EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(9), 298–310
https://doi.org/10.12912/27197050/190384
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.06.22
Accepted: 2024.07.10
Published: 2024.08.01

Application of Life Cycle Assessment on Processing of Beef Rendang Products Using Steam Cauldron Technology

Muhammad Fachri Ridwan[1], Rizki Aziz[1*], Rinda Andhita Regia[1]

[1] Environmental Engineering Department, Faculty of Engineering, Universitas Andalas, Kampus Limau Manis, Padang, 25163, Indonesia

* Corresponding author's email: rizkiaziz@eng.unand.ac.id

ABSTRACT

The beef rendang production process at the Payakumbuh Rendang small and medium industry can cause environmental impacts due to the use of energy that produces various emissions, such as using boilers. This research aims to analyze the life cycle of the rendang production process in the form of inventory data, including raw materials, energy, and emissions produced in the production process, and analyze the environmental impact of 250 g packaged rendang, which includes the transportation, storage, washing, cutting, milling, grating, pressing processes, cooking and packaging using the life cycle assessment (LCA) method, and providing recommendations for improvements at stages of the production process. This research uses a gate-to-gate approach on SimaPro 9.4 software with the CML-IA Baseline method and refers to the 2016 ISO 14040 standard. The results of this research show the impact of 250 g of packaged rendang for the global warming potential (GWP100*a*) category of 1.41E-13 kg CO_2 eq, ozone layer depletion 1.45E-16 kg CFC-11 eq, human toxicity 1.06E-14 kg 1.4-DB eq, photochemical oxidation 1.12E-14 kg C_2H_4 eq, acidification 1.07E-13 kg·SO_2·eq, and eutrophication 4.98E-14 kg PO_4 eq. Using electrical energy during storage, packaging, and cooking impacts the environment. Recommendations for improvements given to reduce environmental impacts are that the use of Beef freezers for storing spices can reduce electricity usage in the storage process by 17.9%, optimizing the retort usage time from 1.5 hours to 10 minutes reduces electricity usage in the packaging process by 24%, and the addition of hybrid solar panels for boilers can reduce electricity usage from Coal-Fired Power Plant (PLTU) by 63%. The improvement scenario shows a reduction in electricity use during the production process by 79.1% and a 9–68.4% reduction for all impact categories.

Keywords: CML-IA baseline, environmental impact assessment, gate-to-gate, LCA, rendang.

INTRODUCTION

Indonesia is ethnically and culturally diverse, including traditional customs, food, clothing, and arts. West Sumatra holds a prominent tradition in terms of food (Nurmufida et al., 2017). Rendang is a traditional dish from the Minangkabau tribe in West Sumatra (Tanjung et al., 2020). Rendang is usually cooked using a stove that uses wood and a gas stove. However, along with the times and technology, cooking rendang has developed and uses more modern technology (Gusnita and Filda, 2019). Payakumbuh SMI is the main production site for rendang and is in Padang Kaduduk, Payakumbuh City, West Sumatra. The production house, with an area of ± 1,407.0 m^2, can produce 200–300 kg/day of rendang and has exported to Germany and Norway. Therefore, it is important to conduct LCA research to support the sustainability of rendang products. Some production equipment used are boilers, steam cauldrons, retorts, vacuum sealers, etc. The ingredients used in making rendang are beef, coconut milk, ground chilli, lime leaves, lemongrass, turmeric leaves, salt, etc (Gusnita and Filda, 2019). Rendang production generally includes receiving materials, processing, and packaging (Indriani et al., 2021).

Rendang production houses also impact the environment, which comes from the production process and transportation due to the use of energy that can produce emissions (Akbar and Gusnita, 2020). Based on research results (Fernando et al., 2014) in the tofu industry, using a total energy of 168.22 MJ to produce 315 kg produces CO_2, SO_2, NO_2. Therefore, it is necessary to measure the environmental impact of a rendang product during the product's life cycle (Bulle et al., 2019).

Life cycle assessment (LCA) analyses the environmental impact assessment of a product (goods/services) over its life cycle. LCA follows the ISO 14040:2016 standard on environmental management, life cycle assessment, principles, and framework (Olivier et al., 2016). LCA has four stages: the first stage is the definition of objectives and scope, the second stage is the inventory of data (inputs and outputs) during the product life cycle, the third stage is the calculation of environmental impacts, and the last stage is the interpretation of results and recommendations for improvement (Acero et al., 2016). The use of LCA aims to determine the environmental impact of the product life cycle and assist companies in applying for Eco-label type 3 or environmental product declaration (EPD). Therefore, applying LCA will increase consumers' trust and export destination countries that require environmental impact assessments for each product produced (PRé Sustainability, 2019).

Impact assessments using LCA also have been applied to various products, especially processed food products (Lolo et al., 2021). The production of rendang 'Green Rebels Beefless Randang' or GRBR has an impact of 0.849 $kgCO_2$ eq for the GWP100*a* category (Purnomo, 2021).

Therefore, it is important to analyze the life cycle of the rendang production process and inventory data and calculate the environmental impact of the much-loved rendang product worldwide. This study aims to analyze the environmental impact of the rendang manufacturing process and provide recommendations to improve the life cycle of rendang production activities to make it more sustainable and increase its popularity worldwide.

MATERIAL AND METHODS

LCA was conducted utilizing data from the Ecoinvent database (3.8) and the SimaPro software (version 9.4.0) in conformance with the ISO 14040 and ISO 14044 standards. This section should contain an overview of the attributes of the rendang process under analysis and the essential data required to implement LCA.

Data collection

Data collection consists of a foreground system and a background system. The foreground system is a process that can be measured directly or obtained from the research location (primary data) while the background system is a process that cannot be measured directly and is not data from the Rendang Payakumbuh SMI Centre (secondary data).

Primary data collection was conducted through informal interviews, field observations, and data collection. Field observations focused on all processes for making rendang and observing the waste management process. Direct interviews were conducted with those working in the field to help obtain appropriate data. Furthermore, primary data was collected by requesting existing data in the industry's database. Primary data consists of the transportation of raw materials and distance to the production house, the number of materials needed, the quantity of water required, the type of equipment used, how long it took to use, and the type of rendang packaging used. The research site was sampled thrice to make 250 g rendang. Sampling is done three times to ensure that the data obtained is valid and can be used as a reference in calculations. Calculations are carried out by weighing the weight of the material before and after one stage is completed and observing the time for each process. Sampling data is shown in Table 1 and Table 2.

Secondary data was collected from relevant previous research on all the processes involved in making packaged rendang, books, journals, and the SimaPro database. Secondary used consist of emissions from boilers obtained by the intergovernmental panel on climate change (IPCC) for boilers in the food industry, as shown in Table 3; emissions from electricity use are obtained from the SimaPro database (version 9.4.0) for Indonesia, emissions from transportation are obtained from the IPCC for 1 kg/km are presented in Table 4. The type of vehicle (Putri, 2017), raw material weight (kg), and distance used are obtained from the direct data in the field, as shown in Table 5.

Table 3. Emission CO_2, NO_x, N_2O, CH_4 from boiler

LCA analysis

This LCA analysis uses the SimaPro 9.4 software, which is easy to operate and accessible and used by many researchers and industries

Table 1. Primary data collection for raw material needs in making rendang

No	Item	First sampling for raw material	Second sampling for raw material	Third sampling for raw material	Average seasoning requirement for 250g	Unit
1	Coconut milk	399.3	400.9	400.5	400	gram
2	Meat	251.8	248.7	249.8	250	gram
3	Chili	48.8	49.3	50.8	50	gram
4	Shallots	25.4	25.5	24.9	25	gram
5	Laos	25.3	25.4	25.1	25	gram
6	Garlic	12.4	12.6	12.5	12.5	gram
7	Ginger	7.6	7.4	7.7	7.5	gram
8	Orange leaf	1.1	1.2	1.1	1	gram
9	Turmeric leaf	1.4	1.7	1.5	1.5	gram
10	Bay leaf	1.5	1.5	1.6	1.5	gram
11	Lemongrass	1.0	1.0	1.1	1	gram
Total		775.338	775.3	774.9	750	gram

Table 2. Primary data collection on machine usage

Machine	Process	Power (kw)	Average process usage time for 250 gr (h)	Result (kw/h)
		A	b	a × b
Freezer	Storage	0.468	0.1	0.0468
Chiller		0.08	0.0002	0.016
Beef cutting tool	Cutting	0.75	0.0014	0.00105
Coconut cutting tool		2	0.003	0.006
Seasoning grinder	Milling	2.8	0.00011111	0.000311108
Coconut grating machine	Grating	0.75	0.00556	0.00417
Coconut milk squeezing machine	Squeezing	1.8	0.00556	0.010008
Steam cauldron	Cooking	1.5	0.0292	0.0438
Boiler		12.16	0.0333	0.405
Vacuum sealer	Packaging	0.9	0.0111	0.00999
Continues band sealer		0.65	0.0083	0.005395
Retort		3.5	0.0075	0.04375

Table 4. Fuel usage emissions

Fuel type	Fuel Use for 250 g beef (kg)	NCV (TJ/kg)	Emission	EF (kg/Tj)	Result	Unit	Source
LPG	0.435	0.0000473	Methane (CH_4)	0.9	0.0205755	gCH_4	[IPCC, 2006]
			Nitrogen oxide (industrial source emission factor) (NO_x)	4	0.082238	gNO_x	[IPCC, 2006]
			Carbon dioxide (CO_2)	63100	1.298	gCO_2	[KLHK, 2012]
			Nitrous oxide (N_2O)	0.1	0,00205755	gN_2O	[KLHK, 2012]

worldwide. The LCA for the environmental impact of 250 g rendang packaged was performed in this paper using the ISO 14040 guidelines. It is divided into four stages: goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO-14040, 2006).

Goal and scope definition (system boundaries and functional unit)

During this stage, the unit determines the input and output parameters for the data inventory, allowing system comparison analysis (UNEP/

Table 5. Details of transportations

Raw material type	Type of fuel	Raw material weight (kg)	Distance (km)	Result	Unit	Source
		a	b	a × b		
Beef transportation	Diesel	0.25	2.1	0.525	kgkm	Field observations
LPG transportation	Diesel	0.105	6.7	0.704	kgkm	Field observations
Dry seasoning transportation	Petrol	0.01	1.7	0.017	kgkm	Field observations
Wet seasoning transportation	Petrol	0.14	2.4	0.336	kgkm	Field observations
Packaging transportation	Diesel	0.015	1.284	0.0193	tkm	Interview with employees
Water transportation	Diesel	0.335	2.7	0.905	kgkm	Interview with employees
Coconut transportation	Diesel	1.35	2.4	3.24	kgkm	Field observations

SETAC, 2009). The transportation and production of rendang pose limitations to applying LCA in this study. The limit set in each scenario uses the same function unit, which is 250 g of rendang packaged by SMI Rendang Payakumbuh. This functional unit serves as a baseline for all procedures during this investigation (Kholil et al., 2022).

Life cycle inventory analysis

During this stage, data for LCA analysis is collected, known as inventory data. The inventory analysis begins with the determination of functional units, specifically 250 g rendang packaged. This step modelled a table process with multiple situations, each with its own process. Inventory data can then be used for impact analysis (NSF International, 2017).

Life cycle impact assessment

Inventory analysis data were used to evaluate probable environmental impact and provide interpretable information at the end. SimaPro software automatically calculates impact assessments for modelled scenarios using the CML-IA Baseline method (Huijbregts et al., 2017). Table 6 provides descriptions of the impact categories that were chosen for the CML-IA Baseline method (Muralikrishna and Manickam, 2017). In this impact assessment, only

Table 6. Impact categories description

Impact category	Description	Unit
Global warming potential (GWP100a)	The higher the GWP of a gas, the greater its potential to cause global warming. Some compounds that contribute to GWP 100a include methane (CH_4), carbon dioxide (CO_2), and hydrocarbon fluorides (HFCs) which are used as substitutes for gases that are more harmful to the ozone layer, such as chlorofluorocarbons (CFCs) and halons.	$kgCO_2eq$
Ozone layer depletion	Ozone layer depletion is expressed as a ratio compared to the ozone depletion potential of a reference substance, typically CFC-11 (chlorofluorocarbon-11), which is assigned an ODP value of 1. Substances with higher ODP values have a greater ability to deplete the ozone layer.	$kgPO_4eq$
Human toxicity	Some compounds that contribute to HTP include heavy metals such as mercury, cadmium, and lead, organic chemicals such as pesticides, fossil fuels, and organic volatile compounds such as benzene, toluene, and xylene.	kg1,4-DBeq
Photochemical oxidation	Compounds that contribute to POFP include aliphatic, alkene, and aromatic hydrocarbons, as well as nitrogen and oxygen compounds. Boiler use can contribute to POFPs through emissions of hydrocarbon compounds formed during fuel combustion, especially if combustion is incomplete.	kgC_2H_4eq
Acidification	Compounds that contribute to AP include nitrogen oxides (NO_x), sulphur dioxide (SO_2), and ammonia (NH_3), as well as organic compounds such as acetic acid and formaldehyde. In the production process of rendang, there is potential for emissions of compounds that contribute to AP, especially in the heating and fuel use stages.	$kgSO_2eq$
Eutrophication	Compounds that contribute are nitrogen (N) and phosphorus (PO_4^{3-}) contained in chemicals used in rendang production, such as fertilizers and food additives. The process of rendang production that uses these chemicals can increase EP if the waste from rendang production is not managed properly and directly discharged into the environment without treatment.	$kgPO_4^{3-}eq$

impact characterization and normalization of impact categories were conducted. Characterization factors translate inventory inputs into impact indicators, allowing for direct comparison. Meanwhile, normalization indicators result is comparatively high or low in comparison to existing benchmarks. Weighting and single score are not used in this CML-IA Baseline method (Muralikrishna dan Manickam, 2017).

Life cycle interpretation

At this stage the comparison analysis, contribution analysis, and sensitivity analysis of impacts at each stage are analysed and process recommendations are given to reduce the environmental impacts generated in the process that occurs at that stage.

System boundaries and functional unit

The main objective of this study is to assess, quantify the environmental impacts, and provide improvement recommendations for the life cycle of packaged rendang products. A gate-to-gate approach (transportation and production) was used for this study and a cut-off of 1% was applied in SimaPro software to focus on the largest impacts (hotspots). Characterization and normalization are also used in this study to see the impact of each process so that they can be compared so that it can be compared with other studies. The processes studied include transportation of raw materials, and production (storage, cutting, washing, grinding, grating, squeezing, cooking, and packaging) of rendang. The functional unit (fu) used is defined as the total amount of 250 g of packed rendang. Figure 1 shows the stages and system boundaries considered in this LCA study.

Inventory analysis

Material flows, energy consumption, and natural resources were obtained from the appropriate authorities at each site involving processes in the LCA. Energy consumption was determined based on fuel and electricity consumed during material transportation and processing.

Stage I – transportation of the raw materials

Raw materials are transported to a processing factory to produce the final 250 g rendang packaged. The vehicles that are used for this transportation use two different fuels, which are solar and petrol. At this stage, the collected data are the types of vehicles, distance travelled, weight, and quantity of materials used.

Stage II – production of 250 g rendang packages

The production of 250 g rendang packages is being considered at this stage. Eight production processes include storage, cutting, washing, milling, coconut grating, squeezing, cooking, and packaging. Inventory analysis includes materials, raw materials, energy consumption, and natural resources shown in Table 7. The calculations in the inventory data table have gone through data collection for each process and were carried out three times to ensure that

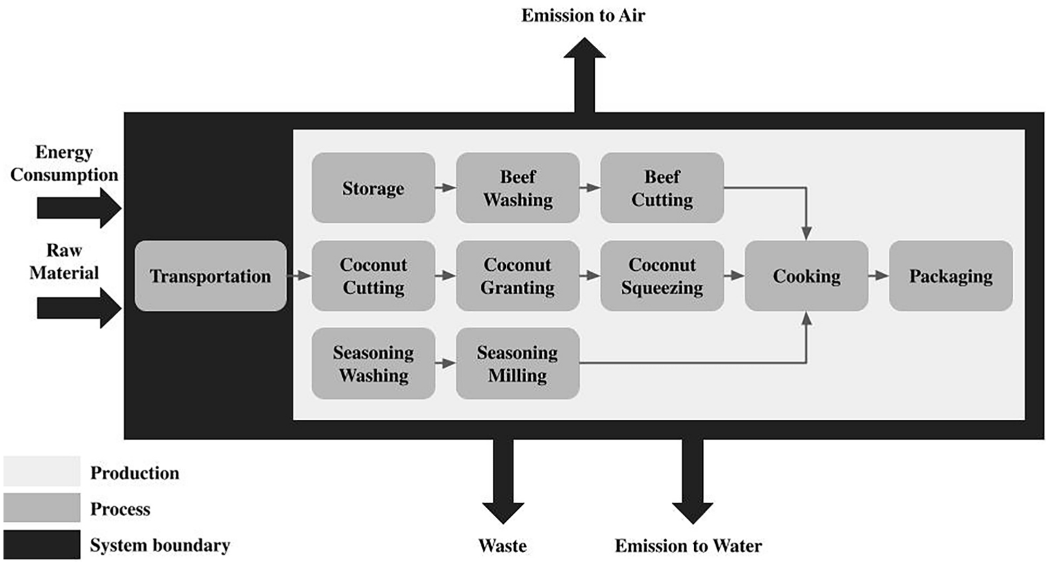

Figure 1. The system boundaries of 250 g rendang packaged

Table 7. Life cycle inventory 250 g rendang packaged for each unit process

No	Process	Parameter	Total	Unit	Source
Transportation of raw materials					
1	Input	Beef transport	0.525	kg/km	Existing condition
		Coconut transport	3.24	kg/km	Existing condition
		Gas transport	0.7035	kg/km	Existing condition
		Water transport	0.9045	kg/km	Existing condition
		Dry seasoning transport	0.017	kg/km	Existing condition
		Wet seasoning transport	0.336	kg/km	Existing condition
		Transport packaging	19.26	kg/km	Existing condition
	Output	Petrol			
		Nitrogen oxide (NO)	3.1	g/kg FUEL	[IPCC, 2006]
		NMVOC	3.85	g/kg FUEL	[IPCC, 2006]
		Carbon monoxide (CO)	50	g/kg FUEL	[IPCC, 2006]
		Carbon dioxide (CO_2)	3.173	g/kg FUEL	[IPCC, 2006]
		Methane (CH_4)	0.3	g/kg FUEL	[IPCC, 2006]
		Solar			
		Nitrogen oxide (NO)	5.68	g/kg FUEL	[IPCC, 2006]
		NMVOC	2.32	g/kg FUEL	[IPCC, 2006]
		Carbon monoxide (CO)	72	g/kg FUEL	[IPCC, 2006]
		Carbon dioxide (CO_2)	3200	g/kg FUEL	[IPCC, 2006]
		Methane (CH_4)	0.06	g/kg FUEL	[IPCC, 2006]
		Raw material			
		Beef	250	g	Existing condition
		Dry seasoning	0.005	kg	Existing condition
		Wet seasoning	0.12	kg	Existing condition
		Coconut	1.35	kg	Existing condition
		Primary packaging	1	pcs	Existing condition
		Secondary packaging	1	pcs	Existing condition
		Gas	0.105	kg	Existing condition
		Gallon water	0.335	kg	Existing condition
Storage					
2	Input	Beef	250	g	Existing condition
		Electricity (ID) (freezer and chiller)	0.0628	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
	Output	Beef	250	g	Existing condition
Cutting					
3	Input	Coconut	1.35	kg	Existing condition
		Seasoning	0.150	kg	Existing condition
		Beef	250	g	Existing condition
		Electricity (ID) (beef cutting tool)	0.00105	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
		Electrical energy (coconut cutting tool)	0.006	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
	Output	Plastic wrap	0.30	kg	Existing condition
		Seasoning	0.010	kg	Existing condition
		Coconut water	0.355	kg	Existing condition
		Coconut coir	0.450	kg	Existing condition
Washing					
4	Input	Seasoning	0.140	kg	Existing condition
		Beef	250	g	Existing condition
		Clean water	0.750	Kg	Existing condition
	Output	Seasoning	0.125	kg	Existing condition
		Beef	250	g	Existing condition
		Wastewater	0.750	kg	Existing condition

Cont. Table 7.

No	Process	Parameter	Total	Unit	Source
Milling					
5	Input	Electricity (ID) (seasoning grinder)	0.00031	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
		Seasoning	0.140	kg	Existing condition
	Output	Fine seasoning	0.125	kg	Existing condition
Grating					
6	Input	Electricity (ID) (coconut grating machine)	0.00417	kWh	Existing condition
		Coconut beef	0.365	kg	Existing condition
		Shell	0.18	kg	Existing condition
	Output	Shell	0.18	kg	Existing condition
		Coconut beef	0.365	kg	Existing condition
Squeezing					
7	Input	Electricity (ID) (coconut milk squeezing machine)	0.010008	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
		Coconut beef	0.365	kg	Existing condition
		Gallon water	0.335	kg	Existing condition
	Output	Coconut beef dregs	0.3	kg	Existing condition
		Coconut milk	0.4	kg	Existing condition
Cooking					
8	Input	LPG Gas (250 g)	0.435	kg	Existing condition
		Beef	250	g	Existing condition
		Seasoning	0.140	kg	Existing condition
		Coconut milk	0.4	kg	Existing condition
		Electricity (ID) (cauldron steam)	0.0438	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
		Electricity (ID) (boiler)	0.203	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
	Output	Nitrogen dioxide	0.000082238	g/kg LPG	Existing condition
		Methane (CH_4)	0.0000185	g/kg LPG	Existing condition
		Carbon dioxide (CO_2)	1.298	g/kg LPG	Existing condition
		Nitrogen oxide (N_2O)	0.00205755	g/kg LPG	Existing condition
		Beef	0.175	kg	Existing condition
		Coconut milk	0.054	kg	Existing condition
		Fine seasoning	0.021	kg	Existing condition
Packaging					
9	Input	Primary packaging	0.010	kg	Existing condition
		Secondary packaging	0.015	kg	Existing condition
		Electricity (ID) (continuing band sealer)	0.005395	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
		Electricity (ID) (vacuum sealer machine)	0.00999	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
		Coconut milk	0.054	kg	Existing condition
		Fine seasoning	0.021	kg	Existing condition
		Beef	0.175	kg	Existing condition
		Electricity (ID) (retort)	0.02625	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
		Electricity (ID) (boiler)	0.203	kWh	https://doi.org/10.1787/enestats-data-en (ecoinvent 2.3.0.0) (data valid for entire period)
	Output	Nitrogen dioxide	0.000082238	g/kg LPG	Existing condition
		Methane	0.0000185	g/kg LPG	Existing condition
		Carbon dioxide (CO_2)	1.298	g/kg LPG	Existing condition
		Nitrogen oxide (N_2O)	0.00205755	g/kg LPG	Existing condition
		Rendang packaging	250	g (Netto)	Existing condition

the data obtained before and after each process unit can be accounted for. All data inputted into the SimaPro software version 9.4.0 for impact analysis is shown in Table 7.

RESULT AND DISCUSSION

Environmental impact assessment

This stage was carried out using the CML-IA Baseline method. This method was chosen because of its overall environmental impact assessment, covering greenhouse gas emissions, energy consumption, and because of the availability of an established databases (Iswara et al., 2020). Based on the characterization as shown in Table 8, all processes in the production of 250 g rendang packaging have an impact on the environment. The packaging process provides the highest environmental impact value in the impact category, namely global warming 100*a* of 0.312E-01 kg CO_2 eq (44.1%), ozone layer depletion of 5.72E-09 kg CFC-11 eq (44.2%), human toxicity by 3.62E-02 kg 14-DB eq (44.5%), photochemical oxidation by 4.17E-05 kg C_2H_4 (44.8%), acidification by 1.33E-03 kg SO_2 (46.5%), eutrophication by 2.91E-04 kg PO_4 (46.8%). The second largest impact after packaging is the cooking process, this process has an impact on global warming 100*a* of 2.94E-01 kg CO_2 eq (41.52%).

Normalization result shown in Table 9, it indicates that the impact category with the highest value is global warming, with an amount of 1.41E-13 and dominates the overall impact with percentage of 44% followed by acidification 33% and eutrophication 16%.

Interpretation

Life cycle interpretation (LCI) is a method for identifying, quantifying, verifying, and evaluating information derived from inventory analysis results. The inventory analysis and impact assessment results are summarized during the interpretation phase. The interpretation should structure the LCI phase results to assist in determining the significant issues by the goal and scope definitions and in collaboration with the evaluation

Table 8. Characterization result impact assessment

Impact category	GWP100*a*	ODP	HT	PO	Acd	Eut
Unit	kgCO_2 eq	kgCFC-11 eq	kg1,4-DB eq	kgC_2H_4 eq	kgSO_2 eq	kgPO_4^-eq
Transportation	1.27E-03	0.00E+00	2.69E-06	7.70E-07	1.12E-06	2.91E-07
%	0.18	0.00	0.00	0.81	0.04	0.04
Storage	7.46E-02	1.37E-09	8.69E-03	9.99E-06	3.14E-04	6.84E-05
%	10.55	10.60	10.59	10.50	10.45	10.43
Cutting	8.38E-03	1.54E-10	9.75E-04	1.12E-06	3.53E-05	7.68E-06
%	1.18	1.19	1.19	1.18	1.17	1.17
Washing	1.61E-05	3.51E-13	4.42E-06	5.16E-09	5.02E-08	6.41E-09
%	0.00	0.00	0.01	0.01	0.00	0.00
Milling	3.70E-04	6.80E-12	4.30E-05	4.95E-08	1.56E-06	3.39E-07
%	0.05	0.05	0.05	0.05	0.05	0.05
Grating	4.96E-03	9.12E-11	5.77E-04	6.63E-07	2.09E-05	4.54E-06
%	0.70	0.70	0.70	0.70	0.69	0.69
Squeezing	1.19E-02	2.19E-10	1.38E-03	1.59E-06	5.00E-05	1.09E-05
%	1.68	1.69	1.69	1.67	1.67	1.66
Cooking**	2.94E-01	5.39E-09	3.41E-02	3.92E-05	1.25E-03	2.74E-04
%	41.54	41.58	41.59	41.26	41.68	41.70
Packaging*	3.12E-01	5.72E-09	3.62E-02	4.17E-05	1.33E-03	2.91E-04
%	44.10	44.17	44.18	43.82	44.24	44.25
Total	7.08E-01	1.30E-08	8.20E-02	9.51E-05	3.00E-03	6.57E-04
%	89	0	10	0	0	0

Note: * highest impact, ** second highest impact.

Table 9. Normalization result impact assessment

Impact category	GWP100*a*	ODP	HT	POD	Acd	Eut
Transportation	2.53E-16	0.00E+00	3.47E-19	9.08E-17	3.98E-17	2.21E-17
%	0.18	0.00	0.00	0.81	0.04	0.04
Storage	1.49E-14	1.54E-17	1.12E-15	1.18E-15	1.11E-14	5.19E-15
%	10.55	10.60	10.59	10.50	10.45	10.43
Cutting	1.67E-15	1.73E-18	1.26E-16	1.32E-16	1.25E-15	5.82E-16
%	1.18	1.19	1.19	1.18	1.17	1.17
Washing	3.20E-18	3.93E-21	5.70E-19	6.09E-19	1.78E-18	4.86E-19
%	0.00	0.00	0.01	0.01	0.00	0.00
Milling	7.36E-17	7.62E-20	5.55E-18	5.84E-18	5.52E-17	2.57E-17
%	0.05	0.05	0.05	0.05	0.05	0.05
Grating	9.86E-16	1.02E-18	7.44E-17	7.83E-17	7.40E-16	3.44E-16
%	0.70	0.70	0.70	0.70	0.69	0.69
Squeezing	2.37E-15	2.45E-18	1.79E-16	1.88E-16	1.78E-15	8.27E-16
%	1.68	1.69	1.69	1.67	1.67	1.66
Cooking**	5.85E-14	6.03E-17	4.40E-15	4.63E-15	4.45E-14	2.08E-14
%	41.54	41.58	41.59	41.26	41.68	41.70
Packaging*	6.19E-14	6.41E-17	4.67E-15	4.92E-15	4.72E-14	2.20E-14
%	44.11	44.17	44.18	43.82	44.24	44.25
Total	1.41E-13	1.45E-16	1.06E-14	1.12E-14	1.07E-13	4.98E-14
%	44	0	3	4	33	16

Note: * highest impact, ** second highest impact.

element (Hernandez et al., 2019). A comparative analysis was carried out to compare each process stage in each category of environmental impacts assessed using the CML-IA Baseline method. Contribution analysis is used to identify the process that contributes most to the impact assessment results. In addition, a sensitivity analysis was conducted to determine how much the impact reduction for each process was influenced by reducing the impact component in the process that made the dominant contribution. The most sensitive or impactful process should be selected for improvement. A scenario recommendation was conducted to determine the best scenario that can be applied to reduce the environmental impact of producing 250 g of packaged rendang. Determining the processes that need to be improved is based on the results of the sensitivity analysis. The interpretation results are presented in the next section.

Comparative analysis

The results of the comparative analysis were obtained from SimaPro software. Figure 2 shows that the percentage value of packaging and cooking impact dominates almost all impact categories known as hotspots. The comparison results of Figure 2 show that the process with the highest impact for GWP100*a* is the packaging process of 3.12E-01 kg CO_2 eq. In this packaging, several machines are used: retort, vacuum sealer, and continuous sealer. For retort, in 1-time, users can spend 1.5 hours with 120 pouches that can be entered. The next process with the biggest impact is the cooking process with a GWP100*a* of 2.94E-01 CO_2 eq. The process that has the next biggest impact on the global warming category is storage, which is 7.46E-02 kg CO_2 eq.

Contribution analysis

CO, CO_2, CH_4, and N_2O dominate GWP100*a* impacts. The four emissions are caused by using electricity in each 250g rendang packaging production process. CO_2 contributes most to the environmental impact at 1.36E-13 (96.8%). The CO_2 content emitted by the packaging process has the highest GWP100*a* impact of 6.02E-14 (44.2%). The impact of ozone layer depletion (ODP) is caused by the

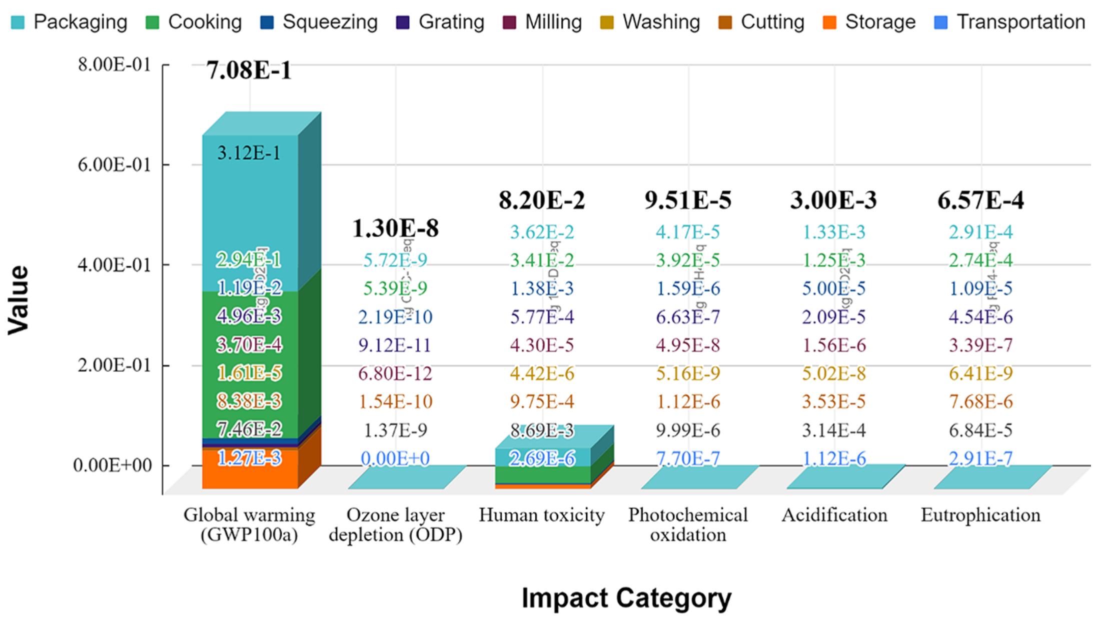

Figure 2. Comparison of the environmental impact on each unit process

emission of Halon 1211, Halon 1301, and CFC-10 from the retort and sealer machines using electrical energy. The total contribution of the packaging process to the ODP impact is 6.31E-17 (43.5%). The impact of the packaging process dominates the impact of human toxicity. The main content is HF and PM2.5. HF emissions are generated mostly using electricity in the raw material packaging process at 1.22E-15 (26%), while PM2.5 is 7.21E-16 (15.4%). SO_2 and CO dominate photochemical oxidation. The packaging process produces SO_2, which affects this impact by 4.25E-15 (86.4%), and CO in the packaging process plays the most role by 2.35E-16 (4.79%). Acidification impacts are dominated by electricity use by the packaging process. Two main emissions cause acidifications, namely SO_2 and NO_x. The amount of SO_2 gas from the packaging process as a cause of acidification is 7.24E-14 (67.9%), followed by NO_x at 3.27E-14 (30.6%). In eutrophication, phosphate made the dominant contribution in this study, PO_4^{3-}3.01E-14 (60.5%), followed by NO_x 1.81E-14 (36.4%).

Sensitivity analysis

Sensitivity analysis is conducted on processes that contribute significantly to each impact category based on the results of the contribution analysis. The packaging and cooking processes will be analyzed because they have a large environmental impact. Based on the previous contribution analysis results, the reduced component of these three processes is the use of electrical energy. The use of electrical energy in this process has the largest impact, according to Table 10, which produces 250 g of packaged rendang. Sensitivity analysis scenarios (SV) are categorized as follows: SV 1 involves a 5% reduction in electricity used during the cooking process, while SV 2 proposes a more substantial 10% reduction. SV 3 focuses on a 5% decrease in electricity consumption during the packaging phase, and SV 4 explores a larger 10% reduction in packaging-related electricity use. SV 5 targets a 5% decrease in electricity usage during storage activities, while SV 6 proposes a more significant 10% reduction in electricity consumption in storage processes.

Table 10 shows that the six scenarios created and planned by reducing certain components show differences in environmental impact values. Reduction in the cooking process provides a reduction in impact of 1.24–2.53% in all impact categories. In the packaging process, a reduction of 5% to 10% causes a reduction in environmental impact of 1.29% to 2.58% in all impact categories. The storage process reduces the impact by 0.48% to 0.96%. The design of the six scenarios provides three processes (packaging, cooking, and storage) sensitive to changes in impact.

Table 10. Sensitivity analysis result

Analysis result	Impact category					
	GWP100a	ODP	HT	PO	Acd	Eut
Initial	100%	100%	100%	100%	100%	100%
SV 1	98.76%	98.76%	98.76%	98.75%	98.76%	98.76%
SV 2	97.47%	97.47%	97.47%	97.47%	97.46%	97.46%
SV 3	98.72%	98.72%	98.72%	98.71%	98.72%	98.72%
SV 4	97.42%	97.42%	97.42%	97.43%	97.42%	97.42%
SV 5	99.52%	99.52%	99.52%	99.53%	99.53%	99.53%
SV 6	99.04%	99.04%	99.04%	99.05%	99.05%	99.06%

Scenario recommendation

Based on the sensitivity analysis results, packaging, cooking, and storage are the processes that have the greatest impact. Therefore, the improvement recommendations that can be given for the 250 g rendang process production process are using one freezer machine, optimizing sterilization time (production management), and using hybrid solar panels. A study (Koide et al., 2022) on storing some vegetables in frozen conditions in Beef freezers showed that the vegetables remained fresh. Apart from using one freezer machine, the sterilization process could be more effective, namely the time needed to use the machine. A retort can be used at a temperature setting of 190 °C with a sterile temperature hold of 10 minutes to achieve the goal of destroying target microorganisms with a lethality value (Fo) of 10.38 minutes. Originally 1.5 hours, the retort became 10 minutes (Praharasti et al., 2014). Identification of the central temperature in the pouch sterilization process was also carried out by Bhowmik (1987) with an autoclave room setting temperature of 121 °C. The experiment also showed that the centre temperature did not reach the sterilization temperature of 121 °C. Based on these things, it is proven that if you want the centre temperature to reach the sterilization temperature, the retort (Troom-TR) setting temperature must be higher than 121 °C (Praharasti et al., 2014).

An improvement analysis can also be done on electricity use, which plays a role in production. Electricity used in the Rendang Payakumbuh SMI Centre comes from a Coal-Fired Power Plant (PLTU) with coal fuel, which can cause an environmental impact of 1.14 kg/kWh (Budi and Suparman, 2014). In the rendang production process at the Payakumbuh Rendang SMI Centre, boilers consume the most electrical energy, so they have a high environmental impact. Therefore, using hybrid solar panels on boilers can reduce the environmental impact of the production process and make it more environmentally friendly (Kinasti et al., 2019). Solar panel technology is considered a solution to answer energy transition innovations and meet increasing energy needs. Solar panel energy development technology continues to progress and innovate. In response to the United Nations (UN) climate plan at the conference (COP26), which targets limiting temperature rise to 1.5 °C, with more than 100 countries achieving net-zero emissions commitments by 2050 (Kinasti et al., 2019). Indonesia is a country that has great opportunities in the development of solar panel technology. Solar panels are not only sustainable energy but also renewable energy due to their inexhaustible source. On a large scale, Indonesia benefits from being located on the equator with high radiation levels, including the provinces of West Sumatra, Riau, West Kalimantan, Central Kalimantan, Central Sulawesi, Maluku Islands with a total untapped potential of 207,900 MW (Sianipar et al., 2022).

Based on the improvement recommendations above, we can carry out calculation analysis using SimaPro, the results can be seen on Figure 3:

Figure 3 indicates that the GWP100a impact category is reduced in scenarios I, II, and III. The reductions in GWP100a are 1,37E-13 (97,3%), 1,31E-13 (93,1%), and 4,50E-14 (32%) for scenarios I, II, and III, respectively. Based on the current study's findings, solar panels are more sustainable than the normal scenario in terms of EC and greenhouse gas emissions because lower levels of energy consumption and greenhouse gas emissions have been achieved. Finally, it is recommended

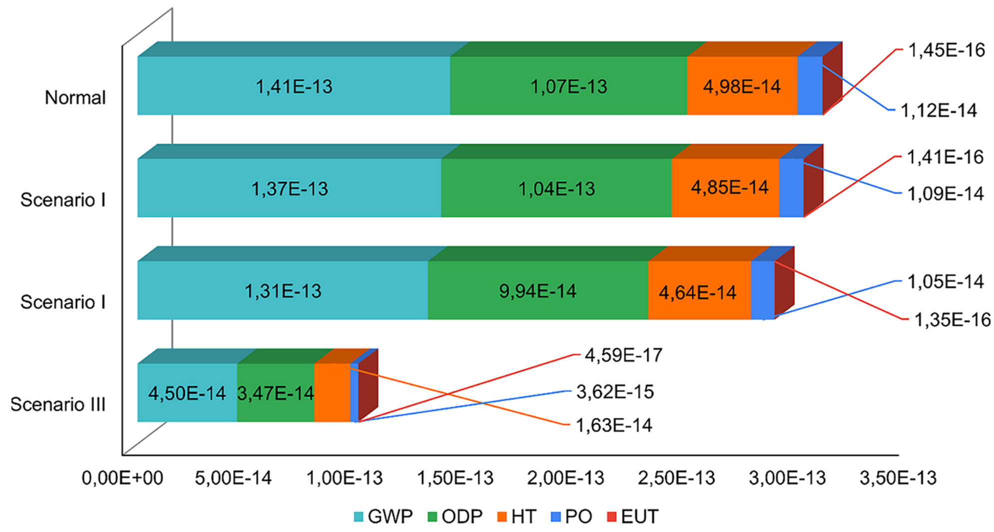

Figure 3. Comparison normalization for each scenario

that a solar power plant be built to reduce greenhouse gas emissions and environmental impacts that can occur in the production of packaged rendang processing to make it more sustainable.

Study limitation

Calculation of emissions generated by the boiler does not use direct sampling emission. The emissions from using boilers are calculated by calculating the fuel (LPG) used to make 250g rendang. The calculation of the total use of boiler fuel consumption is obtained by using the calorific value from the calculation of the theoretical calorific value of LPG (low heating value) and then finding the heat requirement of the boiler according to the type listed on the machine so that the enthalpy value of the boiler is obtained with the help of calc steam software. Another limitation is the need for more information on the distribution of electrical energy supplied for the cooking and packaging process because it uses steam generated by the boiler. A thorough evaluation of the system under study will result from including this additional data in the analysis. In addition, examining the environmental impact and electricity usage is the main objective of this study to compare it with other studies using different and traditional methods. The researchers remain committed to being clear and precise when discussing the fundamental components of environmental impact. Nonetheless, the authors may prioritize a clearer and more straightforward analysis of life cycle impacts on the environment by presenting a complete interpretive analysis with additional sensitivity analysis.

CONCLUSIONS

This study assessed the product life cycle of 250 g rendang packaged: transportation, storage, cutting, washing, milling, coconut grating, squeezing, cooking, and packaging. Normalization at the environmental impact assessment stage for the most influential impact is global warming, with a value of 1.40E-13, and the process that provides the highest environmental impact (hotspots) is packaging, with a value of 6.19E-14. The recommendations scenario shows that all impact categories decreased by 9–68.4%. This decrease was due to the use of machines that were initially inefficient to become more efficient. Changing retort usage in the sterilization process from 1.5 hours to 10 minutes can reduce electrical energy consumption by 16.1%. Adding hybrid solar panels to the boiler shows a large reduction in electrical energy consumption by 63% and a reduction in environmental impact. A decrease in all impact categories evidence this. Therefore, based on the design of the three scenarios above, the best choice lies in scenario 3 to improve the environmental quality and sustainability of rendang production.

REFERENCES

1. Huijbregts, M.A.J., Steinmann, Z.J.N., Elshout, P.M.F., Stam, G., Verones, F., Vieira, M.D.M., Hollander, A., Zijp, M., Zelm, R. 2017. ReCiPe 2016 v1.1 A harmonized life cycle impact assessment method at midpoint and endpoint level Report I: Characterization.
2. Indriani, V., Apriantini, A., Suryati, T. 2021. Application of GMP and SSOP in the Production Process of Beef Rendang at Istana Rendang Jambak Rendang Producer. Journal of Production Science and Technology of Animal Products, 9(3), 127–137. https://doi.org/10.29244/jipthp.9.3.127-137. (in Indonesian).
3. IPCC. 2006. Chapter 2: Stationary Combustion. 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
4. ISO-14040. 2006. Environmental management-life cycle assessment-principals and framework. International Standard ISO 14040. In: International Organization for Standardization-ISO Geneva, Switzerland.
5. Iswara, A.P., Farahdiba, A.U., Nadhifatin, E.N., Pirade, F., Andhikaputra, G., Muflihah, I., Boedisantoso, R. 2020. a comparative study of life cycle impact assessment using different software programs. IOP Conference Series: Earth and Environmental Science, 506(1). DOI:10.1088/1755-1315/506/1/012002
6. Kholil, P.A., Budihardjo, M.A., Muhammad, F., Karno, K. 2022. Life cycle assessment of fuel distribution process at PT Pertamina (Persero) fuel terminal parepare. Journal of Environmental Science, 20(3), 685–695. https://doi.org/10.14710/jil.20.3.685-695. (in Indonesian)
7. Kinasti, Rr. M.A., Puti, D., Lestari, E., Sofyan, M., Wirantina, I., Hidayawanti, R., Sangadji, I. BM. 2019. Socialization and installation of solar panels as renewable energy towards emission-free Indonesia environmental awareness. Journal of Community Service Illuminating the Country, 2(1) (in Indonesian)
8. Koide, S., Ito, T., Osuga, R., Orikasa, T. 2022. Assessment of cumulative freezing frequency of supercooled fresh-cut onion: Effects of sample size, supercooling temperature, and supercooled storage time. Journal of Agriculture and Food Research, 10, 100440. https://doi.org/10.1016/j.jafr.2022.100440
9. Lolo, E.U., Gunawan, R.I., Krismani, A.Y., Pambudi, Y.S. 2021. environmental impact assessment of tofu industry using life cycle assessment (Case Study: Sari Murni Tofu Factory, Kampung Krajan, Surakarta). Serambi Engineering, 4. https://doi.org/10.32672/jse.v6i4.3480. (in Indonesian)
10. Muralikrishna, I.V., Manickam, V. 2017. Life cycle assessment. in environmental management (57–75). Elsevier. http://dx.doi.org/10.1016/B978-0-12-811989-1.00005-1
11. NSF International. 1997. ISO 14040: Environmental Management – Life Cycle.
12. Nurmufida, M., Wangrimen, G.H., Reinalta, R., Leonardi, K. 2017. Rendang: The treasure of Minangkabau. In Journal of Ethnic Foods, 4(4), 232–235. Elsevier B.V.
13. Olivier, J., Saadé-Sbeih, M., Shaked, S., Jolliet, A., Crettaz, P. 2019. Environmental life cycle assessment. https://doi.org/10.1201/b19138
14. Praharasti, A.S., Herawati, E.R.N., Nurhikmat, A. 2014. Environmental impact assessment of tofu industry using life cycle assessment (Case Study: Sari Murni Tofu Factory, Kampung Krajan, Surakarta). Proceedings of the National Seminar on Food Feed and Renewable Energy Synergy, 463–467. https://doi.org/10.55927/eajmr.v2i3.3480. (in Indonesian).
15. PRé Sustainability. 2019. Introduction to LCA and modelling using GaBi.
16. Purnomo, J.I. 2021. Environmental of Green Rebel's Beefless Rendang Through Life Cycle Assessment (LCA) Approach. Bio Scientia International Institute Indonesia.
17. Putri, H. 2017. Life cycle assessment (LCA) of emissions in the gasoline fuel oil (BBM) production process with the analytical hierarchy process (AHP) method approach. Sepuluh Nopember Institute of Technology. (in Indonesian)
18. Sianipar, R., Sidik Boedoyo, M., Sasongko, N.A. 2022. Application of LCA (life cycle assessment) to solar energy development in Indonesia. In International Journal of Innovative Science and Research Technology, 7(3). https://doi.org/10.5281/zenodo.6372469
19. Tanjung, N., Manugeren, M., Purwarno, P. 2020. philosophical meanings of traditional cuisine Rendang Minangkabau as a cultural heritage of Indonesia. https://doi.org/10.30743/aicll.v2i1.81. (in Indonesian)