Agronomy Research **21**(S1), 357–375, 2023
https://doi.org/10.15159/AR.23.010

Life cycle assessment of shallot farming in Food Estate Hutajulu, North Sumatra, Indonesia

R. Sigalingging[1,2,*], J. Simanihuruk[1], N.S. Vinolina[3], L.A. Harahap[1] and C. Sigalingging[4]

[1]Universitas Sumatera Utara, Faculty of Agriculture, Department of Agricultural and Biosystems Engineering, Prof. A. Sofyan No.3, 20155, Indonesia
[2]Universitas Sumatera Utara, Faculty of Agriculture, Laboratory of Energy and Electrification, Prof. A. Sofyan No.3, 20155, Indonesia
[3]Universitas Sumatera Utara, Faculty of Agriculture, Department of Agrotechnology, Prof. A. Sofyan No.3, 20155, Indonesia
[4]Universitas Nahdlatul Ulama Sumatera Utara, Faculty of Agriculture, Department of Food Science and Technology, Jl. H. A. Manaf Lubis No. 2 Helvetia, Medan, Indonesia
[*]Correspondence: riswanti@usu.ac.id

Received: December 10th, 2022; Accepted: March 19th, 2023; Published: April 3rd, 2023

Abstract. Food Estate is a government program as a solution to meeting food demand. However, in order to meet food needs, environmental impacts must be considered. The study objective was to investigate the impacts of shallot production in Food Estate Hutajulu, Indonesia. The study was conducted with the first stage determining the functional unit, namely an area of 0.2 hectares with a gate-to-gate scope. The second is the inventory data analysis by grouping the categories of nursery, tillage, maintenance, harvesting, and transportation. The third is life cycle impact assessment (LCIA) according to the ISO 14044 standard. Every data obtained from each process was processed using the software OpenLCA 1.11.0; the following is the workflow and use of the software. Processes were made based on the five categories of data (soil processing, planting, maintenance, harvesting and transportation), which had been determined to be connected to flow. The product system was adjusted according to the data in each process and then calculated, and the results of calculation data and graph models appear from each processed data category. Fourth is the interpretation that considers the highest environmental impact, namely acidification in the transportation process of 1.8974 kg SO_2 eq, global warming potential in the transportation process of 415.3188 kg CO_2 eq, eutrophication in the transportation process of 0.4364 kg PO_4 eq, and human toxicity in the maintenance process of 1,409.07377 kg 1,4-DB eq. To minimize the impact on subsequent production, reducing diesel fuel, chemical pesticides and chemical fertilizers are recommended.

Key words: crops cultivation, environmental impact, global warming, LCA, sustainability.

INTRODUCTION

Population growth in Indonesia is increasing. Indonesia's population is expected to continue to increase to 319 million in 2045 (BPS & Bapenas, 2018). As the population grows, food security is expected to be maintained and can meet demand. Existing resources cannot meet current human needs, so advanced agricultural approaches have been developed to meet this urgent need (Mousavi et al., 2022). Various government programs have been implemented to achieve food security. One is the Food Estate program targeted at Central Kalimantan, North Sumatra, South Sumatra, East Nusa Tenggara, and Papua.

Food Estate is a government program that aims to maintain food security during a crisis such as the current Covid-19 pandemic. This program is promoted in specific locations that are considered to have adequate natural resources with different commodities. Based on data from the Ministry of Public Works and Public Housing (PUPR), Indonesia, there are three Food Estate locations in North Sumatra with a total land area of 785 hectares, namely Hutajulu Village, 120.5 hectares, Ria-Ria Village, 411.5 hectares, and Parsingguran Village 253 hectares. In 2021, the government planned to plant shallots (*Allium ascalonicum* L.) and Granola potatoes with an area of 8.8 ha (for shallots) and 7.7 ha (for Granola potatoes), respectively, as a digital farming trial program for Food Estate in Hutajulu Village. Shallots and potatoes, as selected commodities in this Food Estate, generally require specific conditions in the cultivation process. Shallots are one horticultural crop commodity used as a cooking ingredient with high economic value (Prasetyowati et al., 2021). The onion plant (*Allium ascalonicum* L.) is a type of annual plant that belongs to the Liliaceae family. Some shallot varieties in the lowlands have a relatively short lifespan of 55–70 days, depending on the variety and growing season (Baluwo et al., 2021).

The Food Estate program with a digital farming system is expected to achieve maximum total production with maintained commodity quality. This is because all production processes and parameters are controlled in a digital farming system so plants can grow at optimum conditions. Technologies used in intelligent agriculture include liquid fertilizer and pesticide spraying drones, surveillance drones, and soil and weather sensors. Precision Farming does farming practices related to growing crops and raising livestock more accurately and in control. The system can be divided into data collection, data analysis, managerial decisions and variable-rate applications (Cambouris et al., 2014; Balafoutis et al., 2017).

On the other hand, industrialization poses energy unsustainability issues, especially for fossil fuels, and poses severe challenges to food production. Studies have reported the impact of extreme weather events on agricultural production and the application of innovative management strategies to reduce environmental emissions from grain, cash, corn and cotton production in Pakistan (Abbas et al., 2021; Elahi et al., 2022a; Elahi et al., 2022b; Abbas et al., 2022a, 2022b). Improving energy efficiency helps reduce severe environmental impacts, and proper use of energy in agriculture and nurseries leads to sustainable production, cost efficiency and slowing the depletion of fossil fuel sources while preventing air pollution (Karami et al., 2021; Tatli et al., 2021; Elahi & Khalid, 2022; Parhizi et al., 2022). A 5–100% reduction in chemical fertilizers will reduce the environmental impact by 4.38–87.58% and 2.16–43.30%, respectively, on aquatic acidification and global warming in corn production (Abbas et al., 2020; Abbas et al., 2021). Improved agricultural management practices, production methods, and resource conservation measures through expansion activities are needed to improve energy efficiency. Targeted energy use and replacing diesel with green power can reduce environmental emissions and wasteful use of non-renewable resources.

Farmer education, farming experience, and well-controlled temperature and ventilation systems have significantly improved the energy performance of poultry farms (Elahi et al., 2022c). The agricultural environment structure analysis requires a thorough understanding of energy consumption behaviour and greenhouse gas emissions (GHGs) in crop production. Discharging numerous contaminants with detrimental environmental impacts is one of the drawbacks of considering agriculture inputs (Reichmann & Sala, 2014; Huang et al., 2016; Yan et al., 2019).

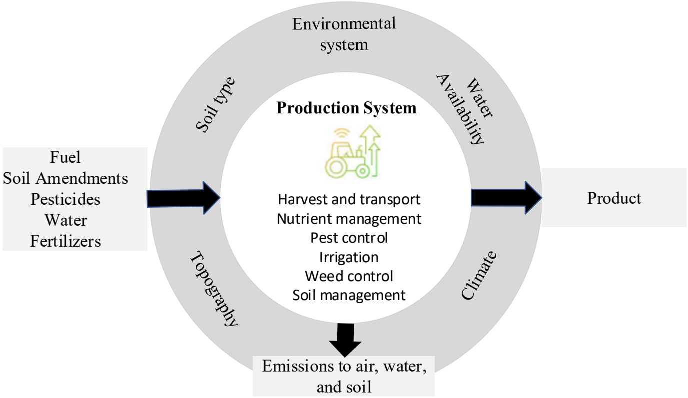

Figure 1. Agricultural life cycle components and flows between environment and production systems.

Life Cycle Assessment (LCA) is a tool used by the International Organization for Standardization (ISO) to analyze a product's potential environmental impact. It examines the entire life cycle of a product, from sourcing and production to product use, packaging, and recycling or final disposal, for components of the agricultural life cycle and the flow between the environment and the production system, as shown in Fig. 1 (Cambouris et al., 2014). In addition, it is intended to evaluate the effects of greenhouse gas emissions on the natural environment. An LCA, also known as a life cycle assessment, is a method of analysis that considers all of the resources related to the inputs and outputs of a production system. This method can also analyze greenhouse gas emissions and other environmental factors, such as acidification, eutrophication, and ecotoxicity. It can analyze and lessen the related environmental problems that result from a particular process or activity. It possesses many tactics that can set it apart from other approaches, such as modelling. The LCA process adheres to the standards produced between 1997 and 2006, beginning with ISO 14040 and going up to ISO 14044. (Hammond & Jones, 2008). The operational stage is comprised of the following four primary steps: defining the goals and scope of the project; doing a Life Cycle Inventory (LCI); performing a Life Cycle Impact Assessment (LCIA); and interpreting the results of the LCIA (Fig. 2) (Rabl & Spadora, 2006; Greenhut et al., 2013; Rahman et al., 2019; Morandini et al., 2020; Sillero et al., 2021).

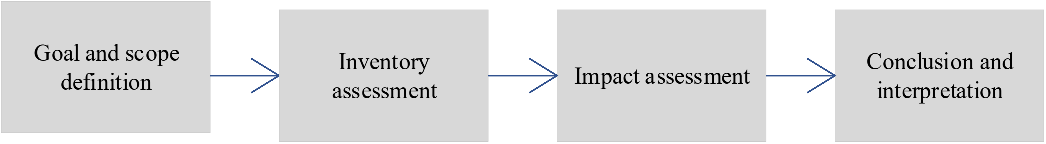

Figure 2. Components of Life Cycle Assessment (The four main components of an LCA are often interdependent, as the outcome of one component will inform how the other components are accomplished).

The agricultural sector is responsible for producing a variety of commodities and services; nevertheless, the industry's expansion has been significantly limited by the paradox of poor land productivity and high population density. Large-scale, high-intensity farming that uses a high input of chemical fertilizers, pesticides, and agricultural film has resulted in negative environmental repercussions, such as damage to natural resources, decreased land productivity, the rapid spread of pests and diseases, and a decline in biodiversity. These effects include harm to natural resources; decreased land productivity; the rapid spread of pests and diseases; and declining biodiversity (Tilman et al., 2001; Tilman et al., 2006; Fan et al., 2022). Operations related to agriculture, forestry, and other land uses contributed 23% of the total net anthropogenic emissions of greenhouse gases (GHGs), including 13% of the world's carbon dioxide (CO_2) emissions, 44% of the world's methane (CH_4) emissions, and 81% of the world's nitrous oxide (N_2O) emissions (IPCC, 2019). It is necessary to undertake a Life Cycle Assessment (LCA) to help farmers and policymakers understand the total environmental impact of agricultural production systems to promote green and low-carbon development of agriculture. This study used this tool opens up new opportunities for 'green marketing' to better use energy, equipment and agrochemical resources to expand land through digital farming systems in Indonesia, especially food estates in North Sumatra. It can even reduce the overall cost of growing shallots in future.

MATERIALS AND METHODS

Life Cycle Assessment (LCA) is a process that evaluates a product's or service's environmental impacts throughout all stages of its life. It is standardized by international regulations ISO 14040:2006 and ISO 14044:2006. The methodology used throughout this study followed the guideline of ISO 14044 (2006). Key features include the use of functional units, the flexibility of methods to implement the process, and the product system, which can be divided into unit processes linked to one another. A specified unit process of a product system defined based on criteria is called a system boundary (Fig. 3).

Materials

The materials used in this study were data and information obtained from the Food Estate Hutajulu for four months, from seedling to harvesting, on aspects of the volume of water use, electrical energy, chemical fertilizer energy, transportation energy, fuel energy, irrigation energy and human labour. The tools used were Personal Computer (PC) with Intel(R) Core(TM) i7-6500U CPU @ 2.50GHz 2.60 GHz with 8.00 GB and 64-bit operating system, x64-based processor as hardware; OpenLCA 1.11.0 as the official life cycle assessment data processing application; elcd_3_2_greendelta_v2_18 and usda_190109_2 as databases; and openlca_lcia_v2_0_5_20200610 as the life cycle impact assessment database.

OpenLCA 1.11.0 is a software used to analyze the stages of research related to life cycle assessment (LCA). There are three application flow types: environmental life to analyze energy in and out of the environment; product flows, whose purpose is to analyze the energy exchanged during the process production takes place; and waste flows. Following are parts of the OpenLCA 1.11.0 software according to GreenDelta (2016): 1) Flows are overall products, materials, or energy as input and output in the product system analysis. There are three types of flows in OpenLCA 1.11.0: a. elementary flows: material or energy from the incoming environment and exit the product process, b. product flows material or energy that undergoes changes or is exchanged during product processing, c. waste flows: material or energy leaving or leaving the product process. 2) Databases use of OpenLCA 1.11.0 requires a database for operation. The database itself is a data assortment matters relating to the production process. 3) Processes are activities that transform inputs into outputs determined based on flow as a quantitative reference.

Methods

Data were collected from the field of 0.2 ha by investigating and measuring included crop type, sowing date, the number of seeds used and variety of cultivation, type and rate of fertilizers used, number of pesticides and fungicides used, fuel consumption and machinery used and amount of physical work for crop period. These energy used were determined according to Sigalingging et al., 2023 and also using the energy coefficient as shown in Table 1.

Table 1. The energy equivalent coefficient on shallot cultivation

		Energy coefficient (MJ per unit)	Unit	Reference
	A. Input			
1	Mechanization			
	Tractor	9–10	kg year^{-1}	Kitani, 1999
2	Fertilizer			
	Nitrogen (N)	78.1	kg	Kitani, 1999
	Phosphate (P_2O_5)	17.4	kg	Kitani, 1999
	Potassium (K_2O)	13.7	kg	Kitani, 1999
3	Pesticides	120	kg	Mohammadi et al., 2008
4	Electricity	12	kWh	Elhami, 2019
5	Manure	0.3	kg	Esengun et al., 2007; Naderi et al., 2019
6	Transports	1.6–4.5	km	Fluck & Baird, 1980
7	Irrigation	0.63	m^3	Yaldiz et al., 1993
	B. Output			
	Shallot	1.85	kg	Kitani, 1999; Allali et al., 2017; Esmaeilzadeh et al., 2020

Fuel consumption was obtained using the Full to Full method to determine how many litres are spent cultivating the land or carrying out other processes with agricultural machines. The Full to Full method was applied before the engine runs, the engine oil tank was filled, and then the engine was run until the processing or process wanted to run entirely. When finished, the tank was again filled with fuel while measuring how many litres were used up. As long as the agricultural machinery is operating in the field, the operating time is calculated, and the data is then used for the operator's calorie calculation.

Some supporting data are needed to find out the calorie consumption used at work, such as age, weight, height, duration of activity and level of activity performed. The basal metabolism was determined by Eq. 1 (Hutabarat, 2009).

$$Basal\ metabolism = [66.5 + (13.7 \times weight) + (5 \times height) - (6.8 \times age)](\text{kkal}) \quad (1)$$

The conventional way of approaching environmental assessment is represented by a system boundary drawn around a manufacturing process or plant. The materials and energy used in production must be obtained from primary resources and processed before use. At the same time, any product has a further environmental impact on how they are used and ultimately recycled or disposed of. Therefore, the environmental impact of each product or service under Analysis is considered part of the life cycle from start to finish and the boundary of the system to be analyzed (Fig. 3).

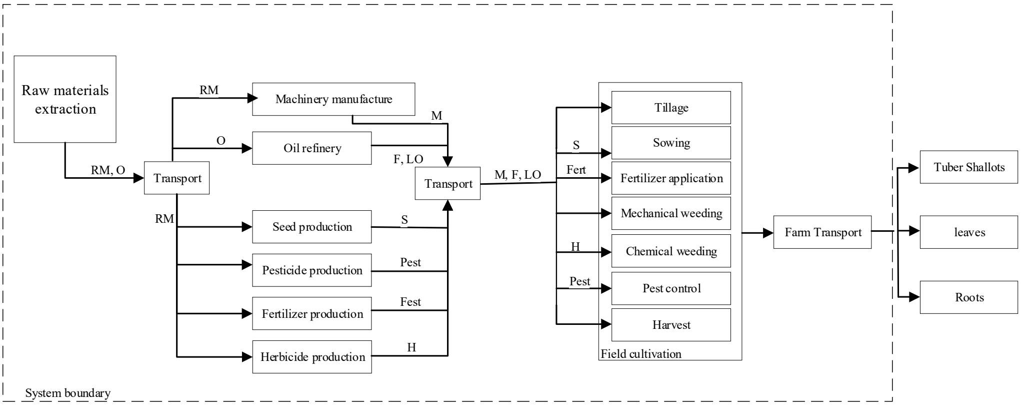

Figure 3. System boundaries for plant production system life cycle assessment by the Crop.LCA tool (RM:Raw Materials; O:Petroleum; F:Fuels; LO:Lubricants; M: Machinery; Fert:Fertilizers; Pests:Insecticides; H:Herbicides; S:Seeds).

Four stages in the life cycle assessment (LCA) are based on ISO 14044:2006 (Fig. 4). 1) Scope/Goal and Scope: The functional unit of this study was the production of shallots in an agricultural area of 0.20 hectares with drone surveillance mapping. The scope used was the Gate-to-Gate Life Cycle Assessment (LCA) method through a review of activities in the shallot production process. 2) Inventory Analysis: Inventory analysis is part of a data set's life cycle assessment process. It flows calculations as input and output data from life cycle assessment stages. Cultivation of shallots has stages including a) nursery with beds; b) tillage using tractors together with trailers; c) planting and maintenance; d) harvesting; and e) transportation. Each stage of the shallot cultivation process uses input from natural resources or energy, with the resulting output in the form of final products and emissions.

The shallot cultivation process starts from the tillage and planting stages. The material used as input is diesel fuel used by the tractor, with each implement having its function for tilling the soil to produce output in the form of fuel combustion emissions.

When spraying pesticides, use a sprayer with a battery input. Pesticides and fertilizers on Food Estates are rumoured to use fertigation techniques to regulate the use of water and fertilizers according to plant needs. The next stage of onion cultivation is harvesting with optimum plant conditions. In the transportation process, diesel is needed to produce output in the form of transportation emissions. 3) LCA analysis: All data were analyzed quantitatively to determine the environmental impact of each stage of the shallot cultivation process. Data was analyzed by calculating input and output at each stage of the production process with a life cycle assessment (LCA) in the energy aspect, including fuel use, electricity use, and gas emission calculations. Every data obtained from each process was processed using the software OpenLCA 1.11.0; the following is the workflow and use of the software. Processes were made based on the five categories of data (soil processing, planting, maintenance,harvesting and transportation), which had been determined to be connected to flow. The product system is adjusted according to the data in each process and then calculated, and the results of calculation data and graph models appear from each processed data category. 4) Life Cycle Impact Assessment (LCIA): The life cycle impact assessment aims to evaluate the impacts generated during the shallot production life cycle, with the primary factor being analyzed as environmental factors. Environmental factors evaluated are acidification, global warming potential, eutrophication, and human toxicity. 5) Interpretation. The data processing results based on inventory analysis and life cycle impact assessment conclude by comparing the values of environmental factors in several studies. The effects are reviewed and evaluated at this last stage to ensure the results are steady with the observed objectives. As proven withinside the diagram, all three different steps are associated with interpretation, indicating that this segment is a significant part of the technique and might constantly result in corrections.

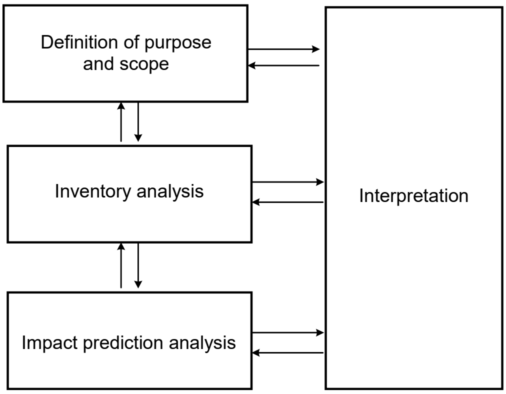

Figure 4. Four stages in the life cycle assessment (LCA) are based on ISO 14044:2006.

RESULTS AND DISCUSSION

Stage 1: Goal and Scope

The goal of LCA in this study is to determine the environmental impacts of acidification, global warming potential, eutrophication, and human toxicity of cultivating shallots in one growing season with an area of 0.2 hectares in Food Estate Hutajulu, Humbang Hasundutan, North Sumatra, Indonesia. The results will be recommended to Food Estate managers for further consideration in cultivating shallots and taking corrective actions for the next growing season to minimise the environmental impact of operations. The scope of this research is the gate-to-gate, which discusses and manages data from soil processing to harvesting shallots in one growing season.

Stage 2: Inventory Data

Inventory data in this study is divided into five categories during the shallot production process: shallot seedling data, soil tillage data, maintenance data, harvesting data and shallot transportation data. Each category analyzed the energy used based on predetermined parameters, namely diesel fuel, fertilizers, pesticides, electricity, human power and irrigation, as shown in Figs 5–8.

Fig. 5 shows the electricity used starting from the seedling process to harvesting. The use of electricity in shallot cultivation was used for a drone sprayer. A drone sprayer was used to help spray pesticides, insecticides, fertilizers, and watering. The drone sprayer used a volume of 16 litres, the same as an electric sprayer, with a spraying speed of 4 m s^{-1} and a battery capacity of 12,000 mAh. The drone sprayer operates on the surface of the air to spray pesticides and fertilize by remote control using a Wi-Fi connection on the operator's remote control equipped with sensors and a global positioning system (GPS). One season's electricity consumption in the shallot cultivation process was 4.64 kWh (1.568 kWh for the nursery process and 3.072 kWh for shallot maintenance).

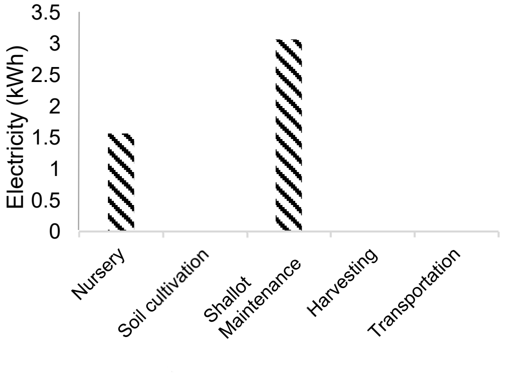

Figure 5. Electric power consumption.

Diesel fuel was used for tractors and transportation, starting from the nursery process until the harvesting process (Fig. 6 and Table 2). In the nursery stage, the initial step for seeding is to cultivate the land where the shallot seeds are sown. The available land area at the Food Estate is 0.04 hectares for later transplanting to an area of 0.2 hectares. This nursery requires several stages so that the plants are suitable for transplanting. The available land in the Food Estate is processed by making beds for sowing shallots with three varieties (Maserati, Lokananta variety, and Sanren). These beds were made by applying organic fertilizer and husk charcoal on the beds before seeding. This stage is done manually. The bed for planting an area of 0.2 hectares is 60.64 meters long and 1 meter wide. Seedling of shallots was made nursery lines on beds with a distance between rows of 15 cm with a density spread of 40 grams per square meter and then covered with husks. Then on the same day, a fungicide was sprayed to prevent the growth of fungi on the beds that had been sown, and then the beds were closed to accelerate seed growth and maintain the air humidity. The hood is made after the seeds are two weeks old or when the shallot seed sprouts have appeared. The hood aims to protect the seeds that have been sown from rainwater and too-hot sunlight. The hood is made of a bamboo

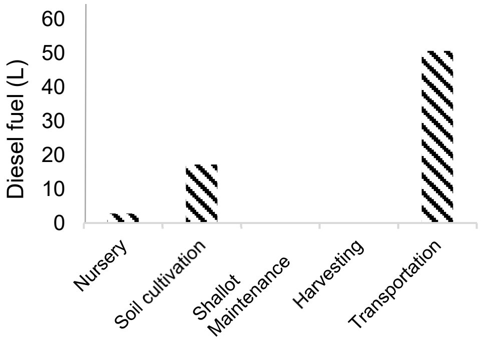

Figure 6. Diesel fuel consumption.

frame and a plastic hood. Maintenance shallots during the nursery stage were carried out manually by watering in the morning or evening to maintain soil and plant moisture, with a total watering of 81.56736 m^3. Then the provision of fungicides, insecticides, and fertilizers regularly keep the plants from pests and diseases, and the plants still have to grow well as needed (Fig. 7 and Table 3).

Table 2. Data on fuel consumption in tillage

Implement	Area (Ha)	Fuel consumption (litre)	Type of fuel	Tractor type
Rotary nursery	0.04	0.540	Diesel	KIOTI DT 4510
Power harrow nursery land	0.04	1.614	Diesel	Farmtrack 120 HP
Nursery field disc bedder	0.04	0.682	Diesel	Kamol 77 HP
Rotary	0.20	2.700	Diesel	KIOTI DT4510
Manure spreader	0.20	3.040	Diesel	Kamol 77 HP
Power harrow	0.20	8.074	Diesel	Farmtrack 120 HP
Disc bedder	0.20	3.410	Diesel	Kamol 77 HP

In soil cultivation stage, the fuel consumption was used for the tractor in soil processing (Fig. 6 and Table 2). Soil processing was carried out in several stages using agricultural mechanization. It started from the rotary stage, levelling, spreading manure, power harrowing, and then making beds. The subsequent tillage was rotary. Rotary on Food Estates used a KIOTI DK4510 tractor with a power of 45 HP, which aimed to chop the soil with a working system; the rotary implement has a knife that moves on an axis driven by a motor so that the knife will chop the soil. On the other hand, land levelling was done by measuring the degree of slope of the land using the Mileseey PF210 600 m Golf Rangefinder. Land with a degree of the slope above 5° was levelled or equalized using a kamol tractor or D31P bulldozer. On valve six land, which is used as a shallot planting area, the degree of slope of the land is 3°, so there is no need for levelling. The shallot planting area at the Food Estate location was spread with manure in cow dung, as much as 7.99 m^3. Manure distribution utilizing mechanization, namely a farm track tractor with a power of 120 HP using a manure spreader implement with a volume of 5.92 m^3 one manure. So the manure spread was carried out twice by the manure spreader. The next stage after spreading the manure is the power harrow. A power harrow is one of the implements whose function is to loosen the soil to a depth of 35 cm, break the soil into smaller sizes, and mix the soil with manure spread over the soil surface. The power harrow uses a rotating blade driven by a rotor of 9 pairs of blades. The power harrow implementation was coupled to a farm track tractor with a power of 120 HP. Making beds on Food Estate land with shallot commodities used a kamol-type tractor with a power of 77 HP in collaboration with a disc bedder implement. The beds' width using a disc bedder was set to 90 cm, with the distance between the beds being 60 cm. On the other hand, diesel fuel was used for transportation. The transportation used in the process of manure is used a Colt Diesel truck with a distance of 207 kilometres and a diesel fuel consumption of 25.875 liters. For shipping the shallot harvest from Hutajulu, Humbang Hasundutan, to towns as far as 198 kilometres using Cold Storage trucks with diesel fuel consumption was 24.75 litres. The highest diesel fuel consumption was used for transportation (Fig. 6) due to the distance of the manure source to the field is too far.

Table 3. OpenLCA input data of fertilizer and pesticide for nursery stage

Active materials	Flow	Total		Information
		(kg)	(kg ha^{-1})	
N	Application of nitrogen fertilizer mix	0.04002	1.0005	Fertilizer
K	Potassium fertilizer, as K	0.00906	0.2265	Fertilizer
P_2O_5	Ammonium nitrate phosphate as P_2O_5	0.02000	0.5000	Fertilizer
Propineb	Propineb	0.14000	3.5000	Pesticide
Propamocarb hydrochloride	Propamocarb HCl	0.30800	7.7000	Pesticide
Mancozeb	Mancozeb	0.16000	4.0000	Pesticide
Dimetomorph	Dimethomorph	0.00788	0.1970	Pesticide
Alkylphenol ethoxylate	Alkylphenol ethoxylate	0.01960	0.4900	Pesticide
Carbosulfan	Carbosulfan	0.00400	0.1000	Pesticide

At the maintenance stage of shallot cultivation, fertilizers, fungicides, and pesticides were applied (Fig. 7 and Table 4), each having a function and role in the plant. NPK Super Folium, a fertilizer formulation containing high doses of NPK and micronutrient elements S, Mg, B, and Zn in the form of white crystals, is 100% soluble in the air without sediment. The function of this fertilizer is to accelerate plant growth, trigger the growth of new shoots, and increase crop yields by increasing fruit/tuber size. Antracol is a fungicide that controls various plant diseases caused by fungi. This fungicide contains the micronutrient Zn, with the active ingredient propineb. Previcur N is a pesticide whose function is to control diseases in shallots with the active ingredient propamocarb hydrochloride. Sidajeb is a pesticide that controls diseases in shallot plants with the active ingredient mancozeb. Acrobat is a pesticide that controls late blight (*Phytophthora infestant*) with the active ingredient dimetomorph. Radix (ZPT) is a growth regulator that stimulates plant roots, growth, flower growth, fertilization, and tubing. Axer is an adhesive for pesticides and foliar fertilizers so that it can survive and penetrate plants. The active ingredients of this product are alkylphenol ethoxylate and sodium succinic sulfonic. Marshall is a pesticide that controls beetles, caterpillars, aphids, seed flies, termites, and armyworms with the active ingredient carbosulfan.

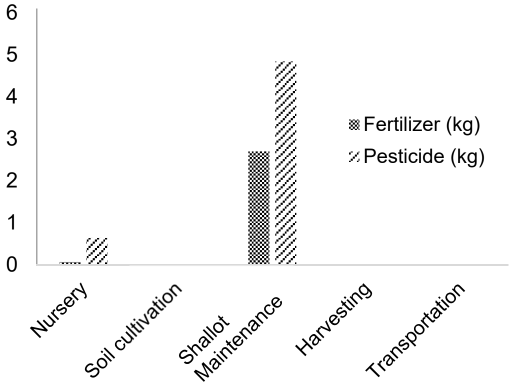

Figure 7. The use of chemical fertilizers and pesticides.

Nebijin is a fungicide that controls club root disease in plants with the active ingredient flusulfamide. Plush is a liquid organic fertilizer to repair soil damage, increase free nitrogen fixation, accelerate plant growth, and increase plant immunity against pests and diseases. Plush contains organic nutrients, N, P_2O_5, K_2O_5, CaO, and MgO. Bazooka 80 WP is a fungicide that controls rot and spot disease on shallot plants in the form of a yellow powder that can be suspended. Bazooka 80 WP has the active ingredient mancozeb 80%. Ultimax 550 EC is one of the clear yellow insecticides in the form of concentrates to control armyworm pests on onion plants. Ultimax 550 EC produced by PT Agricon has the active ingredients chlorpyrifos and cypermethrin. The cluster is also a product of PT Agricon in the form of a colourless solution. It can be mixed with a solution of insecticide, fungicide, herbicide, and acaricide, which aims to reduce the surface tension of the grains resulting from pesticide spray so that the pesticide sprays evenly on the plants. Captive 200 SC is a fungicide in the form of a white suspension concentrate that controls downy mildew (*Peronosclerospora maydis*), late blight or root disease (*Phytophthora infestans*) on shallots with the active ingredient dimethomorph.

Table 4. Data on fertilizer and pesticide needs in maintenance

Active materials	Flow	Total		Information
		(kg)	(kg ha^{-1})	
N	Application of nitrogen fertilizer mix	1.50300	7.5150	Fertilizer
K	Potassium fertilizer, as K	0.33879	1.6940	Fertilizer
P_2O_5	Ammonium nitrate phosphate as P_2O_5	0.77358	3.8679	Fertilizer
Flusulfamid	Flusulfamid	0.00598	0.0299	Pesticide
Mancozeb	Mancozeb	2.99120	14.956	Pesticide
Chlorpyrifos	Chlorpyrifos	0.18400	0.9200	Pesticide
Cypermethrin	Cypermethrin	0.01840	0.0920	Pesticide
Dimetomorph	Dimetomorph	0.93120	4.6560	Pesticide
Broflanilide	Broflanilide	0.00508	0.0254	Pesticide
Flubendiamide	Flubendiamide	0.02240	0.1120	Pesticide
Monosultap	Monosultap	0.35840	1.7920	Pesticide
Dimehipo	Dimehipo	0.32000	1.6000	Pesticide
Cobalt	Cobalt	0.08000	0.4000	Fertilizer

Fig. 8 summarizes the energy specific of shallot cultivation on the Food Estate Hutajulu. As shown in Fig. 8, transportation, mechanization, and pesticide had the highest energy required, approximately 34%, 21% and 18%, respectively. At the same time, fertilizer (3%), irrigation (11%) and labour/human power (14%) had the lowest energy consumption, contributing less than 15%. In addition, Sigalingging et al. (2023) reported that the energy productivity of shallot production was 33.98 kg kJ^{-1}. The authors also reported a mathematical model to predict energy productivity in different growth phases using a convolutional neural network (CNN).

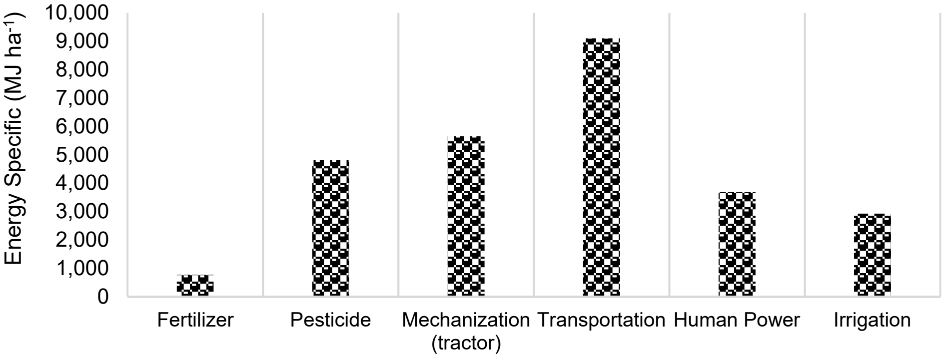

Figure 8. Energy specific of shallot cultivation.

The transplanting of shallots from the Food Estate Hutajulu was done manually with human power. Shallot transplanting was carried out after 51 days of seeding. The land area for transplanting was 0.2 hectares, with a total length of 1,395.5 meters. Similarly, harvesting was done manually with human power. So, to analyze the energy expended during seeding to harvesting, it was calculated using the Hutabarat method (2009) with age, height, weight, duration of work, and a heavy or moderate level of activity. The total human power used for shallot cultivation in Food Estate Hutajulu was 3,682.38 MJ ha^{-1} (Fig. 8). On the other hand, for irrigation, the highest energy specific was during shallot maintenance. The total volume of water used during maintenance was 519.79200 m^3.

Stage 3: Life Cycle Impact Assessment

The field's cultivation process was divided into five categories: shallot seedling, tillage, maintenance, harvesting, and transportation. The five categories of data were processed using the OpenLCA 1.11.0 software. There are four priority contribution impact categories that have an environmental impact (Table 5). Esmaeilzadeh et al., 2020 study on air footprint and the life cycle of edible onion production - a case study in Iran and Abdelkader et al., 2022 on LCA of onion's cultivation processes in Southern Egypt for comparison as shown in Table 6.

Table 5. Results of life cycle impact assessment analysis

Category	Acidification (kg SO_2 eq)	GWP100a (kg CO_2 eq)	Eutrophication (kg PO_4 eq)	Human Toxicity (kg 1,4-DB eq)
Shallot seedling	0.02310	1.27841	0.00545	0.33097
Tillage	0.08750	5.16132	0.01999	1.65311
Shallot maintenance	0.32304	15.98432	0.08017	1,409.07377
Harvesting	0.20647	12.15901	0.04720	3.77075
Transportation	1.89740	415.3188	0.43640	14.51230
Total	2.74541	449.90186	0.58921	1,429.3409

Table 6. Eco invent world average life cycle impact indicators and previous study by others

World average life cycle impact indicators	Esmaeilzadeh et al., 2020	Abdelkader et al., 2022	Unit	Impact
7.45	2.64	1.65	kg SO_2 eq	Acidification
472	324	283	kg CO_2 eq	Global Warming Potential
3.21	1.92	0.66	kg PO_4 eq	Eutrophication
446	446	342	kg 1,4-DB eq	Human Toxicity

Acidification

Acidification produces SO_2 emissions. The acidification value is a degree of air pollution (especially ammonia, sulphur dioxide and nitrogen oxides) in kilograms of sulfur dioxide (SO_2) equivalents (kg SO_2 eq) because of the product existence cycle and contributing to the deposition of acid substances. The resulting 'acid rain' is first-class and regarded as detrimental to forests and lakes. The total impact of acidification in this study was 2.74541 kg SO_2 eq (Table 5), sourced from the transportation process of 1.8974 kg SO_2 eq (Fig. 9). The world average shows that shallot production is equivalent to 7.45 kg SO_2 eq, so the impact of acidity from this study is still low compared to the world average. The study by Esmaeilzadeh et al. (2020) showed that the emissions produced from the effects of acids on the environment on the production of shallots were 2.64 kg SO_2 eq from agricultural machines, while Abdelkader et al., 2022 study was 1.65 kg SO_2 eq (Table 5). Astuti's study (2019) on the analysis of the potential environmental impact of sugarcane cultivation using a life cycle assessment shows that the LCIA analysis results on the impact of acidification are 1.54 kg SO_2 eq sourced from the harvest and transport stages. The largest source of acidification is in the harvesting process. However, in this study, the value of the acidification impact is still relatively large.

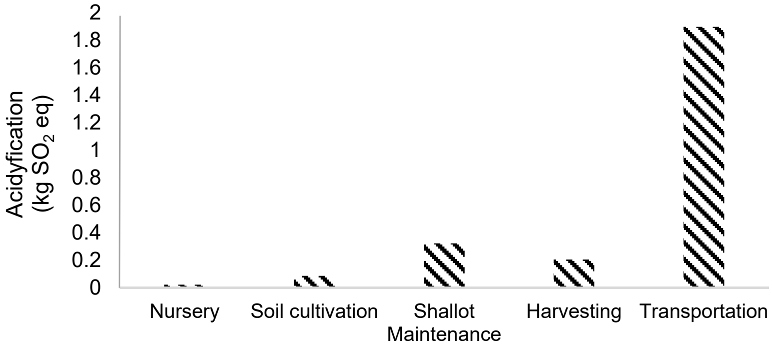

Figure 9. The acidification impact for each category.

The most significant impact of acidification on the environment is the increase in acidity in soil and water systems, with the main pollutants NOx, SOx, NH_3, and HCL being deposited, causing damage to animal and plant populations (Arena, et al., 2003).

Global Warming Potential (GWP 100a)

Global warming is of concern to the world because it can cause various conditions such as rising sea levels, shifting weather, heat waves and other impacts. In this study, the total impact of global warming potential was 449.90186 kg CO_2 eq, with the most significant contributor to GWP being the transportation process of 415.3188 kg CO_2 eq (Table 5 and Fig. 10).

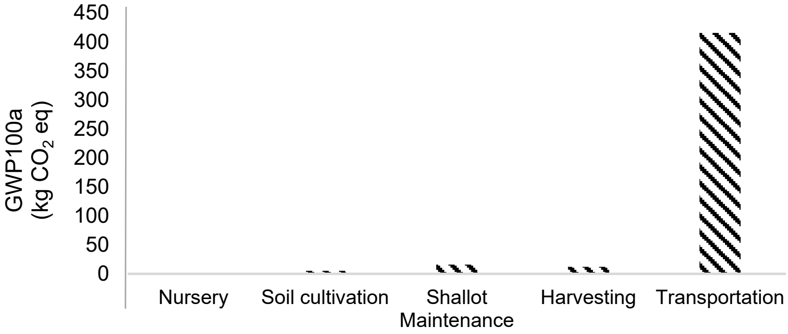

Figure 10. The Global Warming Potential impact for each category.

The global average shows that the impact of global warming was 472 kg CO_2 eq (Table 6), so the results of this study are still below the global average. In the study of Esmaeilzadeh et al. (2020), the impact of global warming on shallot production was 324 kg CO_2 eq. Abdelkader et al. (2022) study on environmental impacts on onion cultivation process in Southern Egypt using the life cycle assessment (LCA) method, the impact value was 3,142.9 kg CO_2 eq.

In Lestari's (2022) study on life cycle assessment (LCA) for the oil palm plantation agro-industry chain, it shows that the plantation process produces an impact of 62 kg CO_2 eq, the distribution process was 1,069 kg CO_2 eq, and the production process was 49 kg CO_2 eq. These results indicate that GWP's impact on shallot production is still lower. Excess doses of fertilizer containing N will produce N_2O emissions, resulting in global warming potential. Through various mechanisms, including an increase in the frequency and severity of heat waves, climate change may impact health. In the near term, health should improve as a consequence of decreasing the consumption of fossil fuels and boosting the utilization of renewable energy sources to combat climate change (Haines et al., 2006). In order to adapt to climate change, public health measures and enhanced surveillance are needed.

Eutrophication

Eutrophication is a process of water pollution caused by phosphate waste, especially in freshwater ecosystems. The results showed the eutrophication was 0.58910 kg PO_4 eq. The most significant contributor to eutrophication was the transport process of 0.4364 kg PO_4 eq (Table 5 and Fig. 11). The global average shows a eutrophication value of 3.21 kg PO_4 eq. This value on the impact of eutrophication on shallot production in Hutajulu was still relatively low. The study by Esmaeilzadeh et al. (2020) showed that the value of the eutrophication impact of shallot production in Iran was 1.92 kg PO_4 eq.

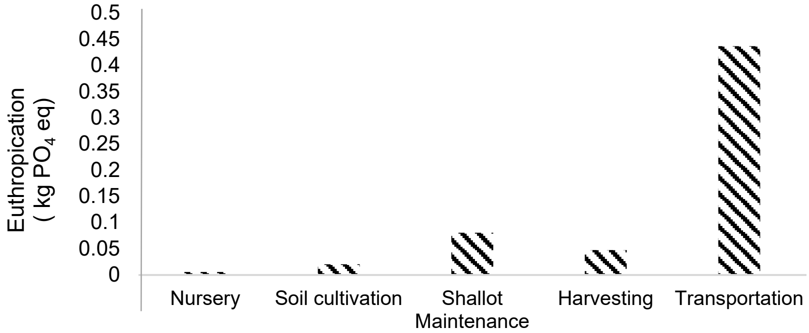

Figure 11. The Eutrophication impact for each category.

In Astuti's research (2019) on the analysis of the potential environmental impact of sugarcane cultivation using a life cycle assessment, it shows that the eutrophication value of 120.24 kg PO_4 eq with the most considerable contribution is the maintenance stage which has an impact on the soil and waters around the land. The most significant contributor to the impact of eutrophication is the maintenance stage. The leading cause of eutrophication is chemical fertilizers which produce nutritional and industrial emissions. Eutrophication has a terrible impact on the aquatic environment because it can reduce oxygen levels in the water due to the uncontrolled growth rate of aquatic plants so that it covers the waters, and animals will have difficulty getting sunlight. This can be minimized if fertilizers are replaced with organic fertilizers that are safer for the environment.

Human toxicity

Human toxicity is closely related to human health and a process's impact. This indicator is intended to quantify emissions to air, water and soil related to the life cycle of a product that is potentially hazardous to human health. Toxicological factors are calculated using scientific estimates of acceptable or tolerable daily intakes of toxicants. However, they are still in the early stages of development, so absolute values can only be used as a guideline. It can not be used as a rough scale. Units of measure correspond to 1,4-dichlorobenzene (DB), a known carcinogen. In LCA, characterization factors are used to compare hazardous chemical compounds by demonstrating how a particular quantity of pollutant leads to environmental or health impacts. The mid-level comprises mechanisms, whereas the endpoint level focuses on human and environmental harm. Midpoint-level characterization is characterized by better links to environmental flows and reduced uncertainty, whereas endpoints emphasize the environmental significance of the impact but give more significant uncertainty. Characterization variables for human toxicity include destiny in the form of environmental persistence, ingestion and accumulation of chemicals in people, and the ultimate toxicity impact. Such as *chlorpyrifos*, as a pesticide in shallot cultivation in this study, is an organophosphate insecticide proven to cause neurotoxicity and is considered a developmental neurotoxicant. It is mainly used in the agricultural sector but occasionally for household pest control. Exposure pathways include inhalation, ingestion and dermal exposure. Chlorpyrifos exposure has been linked to cognitive dysfunctions, smaller head-circumference new-borns, impaired foetal growth, developmental delay, and behavioural problems in children. *Chlorpyrifos* has been linked to neurodevelopmental effects, reproductive toxicity, and endocrine disruption and is not listed by IARC as a potential carcinogen (Papai et al., 2021).

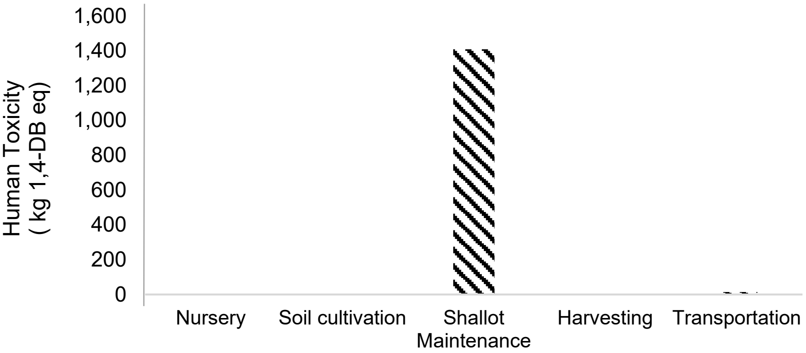

Figure 12. The Human toxicity impact for each category.

The human toxicity obtained was 1,429.34090 kg 1,4-DB eq (Table 5), with the enormous contribution being the maintenance process of 1,409.07377 kg 1,4-DB eq. (Fig. 12). This value is higher than study of Esmaeilzadeh et al. (2020) and Abdelkader et al. (2022). Esmaeilzadeh et al. (2020) reported that the impact value of human toxicity was 446 kg 1,4-DB eq, with the most considerable contribution from agricultural machinery at 90%, while Abdelkader et al., 2022 reported that the human toxicity on anion cultivation process was 342.5 kg 1,4-DB eq.

Stage 4: Interpretation

The stage of the shallot cultivation process that contributes to the most significant environmental impact is shallot maintenance and transportation process. Both of these processes are dominant due to the application of various chemicals to plants and soil, so the best improvement analysis is to replace inorganic fertilizers with organic fertilizers at the appropriate doses. Chemical fertilizers containing NPK can be replaced with cow dung manure to meet NPK needs. According to Rayne & Aula (2020), manure application to land is a viable option to improve and restore the health of degraded land. Nutrient usage efficiency is key to improving soil biological properties, and improving the absorption from manure may minimize the loss of nutrients and environmental contamination. Organic manure of 3 tonnes ha^{-1} as the base treatment of the study was given to increase soil organic matter, cation exchange capacity, and nutrient and water holding capacity (Sutardi et al., 2022). Organic fertilizers significantly affect the pH, organic C, total K, N and P of the soils. According to Gunawan et al., 2019, applying organic matter can increase the C-organic content of the soil. Additionally, The controlling of diseased pests with the technologies of seeds marinating (40–50 °C), PGPR, yellow and green sticky trap, 15 spots per ha, Pheromone - Exi to trap shallot caterpillar moths, and solar-powered light trap, 20 spots per ha to trap insects (trips, aphids and mites) is effective and reduces pesticide residue. Once every 3–5 days, as opposed to once every 10 to 15 days, pesticides suppress infestations. Followed by the yellow sticky trap, the green sticky trap, the white sticky trap, and pheromone-Exi, solar-powered light traps for plant-disturbing organisms are the most effective (Sutardi & Porwoninsih, 2018). For the Food Estate Hutajulu region, however, further research is required to apply organic manure and biological/new pest control technologies.

CONCLUSIONS

The Food Estate Hutajulu was worked on with the aim of the government wanting to start implementing modern agriculture by implementing complete mechanization, irrigation automation, and utilizing digital cultivation from upstream to downstream. The Food Estate program is one of the government programs with a food development concept carried out in an integrated manner, including agriculture in an area. The background of this program is in line with the soaring demand for Indonesian food, which is proportional to population growth and the availability of sizeable potential land. The most significant contribution in the shallot cultivation on the acidification impact, global warming potential and eutrophication impact was the transport process (1.89740 kg SO_2 eq, 415.31880 kg CO_2 eq, and 0.43640 kg PO_4 eq, respectively). In comparison, the impact of human toxicity was the maintenance process of 1,409.07377 kg 1,4-DB eq. The total energy used was diesel fuel (70.685 litres), active fertilizer ingredients (2.76447 kilograms), active pesticide ingredients (5.47614 kilograms) and electricity (4.64 kWh). The recommended improvement analysis is to replace or reduce the use of chemicals in applying fertilizers, pesticides, and fungicides by using organic fertilizers according to the doses required by plants.

ACKNOWLEDGEMENTS. We thank Dr. Petrus (PT. Daya Sentosa Rekayasa), Dr. Van Basten. Pandjaitan (Kemenko MARVEST) and all staff in Food Estate Hutajulu for supporing this study. This study was funded by Directorate of Research, Technology and Community Service, The Ministry of Education, Culture, Research and Technology of the Republic of Indonesia (DRTPM 2022 with Number: 097/E5/PG.02.00.PT/2022 at 10th Mei 2022).

REFERENCES

Abbas, A., Waseem, M. & Yang, M. 2020. An ensemble approach for assessment of energy efficiency of agriculture system in Pakistan. *Energy Efficiency* **13**, 683–696.

Abbas, A., Zhao, C., Ullah, W., Ahmad, R., Waseem, M. & Zhu, J. 2021. towards sustainable farm production system: A case study of corn farming. *Sustainability* **13**, 9243.

Abbas, A., Waseem, M., Ahmad, R., Zhao, C. & Zhu, J. 2022a. Sensitivity analysis of greenhouse gas emissions at farm level: case study of grain and cash crops. *Environmental Science and Pollution Research* **29**, 82559–82573.

Abbas, A., Zhao, C., Waseem, M. & Ahmad, R. 2022b. Analysis of Energy Input–Output of Farms and Assessment of Greenhouse Gas Emissions: A Case Study of Cotton Growers. *Frontiers in Environmental Science*, 725.

Abdelkader, M., Zargar, M., Murtazova, K.M.-S. & Nakhaev, M.R. 2022. Life Cycle Assessment of the Cultivation Processes for the Main Vegetable Crops in Southern Egypt. *Agronomy* **12**, 1527.

Allali, K., Dhehibi, B., Kassam, S.N. & Aw-Hassan, A. 2017. Energy consumption in onion and potato production within the province of El Hajeb (Morocco): towards energy use efficiency in commercialized vegetable production. *Journal of Agricultural Science* **9**, 118–127.

Arena, U., Mastellone, M.L. & Perugini, F. 2003. The environmental performance of alternative solid waste management options: a life cycle assessment study. *Chemical engineering journal* **96**(1–3), 207–222. doi: https://doi.org/10.1016/j.cej.2003.08.019

Astuti, A.D. 2019. Analysis of the potential environmental impact of sugar cane cultivation using a life cycle assessment (LCA) approach. *Jurnal Litbang: Media Informasi Penelitian, Pengembangan dan IPTEK* **15**(1), 51–64 (in Indonesian).

Balafoutis, A.T., Beck, B., Fountas, S., Tsiropoulos, Z., Vangeyte, J., Wal, T. v.d., Soto-Embodas, I., Gómez-Barbero, M. & Pedersen, S.M. 2017. Smart farming technologies–description, taxonomy and economic impact. *In* ‘Precision agriculture: Technology and economic perspectives’, pp. 21–77. Springer.

Baluwo, E., Porong, J. & Ogie, T. 2021. The effect of tubber weight on the growth of red onion (*Allium ascolanicum* L) var. Bima. *In* ‘COCOS’, 2.

BPS (Badan Pusat Statistika) & Bappenas, 2018. Indonesian Population Projection 2015–2045. *Jakarta: Badan Pusat Statistik.* (in Indonesian).

Cambouris, A.N., Zebarth, B.J., Ziadi, N. & Perron, I. 2014. Precision agriculture in potato production. *Potato Research* **57**, 249–262.

Elhami, B., Farahani, S.S. & Marzban, A. 2019. Improvement of energy efficiency and environmental impacts of rainbow trout in Iran. *Artificial Intelligence in Agriculture* **2**, 13–27.

Elahi, E. & Khalid, Z. 2022. Estimating smart energy inputs packages using hybrid optimisation technique to mitigate environmental emissions of commercial fish farms. *Applied Energy* **326**, 119602.

Elahi, E., Khalid, Z., Tauni, M.Z., Zhang, H. & Lirong, X. 2022a. Extreme weather events risk to crop-production and the adaptation of innovative management strategies to mitigate the risk: A retrospective survey of rural Punjab, Pakistan. *Technovation* **117**, 102255.

Elahi, E., Khalid, Z. & Zhang, Z. 2022b. Understanding farmers’ intention and willingness to install renewable energy technology: A solution to reduce the environmental emissions of agriculture. *Applied Energy* **309**, 118459.

Elahi, E., Zhang, Z., Khalid, Z. & Xu, H. 2022c. Application of an artificial neural network to optimise energy inputs: An energy-and cost-saving strategy for commercial poultry farms. *Energy* **244**, 123169.

Esengun, K., Gündüz, O. & Erdal, G. 2007. Input–output energy analysis in dry apricot production of Turkey. *Energy Conversion and Management* **48**, 592–598.

Esmaeilzadeh, S., Asgharipour, M.R. & Khoshnevisan, B. 2020. Water footprint and life cycle assessment of edible onion production-A case study in Iran. *Scientia Horticulturae* **261**, 108925.

Fan, J., Liu, C., Xie, J., Han, L., Zhang, C., Guo, D., Niu, J., Jin, H. & McConkey, B.G. 2022. Life Cycle Assessment on Agricultural Production: A Mini Review on Methodology, Application, and Challenges. *International Journal of Environmental Research and Public Health* **19**, 9817.

Fluck, R.C. & Baird, C.D. 1980. Agricultural energetics, AVI Publishing Co, pp. 192.

Greenhut, R.F., Dufour, R., Kendall, A.M., Strong, E.B. & Steenwerth, K.L. 2013. Life-cycle assessment in agricultural systems. *The National Sustainable Agriculture Information Service ATTRA, National Center for Appropriate Technology, USDA, Tech. Rep.*, 1–24.

Gunawan, G., Wijayanto, N. & Budi, S. 2019. Characteristics of soil chemical properties and soil fertility status of vegetables agroforestry based on Eucalyptus Sp. *J. Trop. Silvic* **10**, 63–69.

Haines, A., Kovats, R.S., Campbell-Lendrum, D. & Corvalán, C. 2006. Climate change and human health: impacts, vulnerability and public health. *Public health* **120**(7), pp. 585–596.

Hammond, G.P. & Jones, C.I. 2008. Embodied energy and carbon in construction materials. *Proceedings of the Institution of Civil Engineers-Energy* **161**, 87–98.

Huang, J., Ji, M., Xie, Y., Wang, S., He, Y. & Ran, J. 2016. Global semi-arid climate change over last 60 years. *Climate Dynamics* **46**, 1131–1150.

Hutabarat, J. 2009. Determination of Caloric Needs by Analysis of Heart Rate in Material Transport Workers at Company "X". In Seminar Nasional Waluyo Jatmiko. Universitas Pembangunan Nasional Veteran Jatim, pp. 13–19 (in Indonesian).

IPCC, 2019. Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P.Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Karami, H., Kaveh, M., Golpour, I., Khalife, E., Rusinek, R., Dobrzański Jr, B. & Gancarz, M. 2021. Thermodynamic Evaluation of the Forced Convective Hybrid-Solar Dryer during Drying Process of Rosemary (Rosmarinus officinalis L.) Leaves. *Energies* **14**, 5835.

Kitani, O. 1999. CIGR Handbook of Agricultural Engineering, Volume V Energy and Biomass Engineering, Chapter 1 Natural Energy and Biomass, Part 1.3 Biomass Resources, pp. 24–37.

Lestari, F., Hawari, N.A., Maureka, R., & Casoni, S.M. 2022. Life Cycle Assessment Using Supply Chain Strategy on Palm Oil Agro-industry. *Proceedings of the 3rd Asia Pacific International Conference on Industrial Engineering and Operations Management*, Johor Bahru, Malaysia, September 13–15, 2022, **12**(6), 664–672.

Mohammadi, A., Tabatabaeefar, A., Shahin, S., Rafiee, S. & Keyhani, A. 2008. Energy use and economical analysis of potato production in Iran a case study: Ardabil province. *Energy conversion and management* **49**, 3566–3570.

Mousavi, A., Aghbolaghi, E.A., Khorramifar, A., Gancarz, M., Darvishi, Y., Stasiak, M., Miernik, A. & Karami, H. 2022. Life Cycle Assessment for Environmental Impact Reduction and Evaluation of the Energy Indices in Lettuce Production. *Applied Sciences* **12**, 10348.

Morandini, N.P., Petroudi, E.R., Mobasser, H.R. & Dastan, S. 2020. Life cycle assessment of crop rotation systems on rice cultivars in Northern Iran. *International Journal of Plant Production* **14**, 531–548.

Naderi, S.A., Dehkordi, A.L. & Taki, M. 2019. Energy and environmental evaluation of greenhouse bell pepper production with life cycle assessment approach. *Environmental and Sustainability Indicators* **3**, 100011.

Papai, S.., de Bruyn, S., Juijn, D. & de Vries, J. 2021. The value of human toxicity. An explorative research for use in environmental prices. CE Delft, Delft, pp. 33–34.

Parhizi, Z., Karami, H., Golpour, I., Kaveh, M., Szymanek, M., Blanco-Marigorta, A.M., Marcos, J.D., Khalife, E., Skowron, S. & Adnan Othman, N. 2022. Modeling and optimization of energy and exergy parameters of a hybrid-solar dryer for basil leaf drying using RSM. *Sustainability* **14**, 8839.

Prasetyowati, K., Kartikasari, R. & Prasetyo, A. 2021. A feasibility study on cultivating shallots (Allium ascalonicum L) in Selo District, Boyolali Regency, Indonesia. *In* "IOP Conference Series: Earth and Environmental Science", Vol. **824**, pp. 012111. IOP Publishing.

Rabl, A. & Spadaro, J.V. 2006. Environmental impacts and costs of energy. *Annals of the New York Academy of Sciences* **1076**, 516–526.

Rahman, M.H.A., Chen, S.S., Razak, P.R.A., Bakar, N.A.A., Shahrun, M.S., Zawawi, N.Z., Mujab, A.A.M., Abdullah, F., Jumat, F. & Kamaruzaman, R. 2019. Life cycle assessment in conventional rice farming system: Estimation of greenhouse gas emissions using cradle-to-gate approach. *Journal of Cleaner Production* **212**, 1526–1535.

Rayne, N. & Aula, L. 2020. Livestock manure and the impacts on soil health: A review. *Soil Systems* **4**, 64.

Reichmann, L.G. & Sala, O.E. 2014. Differential sensitivities of grassland structural components to changes in precipitation mediate productivity response in a desert ecosystem. *Functional Ecology* **28**, 1292–1298.

Sigalingging, R., Nababan, S., Vinolina, N.S. & Harahap, L.A. 2023. Modelling of energy productivity prediction systems of shallots classification growth phase system using convolutional neural network. *Procedia Computer Science* **216**, 328–337.

Sillero, L., Morales, A., Fernández-Marín, R., Hernandez-Ramos, F., Davila, I., Erdocia, X. & Labidi, J. 2021. Life Cycle Assessment of various biorefinery approaches for the valorisation of almond shells. *Sustainable Production and Consumption* **28**, 749–759.

Sutardi, Kristamtini, Purwaningsih, H., Widyayanti, S., Arianti, F.D., Pertiwi, M.D., Triastono, J., Praptana, R.H., Malik, A., Cempaka, I.G., Yusuf, Yufdy, M.P., Anda, M. & Wihardjaka, A. 2022. Nutrient Management of Shallot Farming in Sandy Loam Soil in Tegalrejo, Gunungkidul, Indonesia. *Sustainability* **14**, 11862.

Sutardi & Porwoninsih. H. 2018. Environment friendly cultivation of shallot on sandy land as specified location in Yogyakarta. *Jurnal Sumberdaya Hayati* **4**, 1–6.

Tatli, S., Mirzaee-Ghaleh, E., Rabbani, H., Karami, H. & Wilson, A. D. 2021. Rapid detection of urea fertilizer effects on voc emissions from cucumber fruits using a MOS E-Nose Sensor Array. *Agronomy* **12**, 35.

Tilman, D., Fargione, J., Wolff, B., D'antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D. & Swackhamer, D. 2001. Forecasting agriculturally driven global environmental change. science **292**, 281–284.

Tilman, D., Reich, P.B. & Knops, J.M. 2006. Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature **441**, 629–632.

Yaldiz, O., Ozturk, H., Zeren, Y. & Bascetincelik, A. 1993. Energy usage in production of field crops in Turkey. **In**: 5th International Congress on Mechanisation and Energy Use in Agriculture. Turkey: Kusadasi, pp. 11–14.

Yan, Z., Li, W., Yan, T., Chang, S. & Hou, F. 2019. Evaluation of energy balances and greenhouse gas emissions from different agricultural production systems in Minqin Oasis, China. *PeerJ.* **7**, e6890.