailed cocoa field study location

Table 1. Previously study GWP impact category for 1 kg chocodate production

No	Boundary	Unit faction	Total GWP (kg CO_2-eq)
1	Cradle to gate	1 kg of chocodate bar	1.65-4.21
2	Cradle to gate	1 kg chocodate, packed	2.1-4.1
3	Cradle to gate	1 kg chocodate	2.62
4	Cradle to gate	1 kg chocodate	7.3

Functional units

The functional unit was produced from the production process of 1 kg chocodate cashew production. This referred to the use of inputs and outputs of materials from the cultivation, processing, and transportation stages, LCI and LCIA stages (Permatasari *et al*., 2019). In this study, the standard results for calculating the impact of global warming are based on existing databases. The results were also compared to several previous studies (Busser *et al*., 2009; Rancanati *et al*., 2018; Boakye-Yiadom, *et al*., 2021; Dianawati, *et al*., 2023), as presented in Table 1.

Life cycle inventory (LCI) analysis

LCI is the second framework of LCA method which consists of recording several data from upstream to downstream used in the production process. These stages constitute activities ranging from the initial cultivation in the garden to the inclusion of the Masagena Farmers' Cooperative, subsequent processing in industry, distribution through retailers, and reaching the end consumers. The inventory analysis is divided into two stages, namely data collection and analysis (Waluyo *et al*., 2018). Primary data were obtained through field observation and interviews using a questionnaire on input and output materials. In this context, simple random sampling was used to obtain 321 farmers consisting of members of the Masagena Farmers' Cooperative, and 5 staff of PT Chalodo Sibali Resoe Industry Ltd., Masamba City, North Luwu Regency, as well as individuals included in the process of chocodate cashew production. Concerning the criteria for the survey, respondents were actively working and had at least 8 years of experience in cocoa cultivation and production. Meanwhile, LCI and environmental impact were determined using the ecoinvent 3.8 database and the Midpoint Recipe (H) method based on the ISO 14040 and 14044 standards. The base unit of function was selected as 1 kg chocodate cashew production.

The scope of analysis, shown in Fig. 3, includes cocoa cultivation (land preparation, nursery, storage and garden maintenance, harvesting, post-harvest), chocodate bar processing (cleaning, roasting, dispeller, stone mill, milling, press, dismillcake, mixing, ball mill), printing and packaging, marketing distribution, transportation to consumers, and waste (cradle to grave).

Data collection

The data collected covered the use of fertilizers, pesticides, granulated sugar, cashews, milk, packaging, transportation, and power generation. In this context, the data regarding land preparation consists of the use of gasoline, oil, application of compost, herbicides, and electricity. This is followed by the nursery which consists of seeds, soil, water, plastic polybags, UV (Ultraviolet) plastic for the roof, electricity, and the administration of organic fertilizer mixed with soil at cocoa nursery. The next stage of seed planting consists of input polybags, fertilizer using nitrogen phosphate kalium (NPK) fertilizer (inorganic fertilizer), herbicides in the weed cleaning process, fungicides functioning to control plant pest organisms (PPO) in cocoa plants, electricity use, and water. Cocoa plant maintenance requires NPK fertilizer, liquid organic fertilizer, insecticides, herbicides, fungicides, water, and gasoline. The harvest and post-harvest stages include the use of plastic sacks/bags and gasoline, followed by the harvest transportation to the farmers' house or to the location where the wet cocoa bean is purchased. Subsequently, the process of fermentation and drying of the seeds comprises the use of sunlight with a UV plastic roof, paranet mats (simple greenhouse), plastic sacks/bags, wooden boxes, and banana leaves covering the boxes. Table 2 shows the results of the inventory analysis from the input-output system in cocoa production process, including pre-harvesting and harvesting. Cocoa bean processing consists of sorting, roasting, and deshelling skin from the

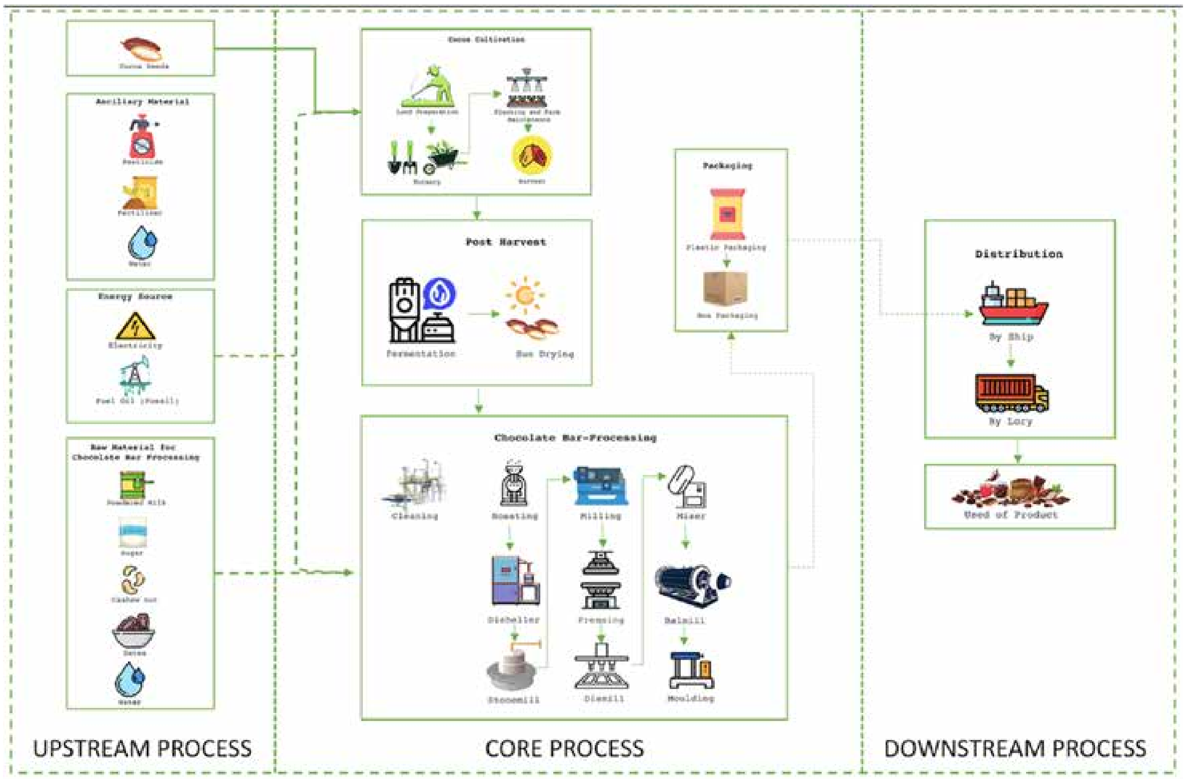

Fig. 3: System boundary of chocodate cashew production processes

nibs using a plastic bag container, LPG (Liquefied Petroleum Gas), and electricity, respectively. The obtained nibs are converted into a coarse paste using a stone mill and electricity, which is then refined in a milling machine to produce liquor. Furthermore, the liquor is pressed to separate cocoa butter and cake. In the next stage, the cake is mashed in a dismillcake machine to produce cocoa powder which is mixed with several additional ingredients to make the final chocodate paste product. This paste is fed into the ball mill to produce a ready-to-mold paste which is put in a cooler before molding into the final products, such as chocodate cashew. Subsequently, cashew is packaged using several layers of packaging before distributing. The main data are the source of cocoa bean (the distance from the Masagena Farmers' Cooperative to the industry), types, sources, and transportation related to the distribution of purchases of materials such as sugar, cashew nuts, milk, and others. Table 3 shows the electricity and water usage as well as the packaging materials.

Data analysis

The collected data were translated into values related to functional units. The adjusted data were entered using the Midpoint Recipe (H) 2016 method and aggregated to produce inventory tables (Muñoz *et al*., 2014).

Life cycle impact (LCI) assessment

Inventory analysis was carried out to calculate the possibility of environmental impacts by identifying the input and output materials used (Caicedo-Vargas *et al*., 2022; Ntiamoah and Afrane, 2008). The stages of measuring the environmental impact of using organic fertilizer on cocoa production are carried out in stages.

1. Due to the limitations of the organic fertilizer dataset, the material input process uses analytical laboratory data information.
2. Information on the composition of organic fertilizer was gathered and calibrated according to the emission factors sourced from the relevant database.

Table 2: Inventory data of the input and output of cocoa cultivation

Unit process	Material	Unit	Amount/6 months production	Amount/1 kg production
Land preparation input	Land use	ha	1	0.002
	Compost	kg	4,500	9
	Gasoline	L	10	0.02
	Herbicide	L	10	0.02
	Lubricant	L	10	0.02
	Groundwater	L	51,000	102
	Plastic bag	kg	15	0.03
Output	Land use	ha	1	0.002
	Herbicide bottle	kg	0.5	6.94E-06
	Lubricant bottle	kg	0.02	2.78E-06
	Waste lubricant	L	0.02	2.78E-06
Nursery input	Land use	ha	1	0.002
	Cocoa tree	tree	650	1.3
	Soil	kg	800	1.6
	Groundwater	L	1,600	3.2
	Polybag plastic/satellite super	kg	1,500	3
	Roofing plastic/UV/polycarbonate	kg	35	0.07
	Electricity	L	100	0.2
	Liquid an-organic fertilizer	kWh	0,05	6.94E-06
		kg	2	0.004
Output	Cocoa tree	tree	625	1.25
	Polybag plastic	kg	775	1.55
	Roofing plastic	kg	5	0.01
	Liquid an-organic fertilizer	kg	25	0.05
	Plastic	kg	0.25	3.47E-05
Planting and Farm Maintenance input	Cocoa tree	tree	610	1.22
	Nitrogen	kg	1,875	3.75
	NPK Phosphorus	kg	1,875	3.75
	Potassium	kg	1,875	3.75
	Organic fertilizer	kg	900	1.8
	Liquid organic fertilizer	kg	36	0.072
	Herbicide	kg	32	0.064
	Fungicide	kg	15	0.03
	Insecticide	L	15	0.03
	Irrigated water	L	100,000	200
	Gasoline	L	100	0.2
Output				
	Cocoa tree	tree	605	1.21
	NPK Phonska Plastic	kg	10	0.02
	Organic fertilizer plastic	kg	3	0.006
	Liquid organic fertilizer Plastic	kg	8	0.016
	Herbicide bottle	kg	3	0.006
	Fungicide bottle	kg	1	0.002
	Insecticide bottle	kg	1	0.002
Harvesting input	Cocoa tree	tree	600	1.2
	Wet cocoa bean	kg	1,400	2.8
	Plastic bag	kg	0.5	6.94E-06
	Gasoline	L	30	0,06
Output	Wet cocoa bean	kg	1,350	2.7
	Plastic bag/polypropylene	kg	0.5	0.001
	Gasoline	L	30	0.06

Continued Table 2: Inventory data of the input and output of cocoa cultivation

Unit process	Material	Unit	Amount/6 months production	Amount/1 kg production
Transportation to fermentation Input	Wet cocoa bean	kg	1,400	2.8
	Plastic bag	kg	0.4	5.56E-06
	Gasoline	L	26	0.052
Output	Wet cocoa bean	kg	1,400	2.8
	Plastic bag /polypropylene	kg	0.4	5,56E-06
Fermentation Input	Wet cocoa bean	kg	1,400	2.8
	Wood fermentation	kg	50	0,1
	Banana leaf	L	0.2	2,78E-06
	Plastic bag	kg	0.5	6,94E-06
Output	Wet cocoa bean	kg	1,300	2.6
	Plastic bag /polypropylene	kg	0.5	6.94E-06
Drying input	Wet cocoa bean	kg	1,250	2.5
	Plastic UV	kg	0.7	9.72E-06
	Paranet mat	kg	4	0.008
	Plastic bag	kg	10	0.02
Output	Dry cocoa bean	kg	550	1.1
	Plastic bag /polypropylene	kg	18	0.036
Transportation to manufacturing	Dry cocoa bean	kg	500	1.1
	Plastic bag	kg	0.2	1
	Gasoline	kg	26	2.78E-06
Output	Dry cocoa bean	kg	500	1
	Plastic bag /polypropylene	kg	0.2	0.0004

The ISO 14040 guidelines show that there are four optional elements, namely normalization, scoring, clustering, and data quality analysis. This guide applies the results of inventory data to classify and characterize potential environmental impacts. In this context, the classification and characterization using mandatory elements are considered to be sufficient to achieve the stated objectives. According to (Armengot *et al*., 2021), in the classification stage, generating the inventory data from the calculation results is performed by multiplying the relevant emission mass value. This is achieved by the appropriate characterization factor provided by the ecoinvent 3.8 databases to produce the indicator results for inventory items. The impact category is the impact score or characterization results obtained from the sum of the indicators in each category. In this study, the characterization obtained is grouped into environmental impacts of freshwater ecotoxicity potential (FEcP), human carcinogenic toxicity (HCP), freshwater eutrophication potential (FEP), ozone depletion potential (ODP), human non-carcinogenic toxicity potential (HnCT), water scarcity (WS), terrestrial acidification potential (TAP), global warming potential (GWP), marine eutrophication (MEP), land use potential (LUP), ozone depletion potential (ODP), and mineral resources scarcity (MRS).

Study limitations

The scope of this study is restricted to North Luwu Regency, South Sulawesi Province, Indonesia. Therefore, it is not possible to generalize the results to the entire country. In this context, the expansion of the scope to include other cocoa production locations is a valuable prospect for future investigations. In this technical assessment, there are several limitations:

1. The characterization factor of the material is not found in available databases, hence, the value is adjusted by the characterization factor from the dominant constituent materials.
2. All infrastructure and equipment that supports cacao production are not included in impact calculations.
3. The transportation data used are the result of accommodation with the sharing loading method.

Table 3: Inventory data of the inputs and outputs of cocoa processing

Unit Process	Material	Unit	Amount/6 month production	Amount/1 kg production
Cleaning input	Dry cocoa bean	kg	450	0.9
	Plastic bag/polypropylene	kg	0.1	1.39E-06
Output	Dry cocoa bean	kg	450	0.9
Roasting input	Dry cocoa bean	kg	450	0.9
	LPG Dutching-Alkaline	kg	3	0.006
Output	Roasted cocoa bean	kg	449	0.898
Desheller input	Roasted cocoa bean	kg	449	0.898
	Electricity	kWh	840	1.68
	Shell/husk	kg	20	0.04
Output	Nibs	kg	429	0.858
Stonemill input	Nibs	kg	429	0.858
	Electricity	kWh	820	1.64
Output				
	Coarse pasta	kg	427	0.854
Milling input	Coarse pasta	kg	427	0.854
	Electricity	kWh	320	0.64
Output	Cocoa liquor	kg	420	0.84
Pressing input	Cocoa liquor	kg	420	0.84
	Electricity	kWh	240	0.48
	Cocoa Butter	kg	110	0.22
Output	Cake	kg	310	0.62
Dismillcake input	Cake	kg	310	0.62
	Electricity	kWh	600	1.2
Output	Cocoa powder	kg	300	0.6
Mixing input	Cocoa powder	kg	300	0.6
	Powdered milk	kg	3	0.006
	Sugar	kg	3	0.006
	Vanilla	kg	0.7	9.72E-06
	Lecithin	kg	0.5	6.94E-06
	Cashew nuts	kg	2.2	0.000169
	Dates	kg	1.2	8.61E-05
	Water	L	5.0	0.000417
	Electricity	kWh	340	0.68
Output	Brown fat	kg	70	0.14
	Chocodate paste	kg	400	0.8
Ballmill input	Chocodate paste ready to print			
	Electricity	kg	400	0.8
		kWh	100	0.8
	Chocodate paste ready to print			
Output		kg	400	0.2
Moulding input	Chocodate paste ready to print	kg	400	0.8
	electricity	kWh	100	0.2
Output	Chocodate cashew	kg	408.6	0.817
Packaging input	Chocodate cashew	kg	408,6	0.817
	Metallic paper	kg	0.001	0.000002
	Parchment paper	kg	0.01	1.39E-06
	Wire tape	kg	0.002	0.000004
	Stand pouch	kg	0.02	2.78E-06
	Plastic bag	kg	0.1	1.39E-06
	Cardboard box	kg	0.5	6.94E-06
Output	Chocodate cashew	kg	500	1

RESULTS AND DISCUSSION

The characterization results obtained in this study are presented in Table 4. In this context, the global warming potential and the land use potential are 2.092 kg CO_2-eq, 2.084 kg 1,4-DCB (Dichlorobenzene), and 1.102. The amount of square meter (m^2) of change of land cover square meter of change of land cover (m^2a crop eq).

The environmental impact is described by the relative contribution of each studied life cycle stage as shown in Fig. 4. The largest relative contribution in cocoa cultivation stage is LUP, MEP, MRS, ODP, and WS at 82%, 79.5%, 78.8%, 78%, and 77.8%, respectively. The largest and similar stages of chocodate bar processing are Marine ecotoxicity potential (MEcP) at 88%, Freshwater eutrophication potential (FEP), Ionizing radiation (IR), Human carcinogenic toxicity (HCT), and GWP at 67%. At the post-harvest stage, the

Table 4: Characterization results for 1 kg chocodate cashew production

Environmental impact category	Total impact score	Unit
Marine ecotoxicity	0.124	kg 1,4-DCB
Freshwater ecotoxicity potential	0.101	kg 1,4-DCB
Human carcinogenic toxicity potential	0.086	kg 1,4-DCB
Human non-carcinogenic toxicity potential	2.084	kg 1,4-DCB
Terrestrial ecotoxicity	6.812	kg 1,4-DCB
Freshwater eutrophication potential	0.001	kg P eq
Fossil resource scarcity	0.467	kg oil eq
Ozone formation, terrestrial ecosystem	6.812	kg NOx eq
Ionizing radiation	0.204	kBq Co-60 eq
Ozone formation	0.007	kg NOx eq
Water scarcity potential	0.093	M^3
Terrestrial acidification potential	0.012	kg SO_2 eq
Global warming potential	2.092	kg CO_2 eq
Fine particulate matter formation	0.005	kg $PM_{2.5}$ eq
Marine eutrophication potential	0.001	kg N eq
Land use potential	1.102	m^2a crop eq
Stratospheric ozone depletion potential	7.10454E-06	kg CFC11 eq
Mineral resource scarcity potential	0.001	kg Cu eq

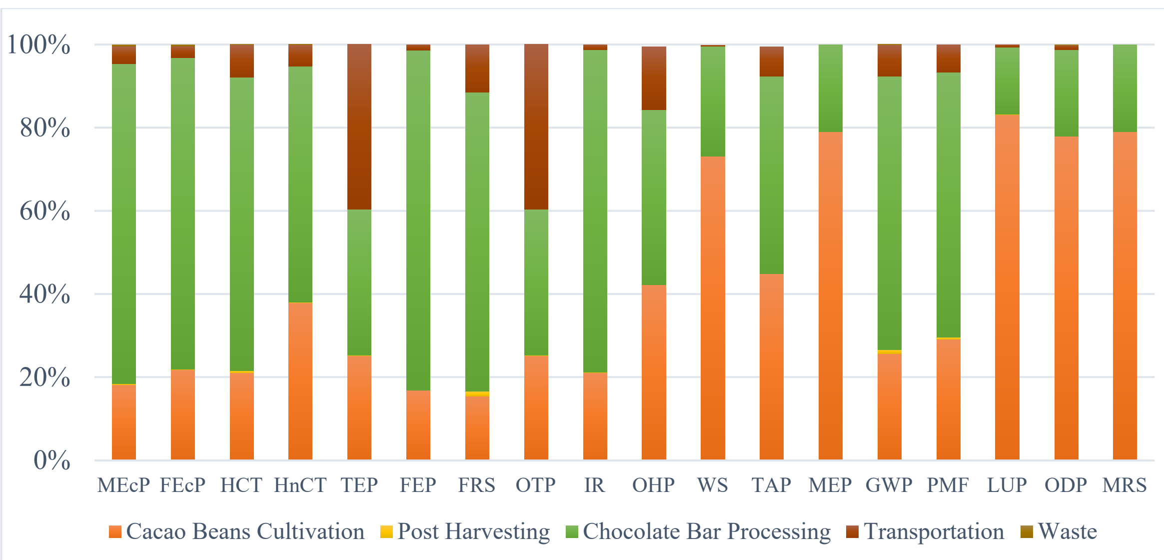

Fig. 4: Contribution by different production stages to the overall environmental impact score

scarcity of fossil resources scarcity (FRS) is very small, and at the transportation stage, the biggest source of environmental impacts is the formation of ozone, terrestrial ecosystems, and Terrestrial ecotoxicity potential (TEP) at 38%.

LCA can present a more comprehensive picture of the environmental impact of a product or activity through the results of combining the weighing and normalization stages. This enables decision-makers to prioritize and direct improvement efforts or mitigation stages to address the most significant environmental impacts to realize more sustainable products or activities. According to Fig. 5, the impact assessment of the life cycle normalization of cocoa production with the largest environmental impact is MEcP, followed by FEcP, with LUP the third lowest after ODP.

Cocoa cultivation stage

The stages of cocoa bean cultivation consist of land preparation, nursery, garden planting and maintenance, harvesting, and post-harvesting. Fig. 4 shows that the environmental impacts have the highest average distribution at cocoa bean cultivation stage, particularly LUP, MEP, MRS, ODP, and WS is 77–82 %, while at the very small post-harvesting stage the impacts are due to from FRS. The results of the analysis indicate that the highest environmental impact is at cocoa cultivation stage, namely LUP at 82%, where land use with one type of NPK fertilizer is the main cause of the environmental impact at the production stage of 0.215 kg CO_2 eq or 10.27%. The use of NPK fertilizer at the stage of maintaining the garden contains several nutrients needed by plants with high levels of N, P, and K (inorganic fertilizers). This is achieved by physically mixing three quality raw materials which include urea granules, diammonium phosphate granules (DAP)/$(NH_4)_2HPO_4$, and Potassium chloride (KCL) flakes (Albaugh *et al.*, 2021). The global warming potential is due to the fertilization process as the main concern regarding environmental impacts. In this context, phosphate emission is the main contributor to heavy metals from the production of P contained in NPK fertilizer at the cultivation stage. Therefore, improvement measures must be focused on reducing the use of fertilizer to design a sustainable cocoa industry (Suh and Molua, 2022). These measures should be implemented with minimal resource input to preserve limited resources, and manage waste, water, and soil pollution (Armengot *et al.*, 2021; Ratnawati *et al.*, 2023). Other beneficial approaches include using compost, avoiding the use of chemicals, enhancing integrated pest management through the right plants, and implementing efficient

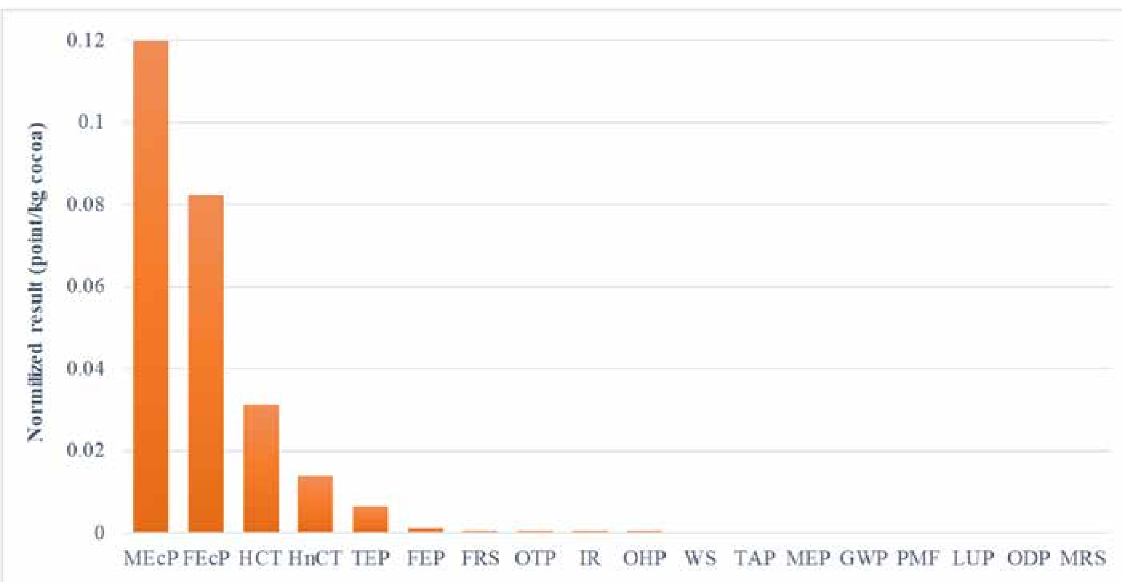

Fig. 5: Life cycle impact assessment normalization of cocoa production

irrigation and xeriscaping. This effort is closely related to the technical ability of farmers in adopting GAP to provide farmers with an understanding of the dependence of cocoa plant on climatic elements, such as rainfall fluctuations, availability of quality infrastructure, soil management to reduce land degradation, nutrient balance, resource capacity to access environmentally friendly technology (Idawati *et al*., 2023). The use of agricultural machinery and equipment in cocoa production remains quite rudimentary and labor-intensive. This is attributed to the small-scale nature of the plantations, typically ranging from 1 to 2 ha/farmer, and the heavy reliance on rainfall for production. The drying of cocoa bean is managed at the Masagena Farmers' Cooperative, using a basic greenhouse system where sunlight serves as the primary source for the drying process. Therefore, improvement measures must be focused on constructive and vegetative methods through government, private, and community policies as well as land use depending on suitability and cost requirements. These actions should be regulated by spatial policies and market forces through landscape configuration, agricultural location, and intensification of practices by reducing the use of chemicals and introducing organic fertilizers (Mugiyo *et al*., 2021). An essential impact during cocoa cultivation stage is the substantial generation of solid waste post-harvesting. Specifically, the accumulation of cocoa pod shell in large quantities merits significant attention and consideration (Walkiewicz *et al*., 2021). Approximately 67% of the weight of fully ripe cocoa pod is composed of the fruit skin. Among the environmental impacts, cocoa pod shell waste is not assessable through LCA method. Therefore, it becomes important to manage this waste by implementing processes such as garden sanitation, as recommended in GAP, in line with the principles of sustainable agriculture. Furthermore, solid cocoa pod shell waste can be converted into a liquid form, which serves as valuable compost and even be commercialized. An innovative application for cocoa pod shell waste includes its transformation into charcoal briquettes, presenting a relatively recent alternative energy source at the household level. This multifaceted approach addresses waste management and contributes to sustainable practices as well as alternative energy solutions (Duan *et al*., 2020). Charcoal briquettes are produced from burning cocoa pod shell and can be an alternative energy source produced on a household scale. These materials can be a source of C and N used by microbes in the soil through the decomposition process during the rainy season to reduce CO_2 emissions. In this context, land use and the presence of drainage channels cause an increase in CO_2 emissions due to a decrease in the groundwater level. Therefore, increased oxygen levels accelerate the process of decomposition of organic matter in the soil. This effect occurs when the process of litter by soil microorganisms decomposes and can become a source of organic matter in the soil (Nuriana and Anisa, 2014). This method should be followed by more farmers to minimize the dependence on chemical fertilizer. Meanwhile, important environmental issues are land degradation and loss of biodiversity due to excessive use of fertilizer by farmers. The monoculture system applied with the same cocoa clones reduces or eliminates the diversity of natural flora and fauna as an effort to balance the ecosystem through the application of agroforestry system (Akrofi-Atitianti *et al*., 2018). This system establishes native vegetation such as forests by combining plants with plantations and replacing chemical pesticides with more environmentally friendly biopesticides.

Cocoa processing stage

Cocoa or chocodate bar processing stage has the most significant environmental impact on MEcP, FEcP, WS, MEP, and LUP. Furthermore, it has the largest contribution to FEP and FEcP at 27.21% and 24.78%, and in electricity usage which is the main cause of the environmental burden at 0.438 kg CO_2 eq, or 20.97%. Electricity usage was identified as the main environmental impact contributor at PT Chalodo Sibali Resoe Industry Ltd., in the manufacturing of chocodate cashew (Perez *et al*., 2021). Therefore, it is important to enhance the efficacy of electrical energy use in the energy-intensive apparatus. In this context, there is a suggestion to substitute the utilization of electricity with natural gas due to the recognized comparative environmental friendliness. The derivative of the processing sector, namely cocoa shell/husk, has transformed in its classification from solid waste to a marketable commodity, after processing and packaging procedures (Barišić *et al*., 2020).

Marketing distribution stage

The marketing distribution and transportation stage has an environmental impact with a low contribution to the category. The effects of transportation on consumers consist of FEP, ODP, HnCT, TAP, and GWP, and the biggest impact on waste is HCT. The transportation stage includes transportation to consumers as the most relatively environmentally friendly because the category of impact is not considered significant. This is because the marketing process outside Masamba City has not been optimal and the production is on a small scale.

Improvement analysis

Modifications are offered as models and improvement options for reducing potential environmental impacts. The base case of cocoa cultivation, cocoa processing, and transportation is in North Luwu Regency, and the proposed improvement options are presented in Table 5. From the results of the environmental impact analysis of the three stages, the biggest impacts are GWP and LUP. Therefore, improvement options can be recommended using the improvement analysis, to determine the calculation of different scenarios by analyzing the effect of input parameters on the LCIA output. The sensitivity analysis for environmental impacts was applied for the use of fertilizers at cocoa cultivation stage.

The impact of changing scenarios on GWP and LUP is presented in Fig. 6. The results show that by changing the input of Phonska NPK fertilizer (Inorganic fertilizer) to be more efficient, GWP decreases to 1.745 kg CO_2 eq. Changes in GWP through the level of fertilizer input in the design of an information system have a more significant effect on the results of the environmental impact characterization compared to the base case using NPK fertilizer. Therefore, a high percentage of NPK affects the GWP impact through N_2O emissions compared to synthetic or organic fertilizer, manure, plant straw, and waste output. In this context, the use of high chemical inputs is significant for a high GWP. The analysis shows a significant issue with fertilizer usage, with a rate of 3.75/kg of cocoa. Therefore, fertilizer use needs to be reduced to 1.25/kg which leads to a reduction in GWP from 2.09 to 1.745 kg CO_2-eq.

The use of compound (NPK) fertilizer on cocoa provides a very complex response and requires an

Table 5: Proposed improvement options

Life cycle stage	Base case	Proposed improvement options
Cocoa production	NPK fertilizer (compound fertilizers) based on petrochemicals	1. Reduction of petrochemical-based NPK fertilizer (compound fertilizer) 2. The use of bio-based NPK fertilizer (compound fertilizer)

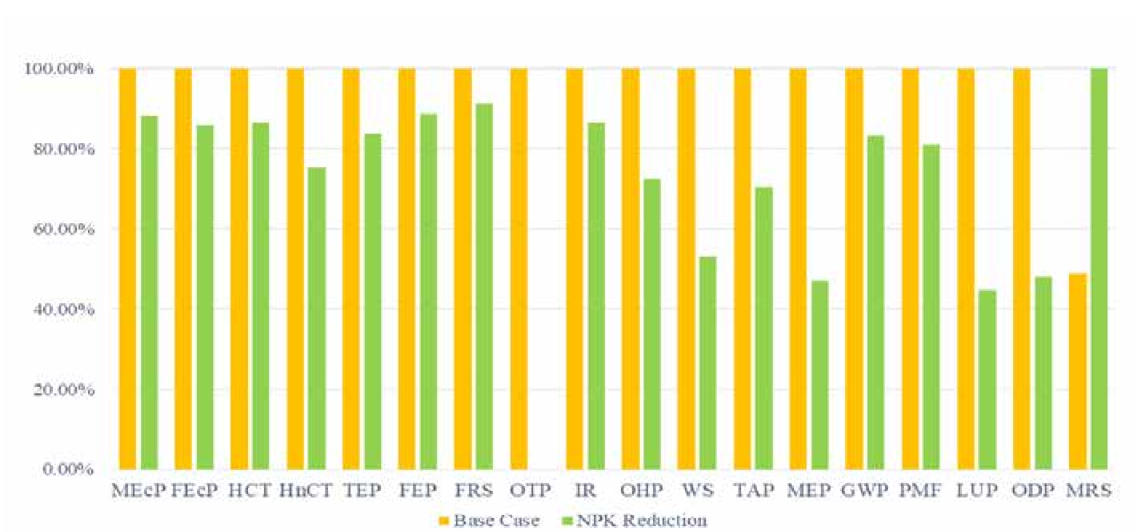

Fig. 6: Comparison of potential environmental impacts between the base case using NPK fertilization and the assumed case of reducing NPK fertilization for cocoa production stage.

optimal fertilization strategy to transmit various land suitability criteria to eliminate cocoa. The results of (Singh *et al*., 2021; Amponsah-Doku *et al*., 2022) provide information that variations in response to the use of cocoa fertilizer are caused by rainfall, slope, and soil conditions, composition, type, and time of fertilizer application. Therefore, it is necessary to recommend the right type of fertilizer, dose, and time to increase the productivity, and longevity of cocoa plants, reduce ecological restoration of the soil, and increase the cost-benefit ratio of fertilization. According to Doe *et al*., (2022), there has been ecological restoration of cocoa agricultural soils, specifically in organic carbon (OC), pH, iron (Fe), and Aluminium (Al). In this context, it is necessary to improve OC and soil pH conditions while trying to adjust Fe and Al levels to Sustainable cocoa farming in Ghana. The fertilization mechanism evaluated constitutes a significant concern related GWP. Furthermore, this study assessed the emissions resulting from the decomposition of cocoa pod shell when incorporated into the soil as part of the composting process. The results indicate that the release of CH_4 and N_2O in the biodegradation process depended on the specific composting technology used and the duration of time. Approximately 8.50 kg of cocoa pod shell yield 1 kg of cocoa. The residual matter remaining in the soil has the potential to generate 2.60 kg CH_4 and 4 gr N_2O, equivalent to 7.69 kg CO_2 eq. Furthermore, the process of composting the waste resulted in the release of 34 grams of CH_4 and 2.55 g of N_2O. These emissions together equal a contribution of 1.61 kg CO_2 eq. In this context, the approach has the potential to decrease the carbon footprint (CF) associated with cocoa production by 6 kg CO_2 eq. The process of immersing cocoa pod shell into the soil has a significant effect on the CF due to the emissions from the anaerobic breakdown of organic waste. These account for approximately 85% of the total emissions observed in the two technologies examined. The result supports the need for action in making decisions regarding the mitigation of GHG emissions. Organic fertilizer is potential viable solution for minimizing the negative environmental impacts linked to GAP (Nemecek *et al*., 2011). The high impact besides the GWP is the LUP of 1.102, decreasing to 0.492 m^2a crop eq from the basic case applied by farmers (Fig. 6). Currently, LUP is the leading cause of biodiversity decline worldwide. Various land use categories have been evaluated for the effects of change, and different intensities due to sustainability of food, livestock, and processed wood production (Accatino *et al*., 2019). According to (Alkemade *et al*. 2009); Bellard *et al*. (2012), the impact of global warming shows a direct correlation with the increase in sea surface temperatures, which can hinder the proliferation of phytoplankton and affect mean species abundance (MSA) as well as the native species in the future. This phenomenon is anticipated to yield varying responses to escalating global average temperatures, exerting differential effects on biomes and species groups across distinct regions. The result indicate that environmental impacts are vulnerable to changes in the amount of material inputs and outputs. In this context, the use of NPK fertilizer is associated with a substantial environmental impact, with the most consequence being a significant escalation in the impact of climate change on MSA of indigenous species. This outcome is anticipated to yield distinct responses to the rising global average temperatures within various biomes and among different species groups across diverse regions. The results indicate that environmental impacts are vulnerable to changes in inputs and outputs. Agricultural landscapes in tropical drylands aim to create future groundwater and food security, as well as energy availability through land conservation management. This include restoration of degraded ecosystems, increased agricultural diversification, and individual initiatives at larger spatial scales (Soulsbury *et al*., 2021). In this context, it is necessary to apply a sustainable cocoa agroforestry landscape design with an energy-saving concept in a spatial and regional arrangement with a pattern of placement of trees and air spaces. This sustainable landscape should be developed with soil management strategies such as compost production and plantation waste handling to maintain and enhance healthy soil, support the diversity of soil life, as well as integrate renewable energy technologies (Santeramo and Lamonaca, 2021). Despite the inherent constraints associated with the use of LCA method in developing nations, the valuable environmental insights provided should be considered. The methods enable the identification of important environmental concerns and can facilitate the implementation of sustainable solutions. This case study has proven successful in measuring and identifying several important impacts related to the upstream-to-downstream cocoa production process (Sasongko *et al*., 2018). Sustainable cocoa production, commencing at the upstream stage, includes a series of measures. These initiatives begin with land preparation and extend to the reduction of bio-based inorganic fertilizers and pesticides. Furthermore, the adoption of cocoa agroforestry practices, which integrate productive shade crops, plays an important role. The sustainable practices enhance both cocoa cultivation and provide additional income streams for farmers. Furthermore, cocoa industry can consider using a full electricity network with the use of photovoltaics (PV) as an energy source (Rosmeika *et al*., 2023). The use of PV as an energy source in electric vehicles that use a full network has reduced the environmental impact significant to GWP, FEP, ODP, POFP, and TAP. A study conducted in Columbia made a significant contribution to the environmental impact caused by the assessment of the life cycle of cocoa production. In this context, the production with a composting system carried out in handling cocoa pod shell waste by immersing in the soil or rotting outside can be a source of emissions. However, these emissions cannot be predicted precisely because of the different management systems for cocoa plantations. The difference depends on the treatment of farmers based on crop needs, number of family dependents, soil conditions, type and dosage of chemical fertilizers, need for future demand for food products, as well as other considerations such as energy consumption from CO_2 emissions (Cheng *et al*., 2011). According to (Ortiz-Rodríguez *et al*., 2016), the potential for global warming emissions from cocoa plantations in Colombia produces 2–4 kg CO_2 eq/kg cocoa. Therefore, a way to achieve a constant level of reduction in N_2O emissions is to maintain the use of balanced fertilization doses. The application of agroforestry landscape systems and conventional management has an environmental impact measured in GWP kg CO_2-eq/ kg of the same magnitude, even though the impact may be lower (Schreefel *et al*., 2020). (Asitoakor *et al*. 2022; Sassen *et al*., 2022) show that the agroforestry system is an effort to conserve biodiversity and provide ecosystem services since P is available in the soil around cocoa plants. This level of productivity can be attained when shade trees are incorporated, resulting in higher yields compared to cocoa plant cultivated without such trees. A sustainable approach to food systems, which emphasizes the augmentation of production and consumption, must be obtained with the ecological surroundings. This includes the establishment of a circular food system, with the overarching goal of advancing global food security by minimizing external inputs carrying adverse environmental impacts. In this context, this current study aims to protect natural resources by closing the cycle of nutrients and carbon in circular food systems (Sasongko and Pertiwi, 2023). Regenerative agriculture is an approach that promotes soil and water conservation by applying cocoa agroforestry landscapes. This improves the quality management of agricultural land by implementing rehabilitation and revitalization of the entire ecosystem and contributing to various ecosystem services. The concept of cocoa agroforestry landscapes, which includes mixed cropping systems in a single land area is a significant catalyst for global environmental change. This approach adds economic value and bears responsibility for a substantial portion of total greenhouse gas emissions. The outcomes are achieved through the promotion of agroecosystem diversity and the integration of comprehensive environmental management practices (Sgroi, 2022). According to (Schroth *et al*., 2016), a mixed cropping system contains a variety of forestry crops (teak, pepper, dogfruit, cloves), fruits (durian, rambutan, mango, etc.), short-term crops (banana, papaya, cassava, corn, patchouli), medicinal plants, and farm animals such as chickens. This system includes cocoa land with a planting density of 4×4 m^2 which provides many ecosystem benefits, such as climate mitigation, carbon sequestration, biodiversity, nutrient cycling, and maintenance of soil fertility. Cocoa agroforestry is a sustainable forest intensification and protection policy implemented in the plantation landscapes as the key to environmental sustainability. Cocoa agroforestry with Melina trees (*Gmelina arborea*) is an alternative approach when there is a decrease in cocoa yields due to plant age. This reduces the impact of agricultural production systems, increases farmer productivity and income, reduces CO_2 emissions, and increases carbon sequestration (Ballesteros-Possú *et al*., 2022; Udawatta and Jose, 2011). Some relevant environmental impacts due to cocoa production include GWP and LUP, such as loss of biodiversity and the need for soil management due to the excessive use of chemical fertilization (Gaidajis and Kakanis, 2020; Rahmah *et al*., 2022).

CONCLUSIONS

In conclusion, fertilizer use during the cultivation stage of chocodate cashew production was reported to directly impact GHG emissions. This made a significant contribution to MEP due to the N and P derivatives contained in NPK fertilizer. LCA results focused on considering environmental elements and consequences as a tool used to plan sustainable development, explaining the principles, methods, and benefits to policymakers and decision-makers. In this context, this study represented one of LCA analysis conducted in cocoa industry, particularly in South Sulawesi. The objective of implementing the method was to measure the potential environmental impacts of cocoa cashew produced by PT Chalodo Sibali Resoe Industry. Furtehrmore, LCA was carried out to build a scientific basis for analyzing improvements in production sustainability. An assessment was conducted on the life cycle sustainability of cocoa farming by applying compound fertilizer at various stages of chocodate cashew production process. The results showed that reducing the use of chemical fertilizers was better for the environment to reduce the categories of impacts assessed. In this context, the total potential global warming impact from chocodate cashew production was equivalent to 2,092 kg CO_2. The main contributors to environmental pollution were electricity and fertilizer which contributed 0.438 kg and 0.215 kg CO_2-eq at 20.97% and 10.27%, respectively. The largest relative contribution at cocoa cultivation stage was LUP at 82%, followed by MEP, MRS, ODP, and WS at 80%. Chocodate bar processing stages are MEcP at 88%, FEP, IR, HCT, and GWP at 67%. At the post-harvest stage, FRS was very small but at the transportation stage, the largest impact contribution was ozone formation, land ecosystems, and TEP potential at 38%. Based on input in sequence, electricity and fertilizer contributed 0.438 kg CO_2-eq (20.97%) and 0.2148 kg CO_2-eq at 20.97% and 10.27%, respectively.

RECOMMENDATIONS

North Luwu Regency = is one of the largest cocoa producers in Indonesia. For the development of internationally competitive and sustainable products, it is important to understand the importance of industrial development, focusing on economic and social aspects and their impact on the environment. The following recommendations are possible:

1. Environmentally friendly: The improvement analysis shows that by reducing the application of inorganic fertilizer, specifically by decreasing the usage of potassium nitrogen phosphate from 3.75 to 1.25/kg cocoa, or by transitioning to vegetable-based potassium nitrogen phosphate at a rate of 2.5/kg, it is possible to significantly mitigate the environmental impact. This reduction amounts to approximately 16%, leading to a decrease in the global warming potential from 2,092 to 1,745 kg CO_2-eq.
2. Reducing the use of NPK fertilizer and replacing with environmentally friendly organic fertilizer. Recommended organic fertilizer includes compost, bokasi, petrogenic, and several liquid organic fertilizers for cocoa plant used to reduce chemical fertilizers. Furthermore, there are recommendations for fertilizer other than Phonska NPK, namely Rainbow NPK and the need to use lime to reduce the soil dryness.
3. Economically: The augmentation of cocoa agricultural production can be achieved by adopting agricultural practices rooted in regenerative and circular principles. This includes the provision of organic inputs and the integration of diverse varieties of cocoa clones in a single cocoa agroforestry landscape system.
4. Socially: The capacity of farmers can be increased through counseling and training in the manufacture and use of organic fertilizer.
5. Science and technology: The data collection can be used for comparison in future studies. Further analysis is needed regarding alternative electricity sources for cocoa industry, ranging from fossil fuels to new renewable energy sources such as photovoltaic solar cells.

AUTHOR CONTRIBUTIONS

I. Idawati performed the literature analysis, experimental activities, writing of the manuscript, and analyzed the manuscript critically for significant intellectual content. N.A. Sasongko performed the literature analysis, data, and information collection, writing of the manuscript, and analyzed the manuscript critically for significant intellectual content. A.D. Santoso performed the data and information collection, data handling, validation, and LCA data analysis. W.S. Agam performed the experimental activities, data handling, validation, and LCA data analysis. H. Apriyanto performed the experimental activities, writing of the manuscript, and validation. A. Boceng performed the experimental activities, writing of the manuscript, and administration.

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CONFLICT OF INTEREST

The author declares no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and falsification, double publication and submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
Al	Aluminium
ATP	Acidification terrestrial potential
CO_2	Carbon dioxide
CF	Carbon footprint
CFC	Chlorofluorocarbon
CH_4	Methane
DAP	Diammonium phosphate
Eq	Equivalent
Fe	Iron
FEP	Freshwater eutrophication potential
FEcP	Freshwater ecotoxicity potential
FRS	Fossil resources scarcity
GAP	Good agricultural practice
GHG	Greenhouse gas
GWP	Global warming potential
ha	Hectare
HCT	Human carcinogenic toxicity
HnCT	Human non-carcinogenic toxicity potential
IR	Ionizing radiation
ISO	International organization for standardization
KCl	Potassium chloride
kg	Kilogram
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
LCI	Life cycle inventory
LUP	Land use potential
Ltd	Limited
m^2	Square meter
m^2a *crop eq*	Square meter of change of land cover
MEcP	Marine ecotoxicity potential
MSA	mean species abundance

MEP	Marine eutrophication
MRS	Mineral resources scarcity
MSME	Micro, small and medium-sized enterprises
N_2O	Nitrous oxide
$(NH_4)_2HPO_4$	Diammonium phosphate granules
NPK	Nitrogen phosphate kalium
OC	Organic carbon
ODP	Ozone depletion potential
pH	Potential hydrogen
$PM_{2.5}$	Fine particulate matter
PPO	Plant pest organisms
PV	Photovoltaic
PMF	Particulate matter formation
PTCSR	Limited company chalodo sibali resoe
SFITAL	Sustainable farming in tropical Asian landscapes
TAP	Terrestrial acidification potential
TEP	Terrestrial ecotoxicity potential
USD	United States Dollar
UV	Ultraviolet
WS	Water scarcity

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