ASEAN Engineering Journal

Full Paper

LIFE CYCLE ASSESSMENT OF NUTMEG OIL SUPPLY CHAIN

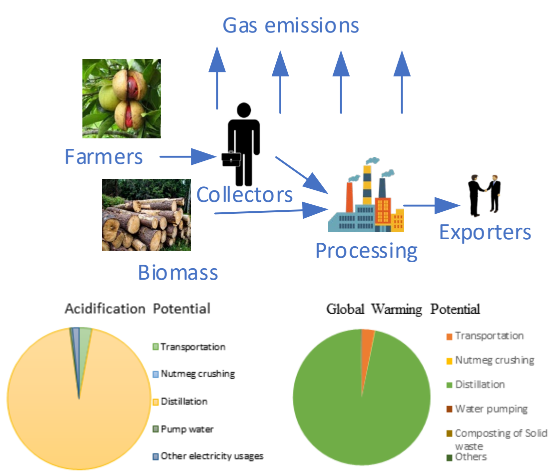
Trisna Trisna[a*], Muhammad Zakaria[a], Mochamad Ari Saptari[b]

[a]Industrial Engineering Department, Faculty of Technique, Universitas Malikussaleh, Kampus Bukit Indah, Jalan Batam, Blang Pulo, Muara Satu, Lhokseumawe, Aceh, Indonesia
[b]Information System Department, Faculty of Technique, Universitas Malikussaleh, Kampus Bukit Indah, Jalan Batam, Blang Pulo, Muara Satu, Lhokseumawe, Aceh, Indonesia

Article history
Received
19 April 2022
Received in revised form
01 January 2023
Accepted
04 February 2023
Published online
30 November 2023

*Corresponding author
trisna@unimal.ac.id

Graphical abstract



Abstract

The nutmeg oil supply chain has several members, including farmers, collectors, traders, processing industries, and exporters. Every activity along the nutmeg supply chain has an environmental impact due to resources usages such as raw materials, water, and energy. This study aimed to measure the environmental impacts along the nutmeg oil supply chain using a life cycle assessment framework. The effects assessed in this study are greenhouse gas emissions, global warming potential (GWP), and acidification potential (AP). The research stages involve preliminary study, objectives and scope determination, data collection, environmental impacts measurement, and interpretation. The results showed that the most significant environmental impact was the distillation process with greenhouse gas emissions are 22,400 kg CO_2, 60kg CH_4, and 0.8 kg N_2O, GWP of 23,908 kg CO_2 (eq), and AP of 34 kg SO_2 (eq). Based on identifying of environmental impacts, it is necessary to improve the existing boiler combustion system by using a closed burning system. These study results are the basis for decision-makers to improve the production process, design green supply chain management, and reduce environmental impacts.

Keywords: Nutmeg oil, Life cycle assessment, Global warming potential, Supply chain

1.0 INTRODUCTION

South Aceh is the largest nutmeg-producing area in Aceh province, Indonesia. Based on data from Central Bureau of Statistics of South Aceh (2019), nutmeg land's scope in Aceh Selatan is 16,941 hectares with a production of 5,251 tons per year.

Nutmeg oil is one type of essential oil made from the distillation of nutmeg. It has been widely used for various industry needs, such as aromatherapy for food additives, medicines, cosmetics, antiseptics, and others. This oil is mainly produced in South Aceh as the largest nutmeg producer. Activities along the nutmeg oil supply chain impact the environment in solids and liquid wastes, and gas emissions. That impacts are caused by using recourses, including raw materials, energy, water, machinery, and electricity. Besides that, inefficient environmental management results in emissions (waste) and losses that pollute the environment. Supply chain activities from upstream to downstream require material and energy resources that impact the environment, such as greenhouse gas emissions and global warming [2].

Environmental impact assessment along the supply chain activities can be carried out using the Life Cycle Assessment (LCA) method. This method is a mechanism for analyzing and calculating the total environmental impact of a product in every stage of its life cycle, starting from the preparation of raw materials, the production process, sales and transportation, and product disposal [3]. Decision-makers, producers, or consumers can use the results of the LCA to select products and production processes that are environmentally sustainable. Besides, the environmental impact analysis results can be the basis for designing a green supply chain (GSC). Every step of production and material flow in the green supply chain process must consider the main idea of the environment to generate green products and services [4].

Several studies on nutmeg oil include chemical composition identification [5], physicochemical characteristics [6], antibacterial properties [7]–[9], antioxidant activity [10]–[12], the profitability of its industry [13], and process improvement [14]–[16].

Life cycle assessment analysis (LCA) is a method used to analyze the environmental impact of a product during its life cycle [17]. Several preliminary studies on LCA in various essential or vegetable oils have been carried out involving edible canola oil [18], olive oil [19]–[21], rapeseed oil [22], [23] palm oil production [24], sunflower oil [25]–[27], and calendula [28].

Based on previous studies, researchers haven't assessed environmental impacts using the LCA framework for the citronella oil supply chain. It is essential to improve operations and processes along the supply chain and its sustainability.

This study contributes to LCA's knowledge and literature which support researchers, practitioners, producers, policymakers, and other stakeholders to analyze and reduce environmental impacts, especially for the nutmeg oil supply chain. This study also provides recommendations for designing a green supply chain of nutmeg oil.

This study aimed to assess the environmental impact in global warming potential (GWP) and acidification potential (AP) based on the LCA framework on activities along the nutmeg oil supply chain. The research stages involve preliminary study, objectives and scope determination, data collection, environmental impact measurement, and interpretation.

Because of limited time, we restricted this study to assess the environmental impact of GWP and AP. For feature study, the others can consider being analyzed.

2.0 METHODOLOGY

In this study, the measurement of environmental impacts throughout the nutmeg oil-supply chain activities used a life cycle assessment (LCA) framework, as shown in Figure 1.

The data required in this study were primary data and secondary data. Primary data sourced from field observations at the nutmeg oil mill, such as production process flow, raw materials, energy types, sources, and the amount of energy used. Secondary data sourced from literature are in the form of net calorific value and gas emission factors. Meanwhile, transportation distance from resources to the mill was measured using google maps.

In this study, GWP comes from the use of energy for transportation and production processes as well as emissions due to the decomposition of solid and liquid waste.

To determine greenhouse gas emissions for energy usage, we can use equation 1, as follows:

Gas emissions = QF x NCV x EF (1)

Where,

QF = Fuel consumption (L or KL)

NCV = Net calorie value (TJ/KL)

EF = Emission factor (Kg CO_2/TJ for CO_2 emission, kg CH_4/TJ for CH_4 emission, and kg N_2O/TJ for N_2O emission.

Emission factors were gained from some literature, such as IPCC inventory [29], previous studies, and free IPCC inventory software.

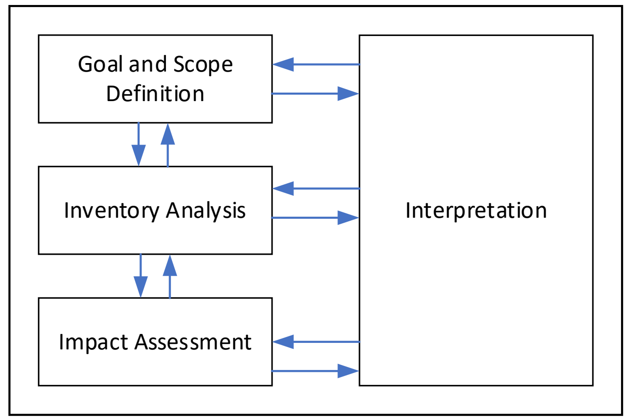


Figure 1 Life cycle assessment framework [3]

3.0 RESULTS AND DISCUSSION

3.1 Goal and Scopes

This study aimed to measure environmental impact involving global warming potential (GWP), and Acidification Potential (AP) throughout the nutmeg oil-supply chain activities. The supply chain's echelon studied starts from the collectors, nutmeg oil mill to exporters. Figure 2 shows the supply chain of the nutmeg oil and the boundary of this study.

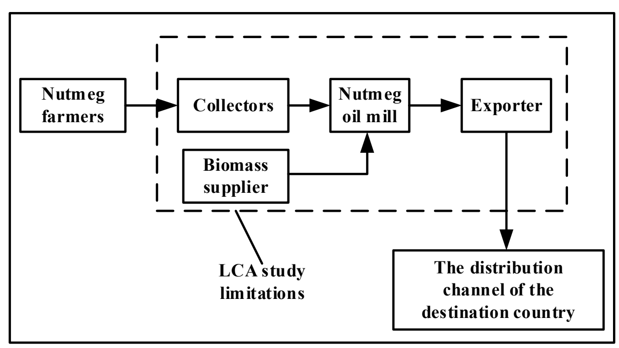


Figure 2 Supply chain of nutmeg oil

3.1.1 Unit Functions Definitions

Table 1 shows the parameters and units used in this study. We used the basis of 250 kg nutmeg oil produced to determine the amount of the required resources. That value is based on the production capacity of the nutmeg mill for once production.

Table 1 Parameters and The Units Required for LCA Study

Parameters	Units
The amount of nutmeg needed to produce 250 kg nutmeg oil	kg
The amount of water needed to produce 250 kg nutmeg oil	kg
The amount of diesel needed to operate crushing machine	litre
The amount of biomass needed for distillation process	kg
The amount of electricity needed to operate mill	kwh
The amount of solid waste produced	kg
The amount of liquid waste produced	litre
The amount of nutmeg oil produced	kg
The amount of fossil fuel needed to transport nutmeg oil to exporter	litre

3.1.2 Input–Output Allocations

This factor divides the input needed and output produced in a production process. The basis for determining the allocation can be mass, energy, and the added value generated by each output. The input-output allocation and the detailed production process of nutmeg oil can be seen in Figure 3. The dried nutmegs are crushed with a crusher and, after that, put in the distilling kettle. Meanwhile, boil water in the boiler and set a low steam pressure (about 0.5-1 bar). Then channel the steam to the nutmeg tank, and the pressure in the boiler is increased to 1 bar. The nutmeg is heated by direct steam will release oil mixed with air vapor. Steam and nutmeg oil vapor flow through the pipe to the condenser. Inside the condenser, nutmeg oil vapor and steam were condensed for the two liquids based on their boiling points. The remaining condensate water is removed, while the essential oil of nutmeg is collected in a storage container.

In this study, we used the basis of 250 kg nutmeg oil for the number of required resources That value is based on the production capacity of nutmeg mill for once production.

.

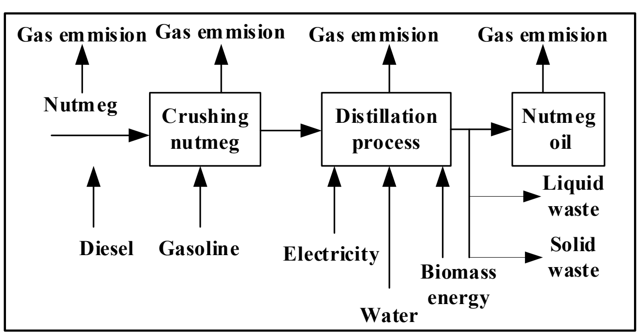


Figure 3 Input-output allocations for production process of nutmeg oil

3.2 Life cycle inventory (LCI)

The data required in this LCA study are classified into raw material and energy requirements to produce 250 kg of nutmeg oil. The supply chain echelon studied from the nutmeg collector, essential oil mil, to the exporter. Tables 2 and 3 show the resources requirement and output produced for one cycle product or production, respectively.

Raw materials come from two sources: South Aceh district, about 15 km from the mill, and West Sumatra province, which is 812 km from the factory. The mill obtains biomass fuel from around the South Aceh district, 14 km away. The nutmeg oil's finished product is sent to exporters in Medan City, about 360 km from the factory location.

To produce 250 kg of nutmeg oil requires raw material of 2500 kg of nutmeg and a processing time of three days or 72 hours. Transportation to exporter uses a diesel truck with a capacity of 5 tons. Biomass fuel was transported from West Aceh to the mill at 200 km.

Table 2 Resource Requirements to Produce 250 Kg Nutmeg Oil[a]

Type of Operation	Description	Type of Resource	The Amount of Requirement
Transportation of raw material	Diesel requirement for transportation of raw material from West Sumatra Province to the mill	Diesel	203 litres
	Diesel requirement for transportation of raw material from South Aceh district to the mill	Diesel	3.55 litres
Transportation of biomass fuel	Diesel requirement for transportation of biomass from West Aceh district to the mill	Diesel	94 litres
Inputs	Amount of nutmeg Amount of water	Nutmeg Water	2500 kg 80 m^3
Nutmeg crushing	Amount of diesel requirement	Diesel	10 litres
Distillation process	Amount of biomass requirement	Biomass	10.53 m^3
Water pumping	Amount of gasoline requirement	Gasoline	10 litres
Transportation of nutmeg oil	Diesel requirement for transportation of raw material from the mill to exporter	Diesel	60 litres
Other	The use of electricity	Electricity for 3 days	62.5 kwh

[a]Observation data

Table 3 Output Produced

Type of Output	Units	The Amount Produced[a]
Nutmeg oil	Kg	250
Solid waste	Kg	2250
Liquid waste	M^3	78.4

[a]Observation data

To determine greenhouse gas emissions, this study needs data on the net calorie value (NCV) for energy consumption and the emission factor. Table 4 shows the conversion of calorie value and emission factors for the consumption of the various types of energy used to produce nutmeg oil.

Table 4 The Inventory of Conversion of Net Calorie Value and Emission Factors Used in This Study [29]

Inventory	Net Calorie Value	Emission Factor		
		CO_2	CH_4 (Kg CH_4/TJ)	N_2O (Kg N_2O/TJ)
Diesel	0.036 TJ/Kl	74,100 Kg CO_2/TJ	3	0.6
Gasoline	0.0448 TJ/Kl	69300 Kg CO_2/TJ	3	0.6
Biomass	0.00002 TJ/Kg	112,000 Kg CO_2/TJ	30	4
Electricity		0.9 Kg CO_2/kwh		

3.3 Life Cycle Impact Assessment (LCIA)

Based on the nutmeg oil-supply chain observations, the operational potential that can emit gas emissions is the crushing of nutmeg, distillation, water pumping, factory lighting, transportation, and solid waste composting.

In the distillation process, the boiler is heated using a furnace with biomass fuel that causes greenhouse gas emissions. Besides, gasoline that uses to operate pump water also generates gas emissions.

3.3.1 Global Warming Potential (GWP)

Global warming potential is an increase in the atmosphere's average temperature due to greenhouse gas emissions that cause solar thermal energy to be trapped in the atmosphere and make the earth hotter than before. GWP value is determined by equivalenting CO_2 CH_4 and N_2O gas emissions relative to CO_2 (CO_2 eq). Non-CO_2 gas is converted to CO_2 with a conversion factor of 21 for CH_4 and 310 for N_2O to obtain the GWP value [30].

The mill disposes solid waste on vacant land near the factory without further treatment. The trash is left unattended, and some people surround use it for organic fertilizer. The solid waste is disposed of open land will decompose and then produces methane gas. That gas is one that causes the greenhouse effect. According to RTI International [31], we classified that solid waste is the agricultural waste category, namely wood and straw waste. According to IPCC (2006) [33], The calculation of emission from not managed solid waste can be determined using equation 2, as follows:

$$A = \left[\sum_{x=S}^{T-1} \left\{W_x L'_x \left(e^{-k(T-x-1)} - e^{-k(T-x)}\right)\right\}\right] \quad (2)$$

Where,
A = CH= generation (Mg/yr),
X = year in which waste was disposed,
S = start year of inventory calculation,
T = inventory year for which emissions are calculated,
k = decay rate constant (yr^{-1}).
Wx = the quantity of waste disposed at the solid waste disposal site (Mg).
Meanwhile, L'_x value can be calculated using equation 3, as follows [33]:

$$L'_x = L_0 \times 16/0.02367 \times 10^{-6} \quad (3)$$

L_0 = CH_4 generation potential (m^3 CH_4/Mg waste)
L_0 = 493× DOC
Where,
DOC = degradable organic carbon [fraction (Mg C in waste/Mg waste)]

From Table 4, the solid waste produced from processing nutmeg oil is 2,250 kg or 0.225 Mg. The mill's location is in a humid tropical climate, so the k value for wood and straw waste is 0.03 and DOC 0.43 [31]. If we assume the year of waste disposal is the first year and the calculation of the inventory for the first year, so the total of emissions for one year, as follows:
L_0 = 493 × DOC
L_0 = 493 × 0.43
= 211.99 Mg C in waste/Mg waste
L'_x= 211.99 × 16/0.02367 × 10^{-6}
= 0.143
CH_4 generation
$A = 2.250 \times 0.143\ (e^{-0.03(1-0-1)} - e^{-0.03(1-0)})$
= 0.01 Mg CH_4
= 10 kg CH_4

From the calculation, we obtained that CH_4 gas emission produced by the nutmeg oil solid waste is 0.01 Mg CH_4 for a year or equivalent with 210 kg CO_2 eq.

NCV and EF have different values for each type of fuel used, as shown in Table 4. GHG emissions for the nutmeg oil supply chain can be obtained using equation 1. GWP is obtained by adding the equivalent CO_2 gas, as shown in Table 5.

Table 5 Greenhouse Emissions and GWP for Oil Nutmeg Supply Chain

Activities of Supply Chain	Gas Emissions			GWP (kg CO_2eq)
	CO_2 (kg CO_2)	CH_4 (kg CH_4)	N_2O (kg N_2O)	
Transportation of raw material from South Aceh district to the mill	9.47	0.0004	0.00008	9.5032
Transportation of raw material from South Aceh district to the mill	541.52	0.0219	0.00438	543.338
Transportation of biomass to the mill	9.47	0.0004	0.00008	9.5032
Nutmeg crushing	26.68	0.0011	0.00022	26.7713
Distillation	22,400	60	0.80000	23908
Water pumping	2.20	0.0001	0.00002	2.2083
Transportation of nutmeg oil to the mill	192.07	0.0078	0.00156	192.717
Composting of solid waste		10		210
Others	56.25			56.25
	23,260.6	**60.03**	**0.81**	**24958.3**

From Table 5 and Figure 4, we can see that the distillation process has the most significant impact on GHG and GWP. That process requires a large amount of wood fuel so that it results in high emissions of greenhouse gases.

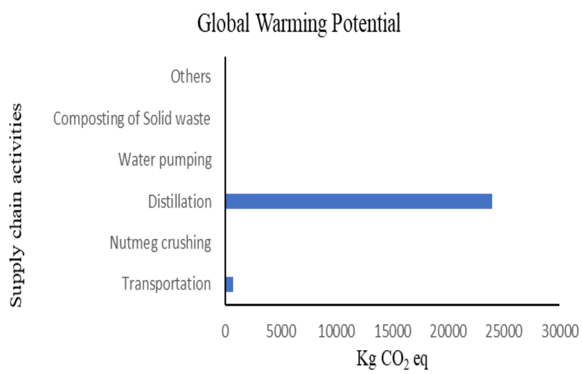


Figure 4 Global warming potential of nutmeg oil supply chain

Transportation generated the second-largest GWP impact. Nutmeg oil-supply chain activities require energy to transport raw materials and fuel from the source to the factory site and transport nutmeg oil from the factory to the exporter.

3.3.2 Acidification Potential (AP)

AP is acidification of the atmosphere derived from gas emissions of SO_2, NOx, and NH_3 converted to SO_2 (eq). According to Heijungs [34], we can obtain the conversion value to SO_2 (eq) by converting 1 kg NOx to 0.7 kg SO_2 (eq) dan 1 kg NH_3 to 1.88 kg SO_2 (eq). Emission factors for that acidification can be shown in Table 6. Figure 5 shows acidification potential for nutmeg oil-supply chain activities. We can see that distillation activity causes the most significant acidification potential impact compared to the others. This activity requires a large amount of biomass fuel, resulting in higher acidification potential than the others. Transportations produce the second most AP impact because it needs an amount of biodiesel to transport raw material and biomass from the sources and nutmeg oil to exporter.

Table 6 Emission Factors of SO_2 and NOx Based on IPCC (2006) [29]

Energy type	Emission factors		
	SO_2+SO_3	NOx (Kg/TJ)	NH_3
Biodiesel	n.a	146	n.a
Wood	0.20%	100	n.a
Electricity	8.1 gr SO_2/kwh	250	n.a
Motor gasoline	0.1%	600 kg/TJ	n.a

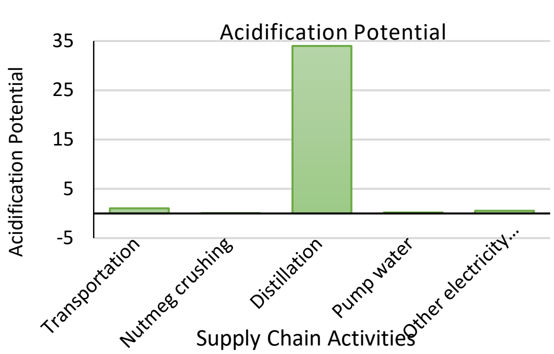


Figure 5 Acidification potential for nutmeg oil supply chain activities

3.4 Interpretations

Based on LCI and LCIA, we identified issues affecting the environment of the nutmeg oil supply chain. The LCA supply chain for nutmeg oil is based on a one-time production cycle of 250 kg of nutmeg oil. The activity that produces the most GHG emissions, GWP, and AP is a distillation process that uses biomass as energy, which is 22,400 kg CO_2, 60 kg CH_4, and GWP of 23908 kg CO_2 (eq). The activity requires biomass a quite large because it has a low heating value than other fuel sources used in this supply chain. To reduce GWP and impact, we can replace wood biomass fuel with gas. Moreover, we can improve the boiler's combustion system more efficiently using a closed combustion system without losing much heat.

Besides the biomass combustion process, GWP and AP also comes from transportation. This activity produces GRH emission from the biodiesel usages. The nutmeg mill obtains raw material from West Sumatera, which is 812 km away, requiring more fuel usages. To reduce GWP and AP impacts, decision-makers can consider looking for alternative suppliers of raw materials from areas closer to the mill location. Apart from producing large gas emissions due to fuel use, the far source of raw materials also requires enormous transportation costs.

The solid waste produced is quite large, at 90% of the total raw material input required. Solid waste without further treatment will decompose with the soil and produce CO_2 and CH_4 gases. In this study, the CH_4 gas produced is the second largest contributor after biomass combustion. To reduce methane gas emissions, we can process the waste into biogas and then used it as a source of energy for the factory, especially to heat the boiler.

4.0 CONCLUSIONS

The LCA study was conducted to measure the environmental impact of GHG, GWP, and AP along the supply chain of nutmeg oil activities. LCA identifies supply chain activities that contribute to environment effects, namely the distillation process, which uses biomass as an energy source. It is necessary to improve the open fire combustion system by creating a closed burning system to reduce emission gases. Besides, transportation is a second contributor to gas emissions, which can be improved by finding raw materials closer to the factory location. The decision-maker can use the results of LCA of the nutmeg oil as the basis for designing green supply chain management.

We realized there were still many shortcomings in this study, especially measuring only two environmental impacts, namely GWP and AP. In future work, we can measure other environmental effects, such as climate change, land use, human toxicity, ozone depletion, eutrophication potential, etc. Furthermore, the researcher can assess other impacts such as social, economic, work accidents, work completion, etc.

Acknowledgement

We thank to the Ministry of Research, Technology, and Higher Education of Indonesia, who supports this study by Fundamental Research Grant with contract no. 180/SP2H/LT/DRPM/2019. We are also grateful for valuable comments and suggestions from reviewers that help to improve our paper quality.

References

[1] Central Bureau of Statistics of South Aceh. 2019. "Kabupaten Aceh Selatan Dalam Angka," Tapaktuan.

[2] K. Igarashi, T. Yamada, N. Itsubo, and M. Inoue. 2014. "Optimal disassembly system design with environmental and economic parts selection for CO2 saving rate and recycling cost," *International Journal of Supply Chain Management.* 3(3): 159–171,

[3] IS/ISO 14044, "Environmental Management-Life Cycle Assessment-Requirements and Guidelines," 2006.

[4] V. G. S. Srivastava. 2019. "The Study to Analyze the Impact of Green Supply Chain Management in India," *International Journal of Supply Chain Management.* 8(3): 1033–1038.

[5] I. P. S. Kapoor, B. Singh, G. Singh, C. S. De Heluani, M. P. De Lampasona, and C. A. N. Catalan, 2013, "Chemical composition and antioxidant activity of essential oil and oleoresins of nutmeg (Myristica fragrans Houtt.) fruits," *International Journal Of Food Properties,* 16(5): 1059–1070.

[6] I. Marzuki, B. Joefrie, S. A. Aziz, H. Agusta, and M. Surahman. 2014. "Physico-chemical characterization of Maluku nutmeg oil," *International Journal of Science and Engineering,* 7(1): 61–64.

[7] K. M. Ibrahim, R. K. Naem, and A. S. Abd-Sahib. 2013. "Antibacterial activity of nutmeg (Myristica fragrans) seed extracts against some pathogenic bacteria," *Al-Nahrain Journal of Science.* 16 (2): 188–192.

[8] H. Cui *et al.* 2015. "Antibacterial properties of nutmeg oil in pork and its possible mechanism" *Journal of Food Safety.* 35(3): 370–377.

[9] S. Nurjanah, I. L. Putri, and D. P. Sugiarti. 2017. "Antibacterial activity of nutmeg oil," *KnE Life Sciences.* 563–569.

[10] A. D. Gupta and D. Rajpurohit, 2011. "Antioxidant and antimicrobial activity of nutmeg (Myristica fragrans)," in *Nuts and seeds in health and disease prevention*, Elsevier, 831–839.

[11] S. P. Piaru, R. Mahmud, A. M. S. A. Majid, and Z. D. M. Nassar, 2012. "Antioxidant and antiangiogenic activities of the essential oils of Myristica fragrans and Morinda citrifolia," *Asian Pacific Journal of Tropical Medicine.* 5(4): 294–298

[12] H. M. Ansory, E. N. Sari, A. Nilawati, S. Handayani, and N. Aznam, 2019. "Sunscreen and Antioxidant Potential of Myristicin in Nutmeg Essential Oils (Myristica fragrans)," in *Proceedings of the 2nd Bakti Tunas Husada-Health Science International Conference (BTH-HSIC), Paris, France*, 5–6.

[13] R. Juwita, S. Tsuchida, and others, 2017. "Current conditions and profitability of the nutmeg industry in Bogor Regency, Indonesia," *J. ISSAAS*. 23(2): 33–44.

[14] R. Syahputra and others, 2018. "Control system based on fuzzy logic in nutmeg oil distillation process for energy optimization," in *2018 International Conference on Information and Communications Technology (ICOIACT)*, 679–683.

[15] I. Hasmita, F. Redha, and R. Junaidy, 2019. "Enhancement of Quality of Nutmeg Oil Using Rotary Vaccumm Evaporator," in *Journal of Physics: Conference Series*, 1232(1): 12039.

[16] N. Fitriadi, E. Saputra, S. Othman, and others, 2021. "Distillation Equipment Design of Nutmeg Oil using Hybrid System," in *IOP Conference Series: Materials Science and Engineering*, 2021, 1062(1): 12057.

[17] International Organization for Standardization. 2006. ISO 14040: 2006," Environmental management — Life cycle assessment — Principles and framework"

[18] M. Khanali, S. A. Mousavi, M. Sharifi, F. K. Nasab, and K. Chau, 2018. "Life cycle assessment of canola edible oil production in Iran: A case study in Isfahan province," *Journal of Cleaner Production* 196: 714–725.

[19] P. Tsarouhas, C. Achillas, D. Aidonis, D. Folinas, and V. Maslis, 2015, "Life Cycle Assessment of olive oil production in Greece," *Journal of Cleaner Production*, 93: 75–83.

[20] A. El Hanandeh and M. A. Gharaibeh, 2016, "Environmental efficiency of olive oil production by small and micro-scale farmers in northern Jordan: Life cycle assessment," *Agricultural Systems*, 149: 169–177.

[21] F. Guarino *et al.*, 2019, "Life cycle assessment of olive oil: A case study in southern Italy," *Journal of Environmental Management* 238: 396–407.

[22] J. H. Schmidt, 2010, "Comparative life cycle assessment of rapeseed oil and palm oil," *The International Journal of Life Cycle Assessment.* 15(2): 183–197.

[23] A. Fridrihsone, F. Romagnoli, and U. Cabulis, 2020 "Environmental Life Cycle Assessment of Rapeseed and Rapeseed Oil Produced in Northern Europe: A Latvian Case Study," *Sustainability*, 12(14): 5699.

[24] H. Stichnothe and F. Schuchardt, 2011, "Life cycle assessment of two palm oil production systems," *Biomass and Bioenergy*, 35(9): 3976–3984, Doi: 10.1016/j.biombioe.2011.06.001.

[25] D. Spinelli, S. Jez, and R. Basosi, 2012 "Integrated Environmental Assessment of sunflower oil production," *Process Biochemistry*, 47(11): 1595–1602.

[26] F. Figueiredo, E. Geraldes Castanheira, and F. Freire, 2012, "LCA of sunflower oil addressing alternative land use change scenarios and practices," in *Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2012)*, 1–4.

[27] I. Muñoz, J. H. Schmidt, R. Dalgaard, and others, 2014, "Comparative life cycle assessment of five different vegetable oils.," in *Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), San Francisco, California, USA, 8-10 October, 2014*, 886–894.

[28] J.-A. González-Aguirre, J. C. Solarte-Toro, and C. A. C. Alzate, 2020, "Supply chain and environmental assessment of the essential oil production using Calendula (Calendula Officinalis) as raw material," *Heliyon*, 6(11): e05606, 2020.

[29] I. P. O. C. Change, "2006 IPCC guidelines for national greenhouse gas inventories," IPCC, Switzerland

[30] IPCC-SAR, 1995, "Climate Change 1995: A report of the Intergovernmental Panel on Climate Change," *Environmental Science & Technology* 48(8): 4596–4603

[31] RTI International, 2010, "Greenhouse Gas Emissions Estimation Methodologies for Biogenic Emissions from Selected Source Categories: Solid Waste Disposal Wastewater Treatment Ethanol Fermentation,". doi: 10.1007/s13770-014-0083-y.

[32] IPCC. 2006. "*IPCC Inventory Software*." IPCC, Switzerland,

[33] IPCC. 2006 *IPCC Guidelines for National Greenhouse Gas Inventories 2*, Energy. Hayam, Japan: Institute for Global Environmental Strategies (IGES).

[34] R. Heijungs et al., 1992, "Environmental life cycle assessment of products: guide and backgrounds (part 1)," Centre of Environmental Science, Leiden.