Life Cycle Evaluation of Frozen Okra by Using Parameter Screening Method

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Abstract

Different methodologies of Life Cycle Assessment (LCA) have been developed all over the world, however, the full implementation of LCA for SMEs is difficult due to its complexity, time consumption and the high cost. These problems were partly solved by using the experience in the development of a "Streamlined LCA" for SMEs. A parameter screening method was applied in the case study of frozen okra which is just one of the highly exported agricultural products of Thailand. The life cycle environmental impacts of this product were evaluated using a method called "Environmentally Responsible Product Assessment (ERPA)". The objective of this research was to identify and quantify the environmental impacts of frozen okra from plantation, manufacturing, transportation, consumption and disposal. The environmental impact can be classified into 5 environmental stressors, which are material procurement, energy consumption, solid waste, wastewater and air pollution. The environmental impact was assessed by rating the collection at the highest impact level for each parameter, such as fertilizers, chemical use, heavy oil use, and direct emissions from energy consumption. All of the rating values were calculated based on the panel weighing method. Finally, the environmental stressors of the whole life cycle stage were shown in the form of target plots with a 25-element matrix. The overall rating (R_{ERP}) was 55.93, and coolant (ammonia and R-22) and energy consumption in the manufacturing stage are regarded as hot-spots. In addition, greenhouse gases from the manufacturing and transportation stages are critical parameters that need to be reduced to increase the environmental friendliness of production.

Key words: Environmentally responsible product assessment/ Life cycle assessment/ Frozen okra/ Screening LCA/ Streamline LCA

1. Introduction

Okra has a variety of good nutritional properties. The main cultivation areas in Thailand are located in Ratchaburi, Kanchanaburi, Nakhonpathom, Suphanburi, Chiang Rai and Chiang Mai. Frozen Okra is one of the most popular vegetables produced for export. In 2010, the number of okra exports was 1,102 tons or 136 Million Baht (National Food Institute, 2010). Its export value is ranked in the top three, after cauliflower and beans. The export market is mainly, Japan, which occupies 94% of that market. However, the Japanese market is not only careful about food safety and food quality but also environmentally conscious products have to comply with the eco-standard such as eco-leaf labeling. Therefore, in order to determine the environmental impact of the resources, greenhouse gas, water pollution, solid waste and energy consumption, a life cycle assessment needs to be applied for overall evaluation and improvement of a product.

Life Cycle Assessment (LCA) is a technique for assessing the environmental aspect and potential impacts throughout a product's entire life cycle from raw material acquisition through to production, use and disposal. This is achieved by complying an inventory of the relevant inputs and outputs in the product's system, evaluating the results of the inventory analysis and implementing impact assessment phases in relation to the objectives of the study. It can also aid

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in identifying opportunities to improve the environmental aspects of the product, at various points in the life cycle, decision-making in the strategic planning of the product/process design, the selection of relevant indicators of environmental performance, and marketing. In this paper, streamlined life cycle thinking is applied and the environmental impact is assessed using the Environmentally Responsible Product Assessment (ERPA) method. This product is divided into five main processes: cultivation; manufacturing; transportation; use; and disposal (Table 1).

Table 1 Inventory data sorted by life cycle stage

INPUT	Life Cycle Stage	OUTPUT
- Material	1. Cultivation	- Product
- Energy	2. Manufacturing	- Waste Effluents
	3. Transportation	- Air Emission
	4. Use	- Solid Waste
	5. Disposal	- Other Impacts i.e. GHGs

1.1 Goal and scope definition

The main goal of this case study was to evaluate the environmental impact, and identify the key issues, associated with the life cycle of frozen okra production using the ERPA method. This includes all steps of the life cycle that play a vital role and have the most significant environmental input and output flows.

1.2 The functional unit

The functional unit (FU) is defined as 1 kilogram of frozen okra.

1.3 The inventory analysis and data collection

The inventory data set was taken from 2010-2011. The inventory data for frozen okra production were collected from a factory in Chiang Mai. The transportation; okra was collected from a factory in Chiang Mai and taken to Bangkok in a mid-size truck (a full load is equal to 16 tonnes).

2. Materials and Methods

The Environmentally Responsible Product Assessment (ERPA) method is a useful tool to qualify and quantify the environmental impact of a product. It can reduce the methodological complexities and resource investment, as well as being developed for screening LCAs [11]. The steps used to evaluate the environmental impacts followed the LCA framework (Figure 1). The evaluation steps were divided into 3 sections; A) creation of evaluation forms; B) data collection; C) assessment and analysis.

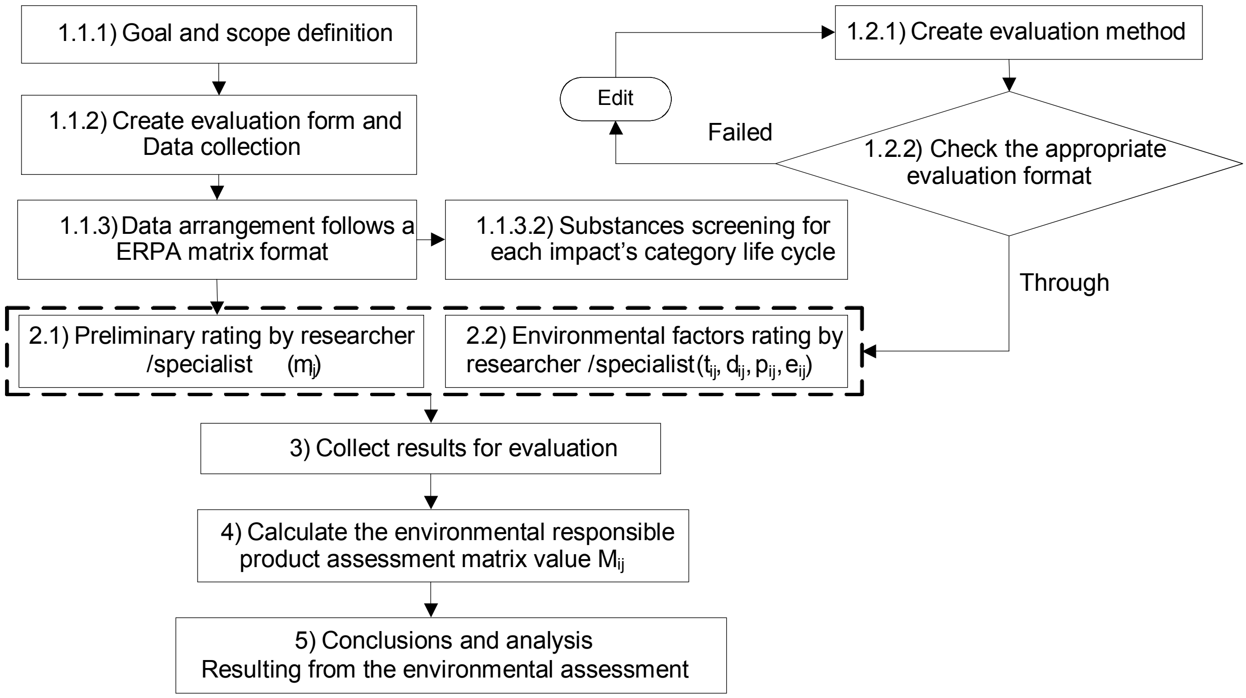

Figure 1 Steps in the environmental impacts evaluation using the ERPA method.

ERPA is calculated on a 5x5 assessment matrix, with one dimension being the life cycle stages and the others being the environmental stressors (Table 2) assigned to each element of the matrix. This is an integrated rating from 0, the highest impact and a highly negative evaluation, to 4, the lowest impact and an exemplary evaluation. The LCA steps are related to the particular circumstances in which environmental changes occur. For example the time scales spatial scale of the impact, severity of the hazard, and degree of exposure.

The matrix element values were calculated using equation (1). The result was that the matrix element values take circumstant factors into account. After the assignment and calculation of each matrix element, the overall Environmentally Responsible Product Rating (R_{ERP}) was calculated as the sum of the matrix element values in equation (2).

$$\mathbf{M_{ij}} = \frac{m_{ij}\,(t_{ij}+d_{ij}+p_{ij}+e_{ij})}{16} \quad (1)$$

$$R_{ERP} = \Sigma_i \Sigma_j \mathbf{M_{ij}} \quad (2)$$

t_{ij} is the time scale over which the stress acts
d_{ij} is the spatial scale over which the stress acts
p_{ij} is the degree of peril attributed to the stress
e_{ij} is the degree of exposure
m_{ij} is the unlocalization matrix element value

Table 2 The Environmental Responsible Product Assessment Matrix: $\mathbf{M_{ij}}$

Life Cycle Stage	Environmental Stressors				
	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues
Pre-Manufacture	1,1	1,2	1,3	1,4	1,5
Manufacture	2,1	2,2	2,3	2,4	2,5
Product Delivery	3,1	3,2	3,3	3,4	3,5
Product Use	4,1	4,2	4,3	4,4	4,5
Disposal	5,1	5,2	5,3	5,4	5,5

3. Results and Discussion

The life cycle system boundary of frozen okra is divided into five stages; cultivation; manufacturing processes; transportation; use (consumption) and disposal. The inventory data for1 kilogram of frozen okra from life cycle perspective are provided in Tables 3.

Table 3 Input data for the cultivation stage

Life Cycle	Sub Process	Input		
		Data Category		Quantity/Unit
1. Cultivation Stage	1.1 Land Preparation	Energy	Diesel fuel	5 Liters
		Machinery	Tractor	1 Car
	1.2 Seed Preparation	Energy	Labor	2 People
		Resource	Okra seed	0.5 Kilograms
			Methomyl 40% SP	20 Grams/ water 20 Liters
			Acetamiprid 2.85% W/V (3%W/W)EC	5 Grams/ water 20 Liters
	1.3 Planting	Energy	Labor	2 People
		Equipment	Hoe	2 Specs
	1.4 Seedling	Energy	Labor	2 People
		Resource	Water (Natural sources)	NA
			46-0-0 Fertilizer	25 Kilograms
			45-15-15 Fertilizer	50 Kilograms
		Equipment	Hoe	2 Specs
	1.5 Cultivation/ Fertilization	Energy	Labor	-
		Resource	46-0-0 Fertilizer	25 Kilograms
			15-15-15 Fertilizer	100 Kilograms
			14-14-21 Fertilizer	100 Kilograms
	1.6Water	Energy	Electricity	0.6 kWh/time
		Resource	Water	7-10 days/time
		Equipment	Water Pump	1 Machine

Table 4 Output data of the cultivation stage

Life Cycle	Sub Process	Output		
		Data Category		Quantity/Unit
1. Cultivation Stage	1.1 Field Preparation	Solid residue	-	-
		Contamination	Emission from burning 1 Liter of diesel fuel.	-
	1.2 Seed Preparation	Solid residue	Carcass of chemical packaging (plastic bottles)	2 bottles
		Contamination	-	-
	1.3 Hole Preparation	Solid residue	-	-
		Contamination	-	-

Table 4 Output data of the cultivation stage (continued)

Life Cycle	Sub Process	Output		
			Data Category	Quantity/Unit
1. Cultivation Stage	1.4 Seedling	Solid residue	Sack of fertilizer (Transparent plastic)	2 sacks
			Sack of fertilizer (White -thick plastic)	2 sacks
		Contamination	Liquid Residue	NA
			Gaseous Residue	NA
	1.5 Cultivation/ Fertilization	Solid residue	Sack of fertilizer (White -thick plastic)	3 sacks
			Sack of fertilizer (Transparent plastic)	3 sacks
		Contamination	Gaseous residue	NA
			Soil residue	NA
	1.6Water	Solid residue	-	-
		Contamination	Emissions from electricity generation.	-
	1.7 Pesticides Protection.	Solid residue	Containers of chemicals. (Plastic Cans)	1 Can
		Contamination	Soil residue	-

Table 5 Input data of the manufacturing stage

Life Cycle	Sub Process	Input		
		Data Category		Quantity/Unit
2. Manufacture Stage	2.1 Material Receiving	Energy	-	-
		Resource	Fresh Okra	1,800 Kilograms
	2.2 Cleaning/ Cutting	Equipment	Basket	-
		Energy	Electricity	2.2 kWh/ 18 m^2/hr of water
		Resource	Water	26 m^3
		Machinery	Water Pump	1 Machine
	2.3 Boiling	Energy	Heavy Oil (Grade A)	22 Liters/hr
		Resource	Hot Water	4 m^3
		Machinery/ Equipment	Boiler	1Machine
			Pot Boiled	1Machine
	2.4 Cool Down	Energy	Electricity	110 kWh
		Resource	Cool Water	20 m^3
		Equipment	Cooling Water	1Machine
	2.5 Freezing	Energy	Electricity	564 kWh
		Resource	Freon Freezer	-
		Machinery/ Equipment	Frozen machine	1 Machine
	2.6 Packaging 1	Energy	Labor	2 People
		Resource	Carton	83 Cartons
			Plastic Bag Size 18 kg	83 Bags
		Machinery/ Equipment	-	-
	2.7 Chilling (Storage)	Energy	Electricity	60 kWh
		Resource	R22 Coolant	
		Machinery/ Equipment	Cold Storage	1 Room
	2.8 Slicing	Energy	Electricity	11.25 kWh
		Resource	-	-
		Machinery/ Equipment	Slicer	1 Machine

Table 5 Input data of the manufacturing stage (continued)

Life Cycle	Sub Process	Input		
		Data Category		Quantity/Unit
2. Manufacture Stage	2.9 Packaging 2	Energy	Electricity	18.75 kWh
		Resource	Plastic Bag (White - thick) Size 10 kg	150 Bags
			Carton Size 10 kg	150Cartons
		Machinery/ Equipment	Sealer	1 Machine
	2.10 Metal Detecting	Energy	Electricity	11.25 kWh
		Resource	-	-
		Machinery/ Equipment	Metal detector	1 Machine

Table 6 Output data of the manufacturing stage

Life Cycle	Sub Process	Output		
		Data Category		Quantity/Unit
2. Manufacture Stage	2.1 Material Receiving	Solid residue	-	-
		Contamination	-	-
	2.2 Cleaning/ Cutting	Solid residue	Okra Residue	595 Kilograms
		Contamination	Emission from electricity generation.	
			Waste Effluents from washing	26 m^3
	2.3 Boiling	Solid residue	Hot water from process	4 m^3
		Contamination	Emissions from heavy oil Burning	
	2.4 Cooling Process	Solid residue	Waste Effluents from Cooling processed	20 m^3
		Contamination	Emissions from electricity generation	-
	2.5 Freezing	Solid residue	-	-
		Contamination	Emissions from electricity generation 1 kWh	
			Emissions from Evaporation of Freon Coolant 1 kg.	
	2.6 Packaging 1	Solid residue	Plastic Bag Scrap	-
		Contamination	-	-
	2.7 Chilling (Storage)	Solid residue	-	-
		Contamination	Emissions from electricity generation 1 kWh	
			Emissions from Evaporation of R22 Coolant 1 kg.	
	2.8 Slicing	Solid residue	Okra Residue	-
		Contamination	Emissions from electricity use	-
	2.9 Packaging 2	Solid residue	Paper Scrap	-
			Plastic Scrap	
		Contamination	Emissions from electricity use	-
	2.10 Metal Detecting	Solid residue	-	
		Contamination	Emissions from electricity use	-

Table 7 Inventory data of the transportation stage

Life Cycle	Sub Process	Distance of transportation 750 Kilometer		
		Data Category		Quantity/Unit
3.Transportation Stage	Input	Material	R22Coolant	
		Energy	Diesel fuel	110 Litre
		Machinery/ Equipment	6wheel truck	1
	Output	Solid residue	-	-
		Contamination	Emissions from R22Coolant	-
			Emissions from diesel fuel burning	-

Table 8 Inventory data of the use stage

Life Cycle	Sub Process	Refrigerate and Ripen		
		Data Category		Quantity/Unit
4. Product Use	Input	Energy	Electricity	The energy used during this process is low
		Machinery	Refrigerator	Most of the materials used are recyclable
			Stove	
	Output	Solid residue	Plastic Bag Residue	The packaging will be burned
			Carton Residue	
		Contamination	Emissions from electricity use	-

Table 9 Inventory data of the disposal stage

Life Cycle	Sub Process	Incineration		
		Input		
		Data Category		Quantity/Unit
5. Disposal	Input	Material	Cement block	Emissions from cement blocks are very low
		Energy	-	-
	Output	Solid residue	Ash	Ash is sent to a nearby landfill
		Contamination	Emissions from residue burning	Recycling involves some open burning of residues
			Emissions from diesel fuel burning	-

The variables of the environmental impacts were selected from the highest impact level for each parameter, in each life cycle stage. After that the rating values of each parameter were assessed using the ERPA. The ratings (m_{ij}) assigned to the life cycle stages of frozen okra production are given in Tables 10.

Cultivation: In this life stage, the amount of fertilizers and chemicals usedare controlled by international standards for frozen food factories. Moreover, most of the biomass was a biogenic fertilizer.

Table 10 Element values in cultivation

Element Designation	**Element Value Explanation**
Materials choice (1,1)	- (3) tractor, motor, feed pump, herbicide, insecticide, and seed plant (Few hazardous chemicals are used under environmental regulations.)
Energy use (1,2)	- (3) diesel oil, gasoline, and electricity (Energy use during manufacturing is moderate.)
Solid residue (1,3)	- (3) chemical packages (The amount of chemical packaging used during maintenance.)
Liquid residue (1,4)	- (3) chemical solvents (Soil pollution was found from thewater-soluble chemical contaminants)
Gaseous residue (1,5)	- (3) VOC and CO_2 (Small amounts of volatile hydrocarbons and hazard chemicals are emitted.)

Manufacturing: The critical points of this stage were the energy consumed in both the boiling and freezing processes, which were the highest energy consumption systems. In both processes, air pollution was produced from heavy oil combustion and electricity generation in the grid-mixed conventional energy resources power plant generation system. One of the greatest impacts in this life stage was the choice of materials in factory production, as detailed in Table 5.

Table 11 Element values in manufacturing

Element Designation	**Element Value Explanation**
Materials choice (2,1)	- (2) okra, water, machines, boiler, motor pumps, cold storage, coolant (ammonia and R22), cooling tower, plastic, and paper (Good material choices, except for the coolant.)
Energy use (2,2)	- (1) heavy oil, diesel oil,and electricity (Energy use during manufacturing is high.)
Solid residue (2,3)	- (3) waste from production and packaging (Modest residues from packaging, material scraps and obsolete parts.)
Liquid residue (2,4)	- (3) waste water from boiling, cooling, washing, and cleaning (Water treatment is used)
Gaseous residue (2,5)	- (1) VOC, CO, CO_2, NO_x, N_2O, NO_2, SO_x, and SO_2 and volatilesinthe coolant (Moderate fluxes in greenhouse gases and hazardous volatiles of the coolant are produced.)

Transportation: The most serious aspect of this life stage is the air pollution from diesel combustion during the transportation of frozen okra from Chiang Mai to Bangkok (750 km). During this stage 4,968.75 kilogram of carbon dioxide gas was produced.

Table 12 Element values in transportation (Product delivery)

Element Designation	**Element Value Explanation**
Materials choice (3,1)	- (3) container, coolant and truck (Sparse, recyclable materials are used during transportation)
Energy use (3,2)	- (3) diesel oil(Over-the-road truck transportation is energy-intensive)
Solid residue (3,3)	- (4) none
Liquid residue (3,4)	- (4) none
Gaseous residue (3,5)	- (2) VOC, CO, CO_2, NO_x, N_2O, NO_2, SO_x, and a volatile of coolant (Moderate fluxes in greenhouse gases and hazardous volatiles from the coolant are produced.)

[1]In the case: The truck uses ~25 Liters of diesel per 100 km. and the carbon dioxide gas was produced 2.65 kg/Liter of diesel: data from EURO Shell, 2008.

Use: In this life stage, the data assumed are as follows: the energy was mainly used for freezing and cooking in the household. The 1 kilogram product was stored for 1 day and cooked once on the stove (5 minutes). This life stage is short and the energy consumption and environmental emissions are lower than other stages.

Table 13 Element values in use stage

Element Designation	**Element Value Explanation**
Materials choice (4,1)	- (3) stove and refrigerator (Most of the materials used are recyclable)
Energy use (4,2)	- (3) LPG or electricity (The energy used during this process is low)
Solid residue (4,3)	- (3) packaging (The package will be burnt)
Liquid residue (4,4)	- (4) none
Gaseous residue (4,5)	- (3) VOC, CO, CO_2, NO_x, N_2O, NO_2, SO_x, SO_2 and volatile of coolant (Small amounts of volatile hydrocarbons and volatiles are emitted from the coolant)

Disposal: in this case, we assumed that the customer placed the garbage in the municipal waste management and was delivered to a landfill.

Table 14 Element values in disposal stage

Element Designation	**Element Value Explanation**
Materials choice (5,1)	- (4) None
Energy use (5,2)	- (4) None
Solid residue (5,3)	- (3) Solid waste (All wastes are delivered t to landfill.)
Liquid residue (5,4)	- (4) none
Gaseous residue (5,5)	- (3) VOC, CO, CO_2, NO_x, N_2O, and NO_2

Table 15 An example of the ratings for individual elements of the environmental factors

Life Cycle Stage	Main Process	Sub Process	Element Designation	Element	t_{ij}	d_{ij}	p_{ij}	e_{ij}
1.Cultivation Steps	1.1 Fieldand Seed Preparation	1.1.1Field Preparation	Materials choice	Unavailable[1]	4	4	4	4
			Energy use	Diesel fuel	2	3	1	2
			Solid residue	Unavailable[1]	4	4	4	4
			Liquid residue	Unavailable[1]	4	4	4	4
			Gaseous residue	CO_2	2	1	1	0
		1.1.2 Seed Preparation	Materials choice	Methomyl	3	2	1	2
			Energy use	Unavailable[1]	4	4	4	4
			Solid residue	Container of chemical	3	3	2	1
			Liquid residue	Toxins in the soil and water	2	2	1	0
			Gaseous residue	Unavailable[1]	4	4	4	4

For each matrix element, the rating was conducted using the environmental assessment criteria that would be evaluated with the Pollution Control Department database. Table 16 presents the stressor values, most of which were air pollution, chemicals, and energy use.

Table 16 Stressor values

Matrix Element	Receptor Group	Predominant Stressor	t_{ij}	d_{ij}	p_{ij}	e_{ij}	m_{ij}	M_{ij}
1,1	RC	Chemicals	3	3	3	3	3	2.25
1,2	E	Diesel oil	4	4	3	3	3	2.265
1,3	SR	Chemical packages	2	3	3	3	3	2.063
1,4	LR	Solvents	3	2	3	3	3	2.063
1,5	GG	VOC, CO_2	1	2	1	1	3	0.938
2,1	GG	Ammonia, R-22	2	2	1	2	2	0.875
2,2	E	Heavy oil, diesel, electricity	1	1	1	1	1	0.25
2,3	SR	Packaging (PE)	2	2	3	3	3	1.875
2,4	LR	Solvents	2	2	3	2	3	1.688
2,5	GG	CO_2, SO_2, NO_2	1	1	1	1	1	0.25
3,1	RC	None	4	4	4	4	3	3
3,2	E	Diesel oil	1	1	2	3	3	1.313
3,3	SR	None	4	4	4	4	4	4
3,4	LL	None	4	4	4	4	4	4
3,5	GG	VOC, CO_2,	1	2	1	2	2	0.75
4,1	RC	Water	4	4	4	4	3	3
4,2	E	Electricity	3	2	3	3	3	2.063
4,3	SR	None	4	4	4	4	3	3
4,4	LL	Solvents	4	4	3	4	4	3.75
4,5	GG	CO_2	2	2	2	2	3	1.5
5,1	RC	Plastic (PE)	3	2	3	3	4	2.75
5,2	E	None	4	4	4	4	4	4
5,3	SR	Plastic ash	3	4	3	3	3	2.44
5,4	LL	None	4	4	4	4	4	4
5,5	GG	CO_2	2	2	2	2	3	1.5

Receptor groups are defined as follow:

- RC, resource consumption
- E, energy use
- W, water Use
- SR, solid residue generation
- LL, liquid residue generation, local impacts
- LR, liquid residue generation, regional impacts
- GG, gaseous residue generation, global impacts

The complete matrices for the frozen okra are illustrated in Table17. The overall rating of this life cycle is 55.93, and the far right column of the table shows the points for each life cycle stage. The rating of all life stages are moderated, except for the manufacturing stage. The environmental impact points are shown as target plots in Figure 2.

Table 17 Environmentally Responsible Product Assessments for frozen okra (M_{ij})

Life Cycle Stage	Environmental Stressor					
	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Total
Cultivation	2.25	2.625	2.063	2.063	0.938	9.58
Manufacturing	0.875	0.25	1.875	1.688	0.25	4.94
Transportation	3	1.312	4	4	0.75	13.1
Product Use	3	2.063	3	3.75	1.5	13.3
Disposal	2.75	4	2.44	4	1.5	14.7
Total (R_{ERP})						55.93

The results of the evaluation using ERPA methods indicated that the manufacturing stage had the lowest score because it consumed a lot of electricity to run the machines and electric devices; and the freezing and chilling (Storage) processes used the maximum amount of electricity. In addition, coolants in the system also contributed to ozone depletion. Moreover, the manufacturing stage consumed the largest amount of water in the cleaning and boiling processes, and it produced highly contaminated waste effluents. In the boiling process thermal energy from burning fossil fuels (heavy oil) was required and carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxide (SO_x), hydrocarbon compounds and other compounds were emitted. The second highest polluter was the transportation stage, and the score on the X-axis showed that the gaseous residues resulted in the lowest score. The third highest pollution point was the cultivation stage, which used chemical fertilizers and pesticides that were directly released into the environment.The presence of toxins in the soil is dangerous to humans and other life, and it also has an impact on the soil and water systems. Follwing this was the product use stage and finally the disposal stage.

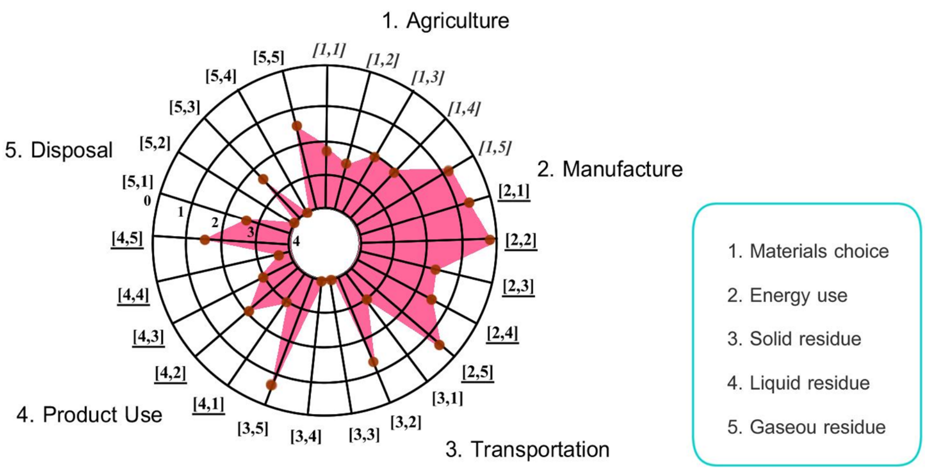

Figure 2 Target plots of life cycle environmental impacts of the frozen okra

In Figure 2 the value of R_{ERP} that is closest to the center represents the lowest environmental impacts,or the most environmental friendly. On the other hand , the plotted values that are furthest from the center are the parts with the highest environmental impacts and are areas that need to be managed and improved.

4. Conclusion

ERPA is a useful but simplified evaluation methodology that can be used to identify the environmental impacts of any product. However, the results will be realistic as they are based on the judgments, or weighting scores, that are made by all the committees. For SMEs, this tool is rather interesting and easy to apply to determine the hot spots and make improvements. In this research, ERPA was applied to the life cycle assessment of frozen okra production. Overall, the manufacturing stage had the highest number of hot spots occupying 57.44% of the overall impacts. Energy consumption and combustion in the manufacturing process seemed to be the main sources of impact due to heavy oil and electricity use. The materials used in this process could have contributed to these serious impacts, such as the use of R22, plastic bags and cartons, and natural water. The cultivation stage had the second highest level of environmental impact occupying 22.4%of the overall impact, due to the use of herbicides and insecticides and chemical fertilizers. Transportation accounted for 13.97% of overall impact because of inappropriate logistics management and the use of trucks with diesel engines.

Further development and improvements should be made to reduce the environmental impact and maximize the eco-efficiency to make the production of frozen okra more environmentally friendly.

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