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Research article

Evaluation and Reduction of the Carbon Footprints Associated with Steviol Glycoside Production

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Abstract: This study aims to evaluate the carbon footprint generated in each step of stevia sweetener (steviol glycosides) production and to find out how to reduce the impact of the sweetener's greenhouse gas (GHG) emissions. In addition, a comparison of the carbon footprints of the sweetener and sucrose is included. A cradle-to-gate LCA was conducted on steviol glycosides (purified rebaudioside A, RA95) production in Thailand. The carbon footprint assessment method is based on the guidelines of the Food Institute, Ministry of Industry in Thailand, corresponding to ISO 14067 and PAS 2050. The study evaluates the carbon footprint by employing two sources of emission factors from the Thailand Greenhouse Gas Management Organisation database for carbon footprint and OpenLCA Version 1.10.3 with eco-invent database Version 2.2 for comparing the carbon footprint and finding out other impacts. The result from OpenLCA reveals the impact on marine aquatic ecotoxicity, followed by the Depletion of abiotic resources and human toxicity. The results showed that a kilogram of the RA95 releases 32.07 kilograms of carbon dioxide equivalent. The highest GHG emissions came from the raw material procurement process, with 53.01%, followed by production, support system, and material transportation, with 28.09%, 16.47%, and 2.43%, respectively. The three production steps with the highest GHG emissions were the second crystallization, the first crystallization, and the drying process, respectively. The RA95 releases a carbon footprint 3.55 times lower than sucrose for the same level of sweetness. The recommendations to reduce the carbon footprint in production are to reduce natural gas usage by improving boiler efficiency and reduce electricity usage by installing an automatic shutdown system for cooling machines (chiller), depending on the production volume. The findings revealed a lower carbon footprint of 0.33 kgCO2eq per kilogram of product after improvement.

Keywords: Carbon Footprint; Stevia Sweetener; Rebaudioside A; Steviol Glycosides; Life cycle assessment

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1. Introduction

Nowadays, consumers are paying more attention to health care. Especially regarding sugar consumption because consuming excessive amounts of sugar causes various health problems such as obesity, diabetes, high blood pressure, heart disease, vascular disease, etc. According to the World Health Organization, in 2016, approximately 1.6 million people died directly from diabetes, and diabetes was the seventh leading cause of death worldwide [1]. Thirty-seven million children under the age of 5 years were overweight and obese, and almost half of their deaths were linked to malnutrition, especially consuming foods and drinks containing more energy (high in sugars and fats) [2]. The rising incidence of diabetes and obesity has consumers seeking natural, calorie-free sweeteners to maintain healthy blood sugar levels. In addition, the sugar tax on beverages containing sugar, such as soft drinks, green tea, coffee, energy drinks, and fruit juices, has increased to change the consumption behavior of Thai people and help reduce the risk of overconsumption of sugar. The price of products containing sugar exceeding the standard is expected to increase, causing consumers to reduce their consumption of sugary beverages and have better health [3, 4]. There are many types of sugar substitute sweeteners. Low and No-Calorie Sweeteners (LNCS) are classified as food additives that are added to many foods and beverages. LNCS is commonly added to products as a sugar substitute because it can provide the desired sweet taste with little or no energy.

Additionally, these substances are not carcinogenic and do not trigger the same metabolic response as sugar. Because of this characteristic, products containing LNCS are often recommended for people with specific health conditions, such as sugar-free food and drinks for people with diabetes [5]. LNCS permitted many sweeteners, including steviol glycosides, in the EU [6].

Steviol glycoside is different from other sweeteners because it is safe to consume and has a very low Acceptable Daily Intake (ADI) of 4 mg/kg. of body weight. It is 200-300 times sweeter than sucrose [6]. In addition, steviol glycosides are natural extracts. At the same time, other low-calorie, no-calorie sugar substitutes are synthetic sweetener substances that have changed their chemical structure (except for thaumatin, which is commonly used to improve taste and is not allowed for use according to the United States Food and Drug Administration standards [6]. Steviol glycosides are extracted from stevia, an economic plant that can be produced in large commercial quantities. Stevia sugar substitute sweetener is an alternative product to reduce sugar consumption. It is highly safe as it is a natural extract with health benefits such as anti-obesity, anti-diabetic, and anti-oxidant [7]. In Thailand, the Food Division of the Food and Drug Administration has designated this sweetener from stevia as a food additive named steviol glycoside. The food additive standards refer to the Codex standards, JECFA Monograph INS no. 960.

Using stevia sweeteners on an industrial scale in Thailand has yet to be very popular. The international sale of stevia sweeteners continues to face commercial problems due to environmental measures that customers value and the desire to consume environmentally friendly products, especially in the European market [9]. Therefore, entrepreneurs must prepare for their business's survival and support increased competition amid changes in the global economy. The way to increase the competitiveness of entrepreneurs is by increasing production efficiency and improving the production process to reduce greenhouse gas emissions. So that consumers and trading partners can accept that this product has undergone a production process that considers environmental protection. Therefore, the carbon footprint is assessed using the principles of Life Cycle Assessment (LCA), a tool used to determine greenhouse gas emissions that occur throughout the product life cycle that leads to formulating strategies to find ways to improve and develop production to reduce greenhouse gas emissions. Resources are used efficiently and have minimal environmental impact, leading to sustainable development and increasing competitiveness in the global market. Additionally, entrepreneurs can register the product's carbon footprint label and request a global warming reduction label from the Greenhouse Gas Management Organization (Public Organization).

More research is needed into the environmental impact of stevia sweeteners. A few studies relating to stevia sweeteners are PureCircle's carbon footprints from farm to stevia sweeteners type RA95 were determined on average to be 44.57 kgCO2eq/kg using sweetness equivalence for comparison. Stevia releases an 82% and 64% lower carbon footprint compared to beet sugar and cane sugar, respectively [10]. The stevia extract type RA60 has a carbon footprint of 20.25 kgCO2eq/kg on a mass basis and 0.081 kgCO_2eq/kg on a sucrose sweetness equivalency basis for the EU's cradle-to-factory-gate life cycle [11]. Mexico's carbon footprint from farm to stevia extract is 1.81 kgCO2eq/kg, and sugar is 2.48 times greater than stevia extract [12].

Furthermore, Thailand has committed to achieving carbon neutrality by 2025 and net zero GHG emissions by 2065 through the Nationally Determined Contribution (NDC) Roadmap. Consequently, by 2030, a goal of 30 to 40% below-average greenhouse gas emissions across all economic sectors should be met [13]. The National Greenhouse Gas Reduction Action Plan, 2021–2030 [13] states that industrial entrepreneurs must develop an action plan and methods for reducing greenhouse gas emissions to support national policy. This research aims to assess the carbon footprint associated with each stage of the production of stevia sweetener (steviol glycosides with purified rebaudioside A, RA95) and determine ways to lessen the sweetener's greenhouse gas (GHG).

2. Materials and Methods

This study covers creating carbon footprint data for the RA95 manufacturing cycle, which involves a Thai factory extracting stevia. The carbon footprint assessment method is based on the "Guideline for evaluating carbon footprint on product for the food industry" assessment method by the Food Institute, Ministry of Industry in Thailand, which details 6 main steps corresponding to ISO 14067 and PAS 2050 [11][14].

2.1 Identification of targets and boundary

This study aimed to assess RA95's carbon footprint by analyzing the greenhouse gas emissions that transpire throughout manufacturing. Every stage of the process was evaluated to ascertain the best method, leading to systematically and effectively reducing RA95's carbon footprint. A comparison of the carbon footprint between RA95 and sugar is also included.

2.2 Product selection

The selected product is RA95, which is rebaudioside A or Reb-A, purified from stevia extract. RA95 requires more energy than other products and takes a long time—roughly 150 hours per batch.

2.3 Definition of system boundary

The system boundary of carbon footprint assessment is focused on the production process by Cradle-to-Gate or Business-to-Business (B2B); that is, it covers sub-processes such as raw materials transportation and production, as shown in the picture below. The functional unit is 605 kilograms of product per production batch.

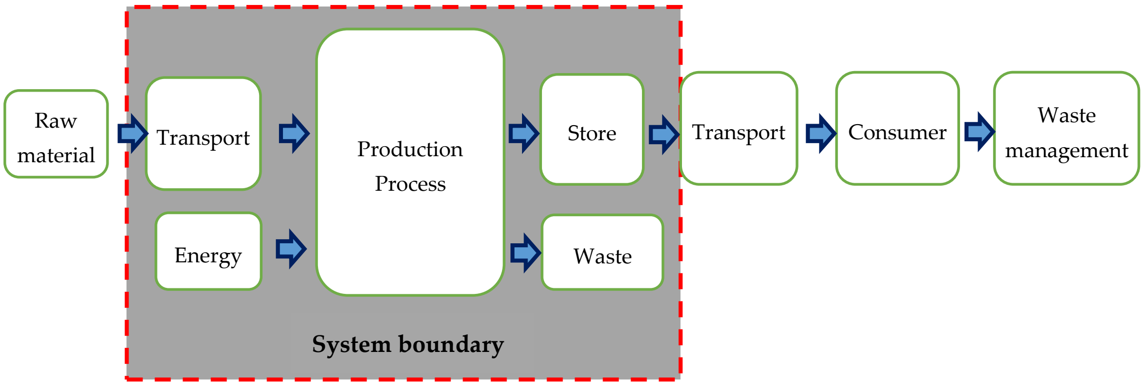

Figure 1. System boundary

2.4 Creation of life cycle diagram

The scope of this evaluation is B2B, as shown in Figure 2, considering the process of acquiring raw materials, consisting of stevia extract, ethanol, corrugated box, and aluminum laminated bag. Stevia extract is imported from China. Ethanol is imported from the United States. Both are transported by ship from the port into the production plant by truck, container, or tank car. Then, all materials enter the production, packing, and warehousing processes. In the factory, water is utilized from the industrial estate. RO (Reverse Osmosis) water is produced for use within the factory. The wastewater flows into the wastewater collection pond and is then sent to wastewater treatment by industrial estates.

2.5 Collection of life cycle data

All input and output data in the production process are collected to evaluate the product's carbon footprint. The data collection period was continuous during the six batches of stevia sweeteners RA95 production for 14 days. Data source for input and output are collected from various sources as follows:

2.5.1 Transportation information

Transportation information refers to the transportation of raw materials, resources, and production aids from suppliers to factories, and it includes detailed information on weight and distance, as shown in Table 1.

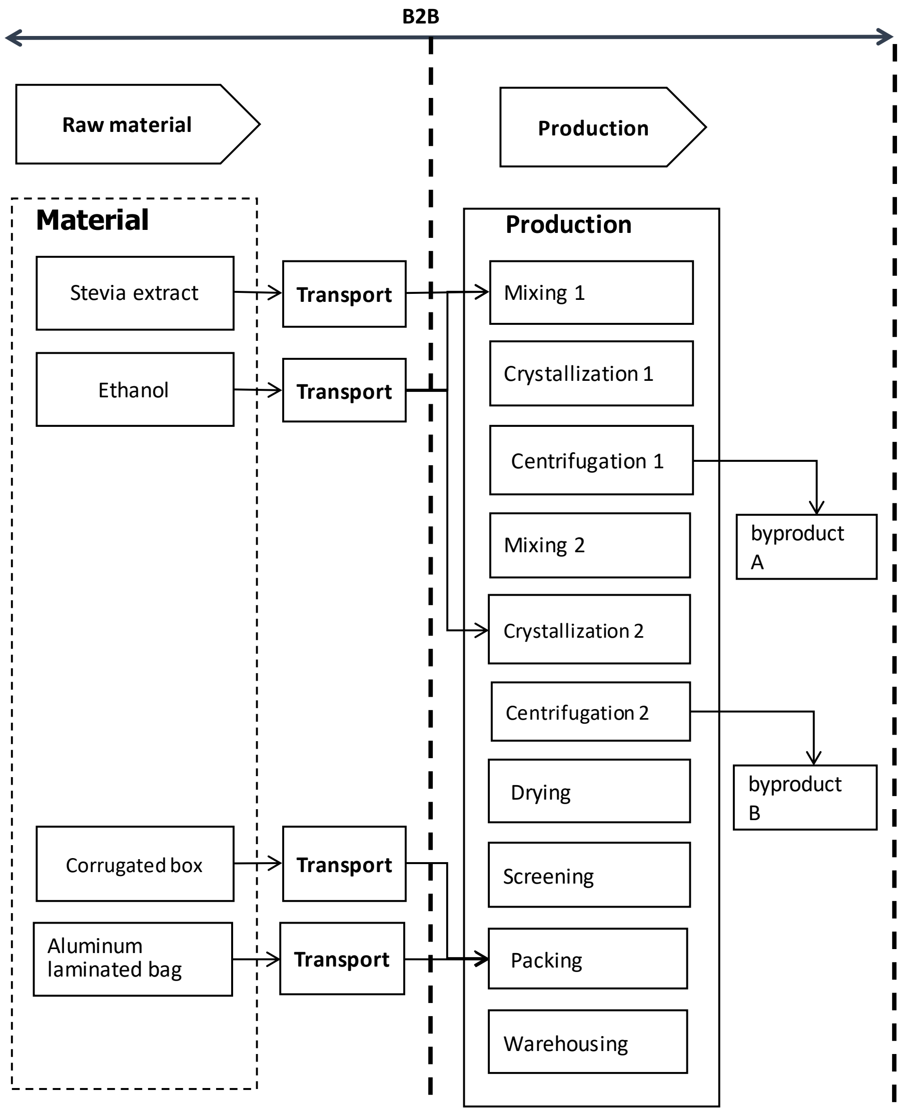

Figure 2. B2B life cycle diagram of Rebaudioside A

Table 1. Information on the transportation of raw materials, resources, and production aids from suppliers to factories

Material list	Weight (kg)	Distance (km)	Truck type
stevia extract	2,400	34	110-wheel truck container, normal running, 50% loading 16 tons
ethanol	14,516	34	Trailer, 18 wheels, 32 tons, normal running, 75% loading
corrugated box	60	16	Small pickup, 4 wheels, 7 tons, normal running, 50% loading
aluminum laminated film	36	154	Small pickup, 4 wheels, 7 tons, normal running, 50% loading

2.5.2 Daily production reports

Daily production reports can show how long each production step takes. Data collection from recording the start and end times of each step, with production data for six batches, takes the production time of each step.

2.5.3 Daily electricity usage report

Electricity meters were used at pre-arranged intervals to monitor and record the daily electrical energy consumption of the industrial process both before and after the experiment was finished. Since the data from the meter cannot show how much electricity is consumed at each stage of production, the readings were averaged to the amount of electricity used per battery. As a result, the amount of electrical energy used is computed using the machinery equipment standards. The total power used in 15 days to produce six batches is 22,934 kWh or 3,822.3 kWh per batch.

The percentage ratio of electric power to machine power, or duty factor, is obtained by dividing the total electricity usage per production batch (x) by the electricity usage from the full machinery standard per production batch (y), then multiplying the result by 100 according to equation (1).

$$\text{Duty factor} \quad = = \frac{x}{y} \times 100 \tag{1}$$

For instance, 5,205.67 kWh of power is used in every batch when calculating the whole machine standard. According to the electricity meter, 3,822.3 kWh of electricity are used overall in each batch. Subsequently, the duty element stands at 73.43%. Therefore, the electrical usage number for each process step was calculated by multiplying the duty factor by the electrical power produced by the machine's standard.

The electricity required to generate cooling water can be obtained from the meter and utilized to determine the electricity consumed step-by-step. To calculate the quantity of electrical energy consumed, Table 3 shows that cooling water was used for the first crystallization process for 26.29 hours, or 47.52%, and for the second crystallization step for 29.04 hours, or 52.48%. The first and second diluted solutions were used to create by-products A and B. Like cooling water allocation, the electrical energy used in this step is distributed. After allocating, 242.78 and 119.43 kWh of electricity were consumed for wet crystal in the first and second centrifugation processes.

2.5.4 Daily natural gas usage report

A flow meter was used to gather information on the natural gas utilized in boilers to produce steam between May 10 and 25, 2021. After the three stages of the first, second, and drying crystallization, the amount of natural gas utilized is 4,561.33 Nm^3, divided into three parts of 1550.40, 1712.32, and 1298.61 Nm^3 or 1040.32, 1,148.97, and 871.37 kg, respectively.

2.5.5 Daily water usage report

Only a minimal amount of water was used during manufacture. Most often utilized in the generation of cooling water. Water meters recorded 281 cubic meters of use between May 10 and 25, 2021, or 46.83 cubic meters per batch.

Mass and energy balance calculations were examined at every stage after inventory data was collected for the boundary study. The life cycle inventory in Table 2 shows the process step, input-output, unit, and amount per functional unit (FU) in each process unit.

2.6 Calculation of carbon footprint

The greenhouse gas emission was calculated as the carbon footprint, which is equal to multiplying the product of activity data with the emission factor (EF). The calculation is divided into three parts as follows.

(1) Greenhouse gas emissions from raw materials

(2) Greenhouse gas emissions from the transportation of materials

(3) Greenhouse gas emissions of production support systems

Production data of input and output that has been mass-balanced is used to calculate the quantity per functional unit. Then, multiply it with the EF value to get the carbon footprint value. Inputs and outputs that do not create greenhouse gas emissions were not calculated. Therefore, the carbon footprint is zero.

The study's greenhouse gas emissions data on electricity for production was obtained from the Thailand Greenhouse Gas Management Organization database. In this regard, all data's conversion of carbon dioxide equivalent (CO_2 eq) was calculated using equation (2).

$$CO_2\ eq.\ (of\ each\ production\ step) = \sum (Q(i) \times EF(i)) \quad (2)$$

Where CO_2 *eq.* refers to the amount of greenhouse gas emission
$\sum Q(i)$ means the sum of the data values of each activity i, $(Q(i))$ multiplied by the emission factor $(EF(i)$ in each activity i

2.7 The Carbon footprint calculated by OpenLCA Version 1.10.3

The assessment was conducted using OpenLCA program version 1.10.3 with ecoinvent database version 2.2, focusing on global warming potential.

Table 2. Life Cycle Inventory

No.	Process unit	Input-Output	Unit	Amount/FU
1	mixing 1	Electricity	kWh	41.25
		stevia extract	kg	2400
		ethanol	kg	14,516
2	crystallization 1	Electricity	kWh	42.47
		Natural gas for boiler	kg	1,040.32
		Electricity for cooling	kWh	941.73
3	centrifugation 1	Electricity	kWh	242.78
4	mixing 2	Electricity	kWh	26.36
5	crystallization 2	Electricity	kWh	46.91
		Natural gas for boiler	kg	1,148.97
		Electricity for cooling	kWh	1,040.24
6	centrifugation 2	Electricity	kWh	119.46
7	drying	Electricity	kWh	571.81
		Natural gas for boiler	kg	871
		Ethanol vapor	kg	56.58
8	screening	Electricity	kWh	71.17
9	packing	Electricity	kWh	17.76
10	Supporting	RO water	M^3	7.33
		Soft water	M^3	39.50
		Electricity	kWh	5235
11	Waste management	Waste water treatment	M^3	46.83
		Products waste	kg	4

3. Results and Discussion

In this study, carbon footprint assessment was carried out according to the "Guideline for evaluating carbon footprint on product for the food industry," corresponding to ISO 14067 and PAS 2050 [14]. The product studied is the sweetener from stevia called steviol glycosides purified Reb-A, which refers to a sweetener that purifies Reb-A from stevia extract by crystallization in an ethanol solvent. The amount of Reb-A must be at least 95%. The study's functional unit is 605 kilogram products. The factory received the stevia extract from the port. After that, it began production, packing, and storing the product to be distributed domestically and internationally. All of this was considered for the carbon footprint assessment by the Cradle-to-Gate life cycle assessment (LCA) standards. The following is a display of the results of the carbon footprint calculation.

3.1 Carbon footprint of transportation of raw materials, resources, and process aids

Raw materials, resources, and process aids are transported from suppliers to the manufacturing facility. As indicated in Table 3, it was discovered that the carbon footprint was 471.57 kgCO_2eq. Most of the carbon emissions came from ethanol and stevia extract, respectively.

Table 3. Carbon footprint calculation of transportation of raw materials, resources, and process aids

Material list	Load (kg)	Distance (km)	Carbon footprint ($kgCO_2eq.$)
stevia extract	2,400	34	53.85
ethanol	14,516	34	413.94
corrugated box	60	16	0.56
aluminum laminated film	36	154	3.23
Total			471.57

3.2 Carbon footprint of the raw material acquisition process

The computation results indicate that the carbon footprint of acquiring raw materials is 10,284.83 $kgCO_2eq$ per functional unit of 605 kg (Table 4). Most of the carbon emissions also came from ethanol and stevia extract.

3.3 Carbon footprint calculation results of the production process

Figure 3 illustrates the carbon footprint associated with the production process, which is 5,445.76 $kgCO_2eq$ per functional unit of 605 kg. The processes of second crystallization (crystallization 2) and first crystallization (crystallization 1) produced the highest levels of carbon emissions, respectively.

Table 4. Results of calculating the carbon footprint of the raw material acquisition process

Input-Output			Emission Factor ($kgCO_2eq$/unit)	Carbon footprint
List	**unit**	**Amount/FU**		**($kgCO_2eq$)**
stevia extract	kg	2,400	1.8069	4,336.52
ethanol	kg	14,516	0.3962	5,751.24
corrugated boxes	kg	60	1.6324	97.94
aluminum laminated bag	kg	36		
- nylon	kg	4	9.2691	37.62
- aluminum foil	kg	5	0.647	2.91
- LLDPE	kg	27	2.1356	58.60
			Total	**10,284.83**

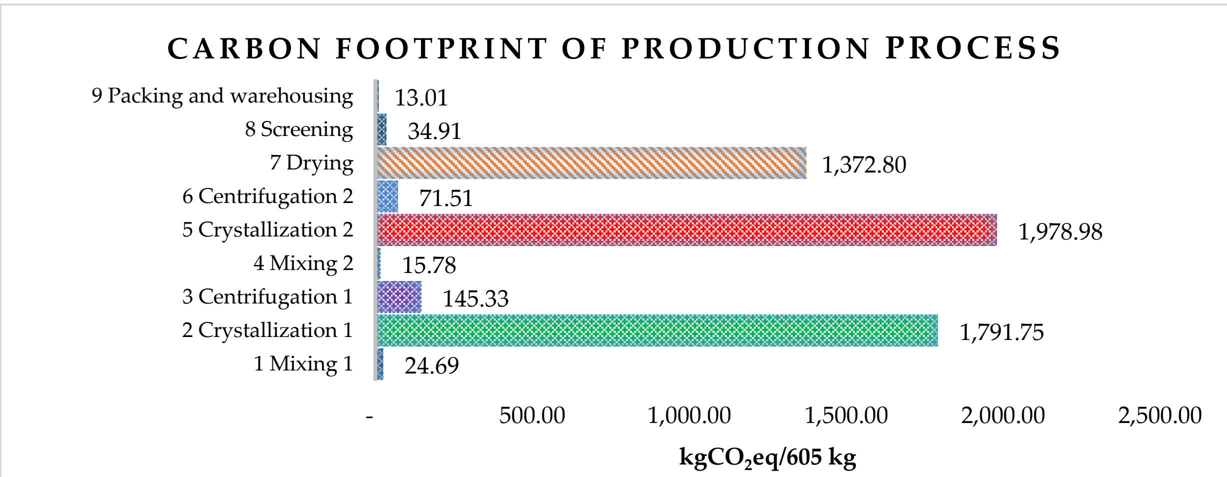

Figure 3. Greenhouse gas emissions from the production process of stevia sweetener Rebaudioside A ($kgCO_2eq$/605 kg)

3.4 Carbon footprint calculation results of production supporting

Table 5 illustrates the carbon footprint of the production support section per functional unit of 605 kg, which is 3,195.79 $kgCO_2eq$—using electricity results in the most significant carbon emissions. It is also found that the electric current used most is in the chiller section, 2526 kWh per functional unit, followed by air compressors, electricity for steam boiler systems, lighting, and water production systems, and electricity for nitrogen tank systems, 2260, 321, 126, 2 kWh per functional unit, respectively. Reducing electricity consumption in the cooling system decreases Reb-A's carbon footprint, which was discussed later in topic 3.8.

Table 5. Carbon footprint calculation results of production supporting

Input-Output			EF, ($kgCO_2eq$/unit)	Carbon footprint
list	unit	Amount/FU		($kgCO_2eq$)
RO water	m^3	7.33	2.1555	15.81
soft water	m^3	39.50	1.0301	40.69
electricity	kWh	5,235.00	0.5986	3,133.67
wastewater treatment	m^3	46.83	0.1201	5.62
			Total	**3,195.79**

3.5. Carbon footprint calculation results of the entire process

According to Figure 4, the results of the carbon footprint calculation for the production activity show that greenhouse gas emissions throughout the production process totaled 19,400.95 $kgCO_2eq$/605 kg or 32.07 $kgCO_2eq$/kg. The method of acquiring raw materials has the highest proportion of greenhouse gas emissions, at 10,284.83 $kgCO_2eq$ (53.01%), followed by the production process at 5,448.76 $kgCO_2eq$ (28.09%), the supporting system at 3,195.79 $kgCO_2eq$ (16.47%), and raw material transportation at 471.57 $kgCO_2eq$ (2.43%) respectively.

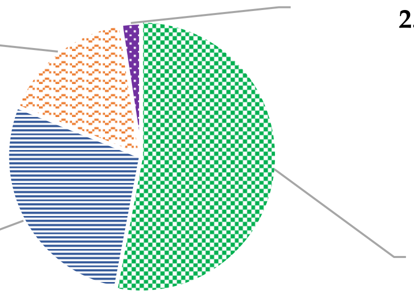

Figure 4. The carbon footprint of the entire process

When comparing the carbon footprint of Reb-A from this study (32.07 $kgCO_2eq$/kg) with the study of PureCircle Company (44.57 $kgCO_2eq$/kg) [10], which has a similar production process, it found that this study has a carbon footprint of less than PureCircle 12.5 $kgCO_2eq$/kg. The proportion of carbon footprint of each process between this study and PureCircle Company found that the highest carbon emission came from the raw material, followed by the production in the same manner.

3.6 Rebaudioside A and sucrose's carbon footprints compared at the same sweetness level

Table 6 shows that sucrose's greenhouse gas emissions value is 0.39 $kgCO_2eq$/kg, whereas the stevia sweetener Reb-A has a value of 32.07 $kgCO_2eq$/kg when used in the same amount. In this study, Reb-A is the ninety-five percent of Reb-A extracted (RA95). The greenhouse gas emissions of RA95 were found to be 89 times higher than those of sucrose. However, RA95 is sweeter than sucrose 290 times at 5% sucrose solution [10]. When used in food, it is used in tiny amounts at the same level of sweetness as sucrose. The ratio of sucrose used to RA95 was 290:1 or 5:0.017. Table 7 also reveals that RA95 reduces carbon emissions by 71.79%, or 3.55 times, compared to sucrose at the same level of sweetness. Sixty percent of Reb-A extracted or RA60 has a carbon footprint of 4.76 times less than sucrose, reducing 78.97% of carbon emission. However, RA95 has a carbon footprint of less than one $kgCO_2eq$ compared to RA60, which has the same sweetness. Reb-A (RA) has been identified as the least bitter, with a minor persistent aftertaste among stevia glycosides.

Bitterness often is significant due to the impurities in extracts [15]. Therefore, RA95 is more purified than RA60, which provides less bitterness.

Table 6. Carbon footprint comparison of Sucrose and Reb-A at the same sweetness level

Products	Usage (kg)	Carbon footprint ($kgCO_2eq/kg$)	Carbon footprint at same sweetness level ($kgCO_2eq$)	Reducing Carbon footprint
sucrose	5	0.39*	1.95	-
RA95	0.017**	32.07	0.55	-71.79% or 3.55 times
RA60	0.020***	20.25	0.41	-78.97% or 4.76 times

* calculated from the carbon footprint of 26 B2B sucrose sources. (Source: Thailand Greenhouse Gas Management Organization (Public Organization))
** calculated at 5% sweetness equivalence by RA95 is 290 times sweeter than sucrose.
***calculated at 5% sweetness equivalence by RA60 is 250 times sweeter than sucrose[11].

3.7 The Carbon footprint calculated by OpenLCA Version 1.10.3

The carbon footprint obtained by the OpenLCA program version 1.10.3 with eco-invent database version 2.2 is 21,901.34 $kgCO_2eq$/ 605 kg, or 2,500.39 $kgCO_2eq$ higher than the calculation in this study (19,400.95 $kgCO_2eq$), and because of the different sources of emission factor (EF), according to the results when using the program to determine other environmental impact. Table 7 illustrates the environmental impact analyzed using the Open LCA method. The most significant impact is attributed to marine aquatic ecotoxicity, followed by the Depletion of abiotic resources and human toxicity.

Table 7. The environmental impact calculated by OpenLCA Version 1.10.3 ecoinvent database version 2.2

Impact category	Reference unit	Result
Acidification potential - average Europe	kg SO_2 eq.	437.09
Climate change - GWP100	**kg CO_2 eq.**	**21,901.34**
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	0.06
Depletion of abiotic resources - fossil fuels	MJ	570,190.83
Eutrophication - generic	kg PO_4- eq.	219.33
Freshwater aquatic ecotoxicity	kg 1,4-dichlorobenzene eq.	13,228.89
Human toxicity	kg 1,4-dichlorobenzene eq.	16,232.51
Marine aquatic ecotoxicity	kg 1,4-dichlorobenzene eq.	30,330,609.46
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	0.00
Photochemical oxidation	kg ethylene eq.	37.71
Terrestrial ecotoxicity	kg 1,4-dichlorobenzene eq.	409.19

Figure 5 shows the comparison results of the carbon footprint determined using this study's Thailand Greenhouse Gas Management Organisation (TGO) database with OpenLCA Version 1.10.3 with eco-invent Database Version 2.2. Based on OpenLCA's calculations, electricity has been shown to have the most significant influence, followed by natural gas and raw materials (consisting of stevia extract and ethanol). According to the study's calculations, natural gas and electricity are the most influential factors after raw materials. As Table 8 illustrates, there are differences in the carbon footprint values computed by OpenLCA and this study due to different sources of emission factors except stevia extract.

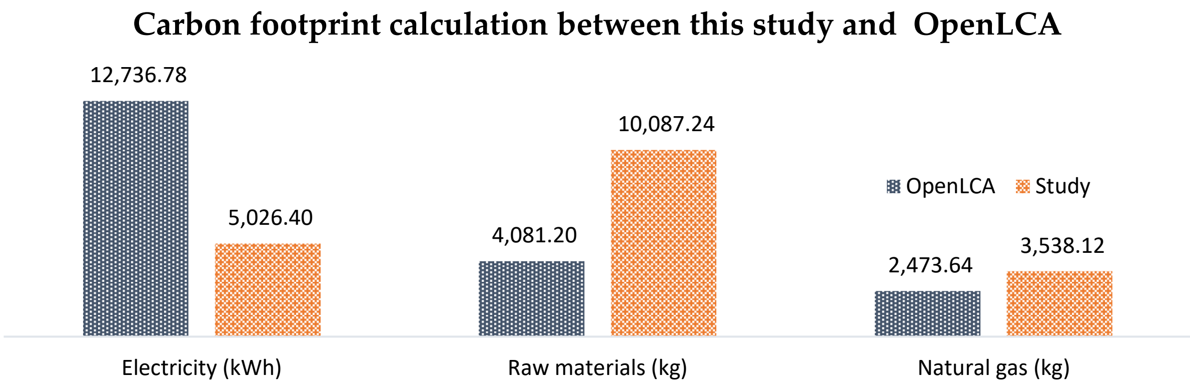

Figure 5. The source of impact of carbon footprint calculated between this study and OpenLCA

Table 8. Emission factor used comparison between this study and OpenLCA

Items	Emission factor ($kgCO_2eq$/unit)			
	OpenLCA ecoinvent 2.2		TGO (Mar, 2021)	
electricity (kWh)	1.1539	electricity, high voltage, at grid-CN	0.5986	electricity, grid mix (2016-2018; LCIA method IPCC 2013 GWP 100a V1.03)
natural gas (kg)	0.01401	natural gas, at consumer-RNA (kg)	1.156	natural gas liquid (LCIA method IPCC 2013 GWP 100a V1.03)
Raw materials				
stevia extract (kg)	1.8069	an emission factor referred to by Salinas et al. (2015)	1.8069	an emission factor referred to by Salinas et al. (2015)
ethanol, 95% in H_2O (kg)	-0.01756	ethanol, 95% in H_2O, from corn, at distillery-US (kg)	0.3962	ethanol, 95% in H_2O, from sugarcane molasses, at sugar refinery

3.8 Reduction of the carbon footprint from the stevia sweetener RA95

As mentioned, using electricity results in the most significant carbon emissions in RA95 production support, which is relatively high supplied to the chiller systems. One way to reduce the amount of electricity consumed is to use an automatic chiller. Setting the start and shutdown time according to the specified period was established. The chiller stops working automatically at the end of the tank's reaction process; do not leave it open for nothing. As seen in Table 9, the amount of electrical energy used in this phase is decreased by 200.19 $kgCO_2eq$ per functional unit or 0.33 $kgCO_2eq$ /kg product.

Table 9. Reducing carbon footprint during the RA95 production process by improving the chiller's automated start-shutdown system

Electricity	kWh/FU	EF ($kgCO_2eq$/kWh)	CFP ($kgCO_2eq$)
before improvement	2,526.00	0.5986	1,512.06
after improvement	2,191.56	0.5986	1,311.87
saving	334.44	-	200.19

Therefore, after improving the automatic start-shutdown system of the chiller project, the carbon footprint of the study factory is reduced by 20,019 $kgCO_2eq$ per year by reducing electrical energy use by 33,444 kWh or **114,387 Baht per year**.

4. Conclusions

The carbon footprint of 605 kilograms of the stevia sweetener RA95 throughout the production process is 19,400.95 $kgCO_2eq$ or 32.07 $kgCO_2eq$ per kilogram of product. The raw materials acquisition process has the highest proportion of greenhouse gas emissions, followed by production, production support, and raw material transportation. The second and first crystallization steps and drying are the top 3 production processes with the highest greenhouse gas emissions. The environmental impact analyzed using the Open LCA method revealed that the most significant impact is attributed to marine aquatic ecotoxicity, followed by the Depletion of abiotic resources and human toxicity. Those significant impacts are derived from packaging consisting of the lamination of three layers of nylon, aluminum foil, and LLDPE. The decrease in the impact could be considered and discussed with the packaging supplier. When comparing the result of the study's carbon footprint with that of OpenLCA, electricity from the OpenLCA revealed the most significant influence, followed by natural gas and raw materials, which are different from the study due to varying sources of emission factors. Improving the chiller system with an automated start-stop system to save electricity in production support can help reduce the carbon footprint during RA95 production. By utilizing the automatic start-shutdown system of the chiller project, power is saved, which can lower the annual release of carbon dioxide equivalent (20,019 kgCO2eq) due to a decrease in electrical energy use of 33,444 kWh, or roughly 114,387 baht, or about $3,300 US dollars. The carbon footprint of the stevia sweetener RA95 compared to the same sweetness level of sucrose presented a carbon footprint 3.55 times less than sucrose and can reduce 71.79% of the carbon footprint. Therefore, stevia RA95 as a substitute for sucrose can mitigate environmental impacts.

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