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Article

Impacts of greenhouse gas performance of cassava factory: An example factory in the northeastern part of Thailand

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Abstract: Most industrial production for exportation is aware of environmental pollution. The cassava starch industry is one of the industries that releases a large amount of greenhouse gases (GHG), especially Thailand has large volume. This research aims to show GHG emissions data by activity of a sample factory in the northeastern region of Thailand. During 2000–2023. In each period of the year, there are measures for energy, waste disposal, and alternative energy use, which result in reducing GHG emissions. The amount of GHG is mostly caused by methane leakage from the treatment system, followed by fuel use in the unit. The main measures to reduce GHG were using renewable energy. In addition, the project to reduce GHG was evaluated by showing the marginal abatement cost curve (MACC). It was found that energy bypass, rooftop and floating solar panels, other energy sources to replace oil in forklifts, and producing electricity from biogas have higher costs compared to the amount of carbon dioxide emissions. The use of solar panels can reduce the most GHG emissions in the range of 591–1200 tons of carbon dioxide equivalent, making the project the largest share compared to other projects.

Keywords: greenhouse gas; policy; marginal abatement cost curve; cassava starch

1. Introduction

The energy and natural resources used in production stages caused environmental pollution (Cem, 2013; Cem et al., 2018). According to the USA environmental protection Agency, 33% of CO_2 emission in the USA are environmental pollution centered on industrial and agricultural production (EPA, 2022). Many countries around the world are aware of global warming causing by the release of greenhouse gases (GHG) because of boundary of exported product. The industrial sector has emitted the most GHG, with 301.34 million tons of carbon dioxide equivalent (CO_2eq) in 2021 (Hannah et al., 2024). The total exports of these products produced by the USA to other country reached $2 trillion in 2022 (CB, 2022). Thailand is one of the countries that exported product globally. In 2023, the industrial sector released 243.6 million tons of carbon dioxide (CO_2) or an average of 59% (Energy Policy and Planning Office, Ministry of Energy, 2023). Most comes from emissions from activities that use fossil energy. Likewise, life cycle assessment (LCA) of product, including activities that occur in the organization is important to identify the causes of activities that cause GHG emissions and are consistent with the Bio-Circular-Green Economy (BCG) Sustainable Development Goals (SDG) by using the circular economy (CE) concept for global sustainability.

Thailand has voluntarily established a database of GHG emissions from industries under the operation of Thailand Greenhouse Gas Management Organization (Public Organization) (TGO) (Greenhouse Gas Management Organization, 2023). Utilizing natural resources to maximize the benefits and reduce waste as much as possible. Thailand issued the Ministry of Industry Announcement on Waste Management or Unused Materials 2023, which stipulates the waste management criteria in Appendix 3, Waste management code or unused materials, namely, reusing waste in a way similar to the circular economy (CE) concept.

The cassava starch industry rank second globally carbon dioxide (CO_2) emissions in the world, using 13,201.7 × 10^6 MJ annually. More than 81% of the energy is used in starch factories. Air conditioning 53%, electricity 28%, oil used in production and transportation account for 6% and 12% respectively (Vo et al., 2024). Cassava (Manihot esculenta Crantz) is an economic crop and agro-industrial with high added value such as starch, modified starch, sweeteners and various derivatives in the food and non-food industries (Kuakoon and Morakot, 2011). Thailand produces more than 20 million tons of cassava per year, ranking second in the world, and its related products. Domestic consumption 30%, 70% sold on the world market. In 2013, more than 12.15 million tons of cassava products were exported, generating more than 95 billion baht in revenue. In 2024, it is expected that the harvest area will be 8.682 million rai, yield 26.877 million tons, yield per rai 3096 kilograms, compared to 2023 with a harvest area of 9.268 million rai, yield 30.617 million tons, yield per rai 3303 kilograms. Harvested area, yield, yield per rai decreased by 6.32%, 12.22%, 6.27% (Jittima and Shabbir, 2021; Research and Development Institute of Kasetsart University, 2024; Tarntip, 2016). Study and collect data on cassava starch factories with production capacity 200–400 tons of flour/day in Thailand, 3 factories in 2014 stated that the tapioca starch industry surveyed released greenhouse gases or carbon footprints between 130.949–572.346 kg CO_2eq per 1 ton of flour (average 281.258 kg CO_2eq per 1 ton of flour), accounting for the entire industry of 847.121 million tons of CO_2eq. Neigh bouring countries in Asia, namely Thailand, Malaysia, and Vietnam, use the full life cycle assessment (LCA) to assess the reduction of carbon dioxide (CO_2) emissions in every step from planting to product production, which contributes to the release of greenhouse gases. Thanathip, 2016 found that land preparation released the most carbon. The carbon equivalent value released throughout the cycle was 35.89 kilograms of carbon per rai per year. Every country is aware of greenhouse gas emissions and has measures to reduce them, including the use of alternative energy. In 2019, Thailand produced approximately 260.7 million Nm3 of biogas from wastewater from 62 cassava starch factories. Cassava pulp is used to produce biogas, reducing the amount of waste and greenhouse gas (GHG) emissions. In terms of economic and environmental costs for Thailand, biogas production is the best choice with the lowest environmental costs.

In terms of global warming, most of organizations have reduced GHG emission by using renewable energy (Achiraya et al., 2017; Tharinya et al., 2017) and the contemporary discourse on sustainable development, integrating environmental, social, and governance (ESG) factors on energy efficiency (Cem et al., 2024). Cassava starch production using wastewater biogas conversion technology was found to reduce greenhouse gas emissions by 0.49–0.75 kg CO_2eq per kg of starch.

Thailand's cassava starch production process reduces greenhouse gas emissions by 0.9–1.0 billion kg CO_2eq per year (Ruenrom et al., 2021). A study (Nanthiya et al., 2016) stated that the introduction of biogas technology in cassava starch factories reduced greenhouse gas emissions by 431–664 kg CO_2eq per ton of starch, compared to the use of oil fuels that reduced 285–438 kg CO2eq per ton of starch, reducing carbon dioxide emissions by 0.9–1.0 million tons CO_2 equivalent per year. Currently, 90% of cassava starch factories in Thailand use biogas for economic and environmental benefits (Thierry et al., 2015). Reducing carbon dioxide (CO_2) emissions from the source is new knowledge that benefits the agricultural industry as a zero-discharge process, reducing resource and waste usage, higher product prices from increased demand for health products and biomaterials, developing Thailand's cassava cultivation potential in line with the BCG (Bio-Circular-Green Economy) economic model, using mechanisms and innovations that are appropriate for the strategy to increase income.

This research aims to show GHG emission information for each activity in organization and show policy to solve the problem of greenhouse gas emission by using marginal abatement cost curve (MACC). MACC has frequently been used to illustrate the economics of climate change mitigation and has contributed to decision making in the context of climate policy (Fabian, 2013; Sumate and Wirote, 2017; Yun-Hsun et al., 2022).

2. Materials and methods

2.1. Experimental procedure

This research is a qualitative and quantitative research. The sample group is purposive informants. The documentary research uses secondary data to determine the research issues from theoretical concepts, data, documents, and stakeholder interviews.

An Example of cassava factory is in the Northeastern Part of Thailand with capacity around 75,000 ton per year. GHG according to TGO have defined several types of greenhouse gases that are naturally occurring and caused by human activities, namely 7 types: 1) Carbon dioxide (CO_2), 2) Methane (CH_4), 3) Nitrous oxide (N_2O), 4) Hydrofluorocarbons (HFCs), 5) Perfluorocarbons (PFCs), 6) Sulfur hexafluoride (SF_6), 7) Nitrogen trifluoride (NF_3) (Vo et al., 2024). Energy usage covering electric and heat by activity have monthly recorded throughout 2020–2023, using 2020 as the base year. Activity by scopes according to:

1) Record direct energy consumption;
2) Indirect energy consumption record GHG emissions from using toilets and wastewater treatment;
3) Emission in other forms with 15 categories.
   (1) Purchased goods and services;
   (2) Capital goods;
   (3) Fuel- and energy-related activities not included in scope 1 or scope 2;
   (4) Upstream transportation and distribution;
   (5) Waste generated in operations;
   (6) Business travel;

(7) Employee commuting;
(8) Upstream leased assets;
(9) Downstream transportation and distribution;
(10) Processing of sold products;
(11) Use of sold products;
(12) End-of-life treatment of sold products;
(13) Downstream leased assets;
(14) Franchises;
(15) Investments.

All activities by scopes were demonstrated in **Table 1**. The data of each activity was collected from inventory of fuel and chemical usage.

Table 1. List of greenhouse gas emissions classified by scope.

Scope	List	Dimension
Scope 1	**Greenhouse gases from mobile combustion**	Liter
	1. Diesel use (all executive cars and central cars)	Liter
	2. Gasohol use (central cars and motorcycles)	
	** Motor Gasoline-uncontrolled **	kg
	4. LPG use (forklifts)	Liter
	5. Diesel use (excavators)	Liter
	6. Diesel use (tractors, plows, harvesters, trailers, six-wheelers)	
	Greenhouse gases from stationary combustion	kg
	7. LPG use (product quality analysis)	kg
	8. LPG use (maintenance)	kg
	9. LPG use (boiler heat production)	Liter
	10. Fuel oil A use (steam heat production)	kg
	11. Wood chip combustion (steam heat production) Biomass wood chip	m^3
	12 Biogas combustion (combustion at boiler + bio gen)	m^3
	13 Biogas combustion (combustion at flare)	kg
	14. LPG use in fire drills	Liter
	15. Diesel use in fire drills	Liter
	16. Diesel fuel usage (Fire pump)	Liter
	17. Diesel fuel usage (Generator)	Liter
	18 Diesel fuel usage (Mobile pump)	Liter
	19. Gasohol fuel usage in agricultural machinery (lawn mowers, water pumps)	
	Greenhouse gases from the production process	
	20. CO_2 emissions from the use of Na_2CO_3	kg CO_2
	21. CO_2 emissions from the use of $NaHCO_3$	kg CO_2
	Greenhouse gases resulting from leakage, etc.	
	22. Use of fertilizers/soil amendments containing nitrogen	kg N_2O
	23. CO_2 (Fossil carbon) emissions from municipal waste combustion **Municipal Solid Wastes	kg CO_2
	24. CH_4 emissions from municipal waste combustion	
	**Municipal Solid Wastes	kg CH_4
	25. N_2O emissions from municipal waste combustion	
	**Municipal Solid Wastes	kg N_2O
	26 SF_6 leakage from circuit breaker	
	27. Use of R-134a refrigerant	kg SF_6
	28. Use of R-407C refrigerant	kg R-1340A
	29. Use of R-404A refrigerant	kg R-407C
	30. Use of R-32 refrigerant	kg R-404A
	31. Use of R-410A refrigerant	kg R-32
	32. CH_4 leakage from biogas system	kg R-410A
	33 CH_4 leakage from Anaerobic Pond wastewater treatment system	kg CH_4
	34 CH_4 emissions from biogas flare system	kg CH_4
	35. CH_4 emissions from septic tank system	kg CH_4
		kg CH_4
Scope 2	1. Electricity use from PEA (market based)	kWh

Scope 3	1. Use of cassava roots	kg

2.2. GHG emission calculation

The calculation of greenhouse gas emissions from the activities will be performed according to Equation (1), with the assessment result collection format being performed on MS Excel presented by TGO, and reported in tons of carbon dioxide equivalent.

$$\text{Greenhouse gas emission} = AD \times EF \times GWP \quad (1)$$

Where A = Activity data; amount of electric (kWh), fuel (litre) paper (kg).

Usage

EF = Emission factor; The intergovernmental panel on climate change.

(IPCC) and TGO factors.

GWP = Global warming potential; The global warming potential of a greenhouse gas depends on its radiative heat emission efficiency and its lifetime in the atmosphere.

2.3. Economic and environmental assessment

Appropriateness of appropriate greenhouse gas reduction measures or policy to create a marginal abatement cost curve (MACC) for each measure. MACC is plotted between marginal abatement (baht/CO_2 equivalent) in *y* axis versus emission abatement (ton CO_2 equivalent per year) in *x* axis.

2.4. Measures or policy determination

Stakeholders within the organization is interviewed to determine measures to reduce GHG emissions. Propose a strategy based on life cycle assessment (LCA) is a tool used to assess environmental impacts throughout the product life cycle, from raw material acquisition, energy use, control, to the final stage of product waste management. Use the study results to determine policies, design products, improve production processes, or add alternatives to reduce environmental impacts and use resources as efficiently as possible.

3. Results and discussion

3.1. Assessment of GHG emissions in the base year 2020

The amount of greenhouse gas emissions in 2020, which is the base year, found that there were greenhouse gas emissions in all 3 scopes. Each scope shows the percentage as shown in **Table 1** and shown in **Figure 1**, comparing all 3 scopes.

The percentage of carbon dioxide emissions in scope 1 is as follows:

(1) CH_4 leakage from Anaerobic Pond wastewater treatment system;

(2) CH_4 leakage from biogas system;

(3) Fuel oil A use (steam heating);

(4) CH_4 gas release from biogas flare system;

(5) Diesel use (excavator).

The top three categories account for more than 1 % of carbon dioxide emissions in scope 1, while scopes 2 and 3 have 100 % emissions from electricity use from Provincial electricity authority (PEA) and use of cassava roots, respectively. Scope 3 is in category 1 and category 4, including indirect greenhouse gas emissions from raw materials and services, and indirect greenhouse gas emissions from the transportation of raw materials and production factors, respectively.

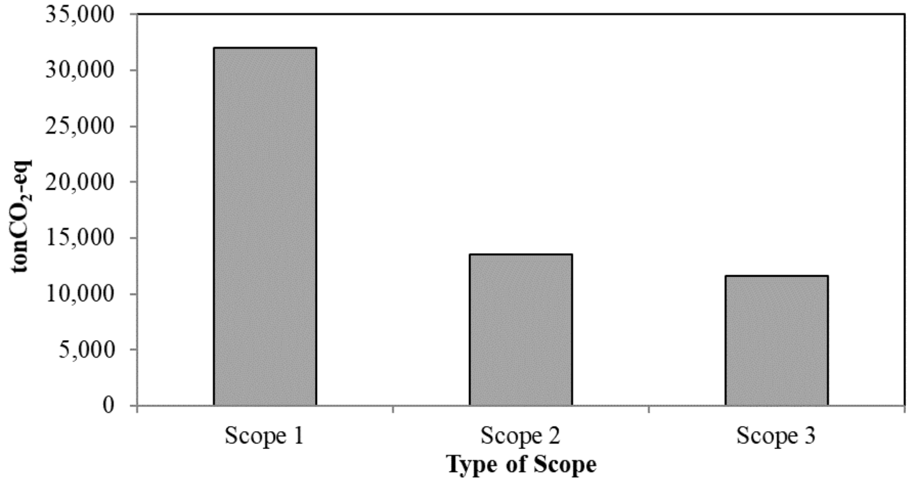


Figure 1. Carbon dioxide emissions of scope 1, 2 and 3 for the base year 2020.

Carbon dioxide emissions in each scope are shown in **Figure 1**. The amount of carbon dioxide emissions from scope 1 is the highest when compared to Scopes 2 and 3, respectively. The amount of carbon dioxide emissions from scope 1 is 32,008 ton CO_2eq, the amount of carbon dioxide emissions from scope 2 is 13,567 ton CO_2eq and the amount of carbon dioxide emissions from scope 3 is 11,591 ton CO_2eq, which shows the amount of carbon dioxide emissions after the next measures.

3.2. Assessment of GHG in 2021

The amount of greenhouse gas emissions in 2021 was found to have released greenhouse gases in all 3 scopes, with each scope showing the percentage as shown in **Table 1** and shown in **Figure 2**, comparing all 3 scopes.

The percentage of carbon dioxide emissions in scope 1 is ranked as follows:

(1) Methane leakage from biogas production system;

(2) Methane leakage from anaerobic wastewater treatment system;

(3) CH_4 gas emission from biogas flare system;

(4) Leakage of refrigerant type R-410 A;

(5) Diesel fuel for vehicles.

All 5 ranks exceed 1 % compared to the carbon dioxide emission in scope 1. Scope 2 and 3 have 100 % emission from electricity usage from PEA and cassava roots usage, respectively. Scope 3 is in category 1 and category 4, namely indirect greenhouse gas emissions from raw materials and services and indirect greenhouse gas emissions from the transportation of raw materials and production factors, respectively.

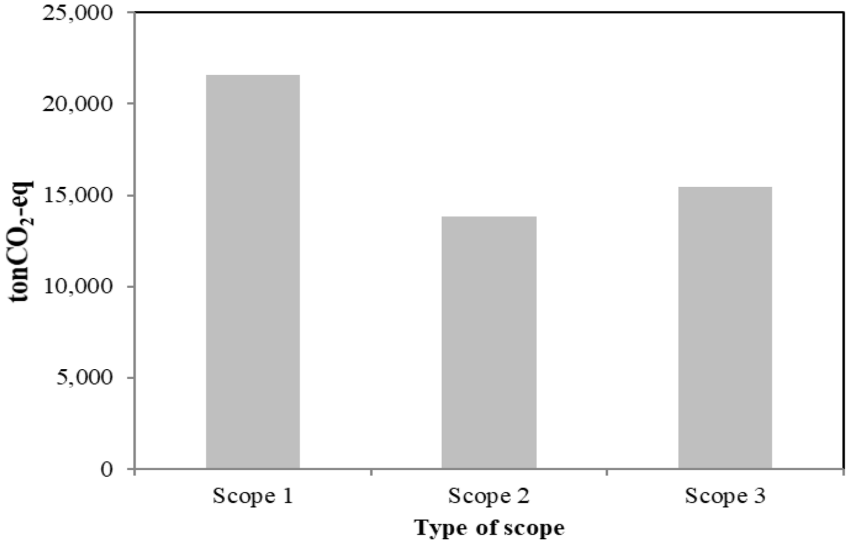


Figure 2. Carbon dioxide emissions of scope 1, 2 and 3 for the year 2021.

Carbon dioxide emissions in each scope are shown in **Figure 2**. The amount of carbon dioxide emissions from scope 1 is the highest when compared to scopes 2 and 3, respectively. The amount of carbon dioxide emissions from scope 1 is 21,620 ton CO_2eq, the amount of carbon dioxide emissions from scope 2 is 13,800 ton CO_2eq and the amount of carbon dioxide emissions from scope 3 is 15,474 ton CO_2eq, which shows the amount of carbon dioxide emissions after the next measures.

3.3. Assessment of GHG emissions in 2022

The amount of greenhouse gas emissions in 2022 was found to be released from all 3 scopes, with each scope showing the percentage as shown in **Table 1** and shown in **Figure 3** comparing all 3 scopes.

The order of the percentage of carbon dioxide emissions in scope 1 is as follows:

(1) Amount of methane leakage from the biogas production system;

(2) Amount of methane leakage from the anaerobic wastewater treatment system;

(3) CH_4 gas emissions from the biogas flare system;

(4) Fuel oil A;

(5) Diesel vehicles.

All ranks exceed 1 % compared to the amount of carbon dioxide emissions in scope 1. Scopes 2 and 3, the emission amount is 100 % from electricity usage from PEA and cassava roots, respectively. Scope 3 is in category 1 and category 4, namely, indirect greenhouse gas emissions from raw materials and services and indirect greenhouse gas emissions from the transportation of raw materials and production factors, respectively.

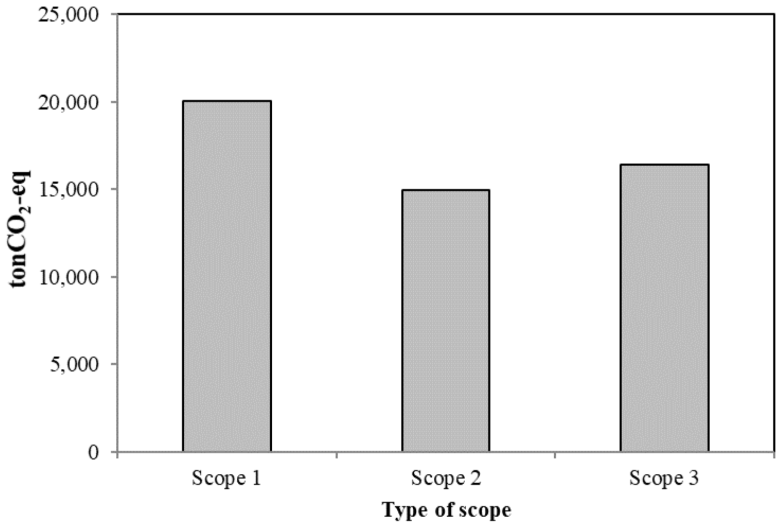


Figure 3. Carbon dioxide emissions of scope 1, 2 and 3 for the year 2022.

Carbon dioxide emissions in each scope are shown in **Figure 3**. The amount of carbon dioxide emissions from scope 1 is the highest when compared to scopes 2 and 3, respectively. The amount of carbon dioxide emissions from scope 1 is 20,054 ton CO_2eq the amount of carbon dioxide emissions from scope 2 is 14,963 ton CO_2eq, and the amount of carbon dioxide emissions from scope 3 is 16,388 ton CO_2eq.

3.4. Assessment of GHG emissions in 2023

The amount of greenhouse gas emissions in 2023 was found to be released in all 3 scopes, with each scope showing the percentage as shown in **Table 1** and shown in **Figure 4**, comparing all 3 scopes.

The order of the percentage of carbon dioxide emissions in scope 1 is as follows:

(1) CH_4 leakage from the biogas system;

(2) CH_4 leakage from the Anaerobic Pond wastewater treatment system;

(3) Use of fuel oil A (steam heating);

(4) CH_4 emissions from the biogas flare system;

(5) Use of diesel (excavator).

All ranks exceed 1 % compared to the amount of carbon dioxide emissions in scope 1. Scopes 2 and 3, the amount of emissions is 100 %, from electricity usage from PEA and cassava roots, respectively. scope 3 is in category 1 and category 4, namely, indirect greenhouse gas emissions from raw materials and services and indirect greenhouse gas emissions from the transportation of raw materials and production factors, respectively.

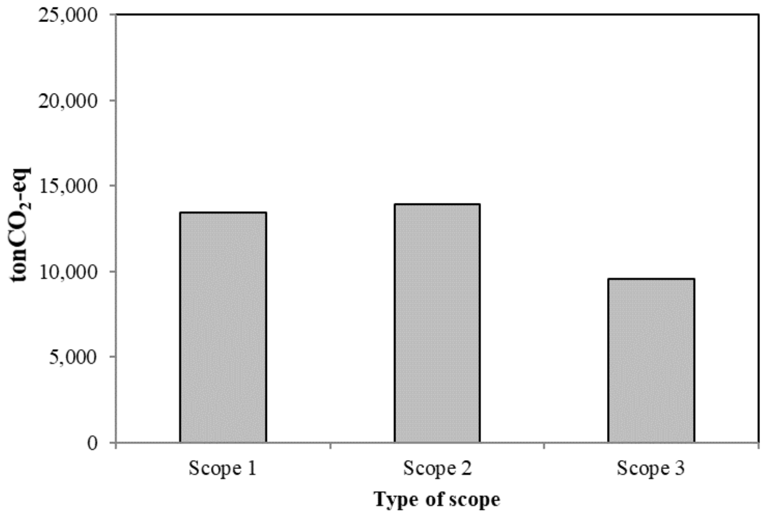


Figure 4. Carbon dioxide emissions of scope 1, 2 and 3 for the year 2023.

The carbon dioxide emissions in each scope are shown in **Figure 4**, Carbon dioxide emissions from scope 1 It has the highest value when compared to scopes 2 and 3 respectively, with the amount of carbon dioxide emissions from scope 1 being 20,054 ton CO_2eq, the amount of carbon dioxide emissions from scope 2 being 14,963 ton CO_2eq, and the amount of carbon dioxide emissions from scope 3 being 16,388 ton CO_2eq, which will show the amount of carbon dioxide emissions after the next measures.

3.5. Comparison of GHG emissions

Carbon dioxide emissions classified by scope during 2020–2023, with 2020 as the base year, are shown in **Figure 5**. The *x*-axis shows the scope type, and the *y*-axis is the amount of carbon dioxide emissions. The results of the overall carbon dioxide emissions are shown on the far right of the figure. Scope 1 released the most carbon dioxide in the base year and decreased in the year with carbon dioxide emission reduction measures. In 2023, the amount of carbon dioxide emissions was reduced the most, while in 2021 and 2022, the decreases were not much different. When considering each scope, scope 1 in 2021 was able to reduce carbon dioxide emissions the most because it had a bypass of the anaerobic water treatment system to export for new crops, reducing greenhouse gas emissions by 27%, reducing CH_4 leakage, reducing greenhouse gas emissions by approximately 14,000 tons of carbon dioxide equivalent per year compared to the base year. scope 2 has measures to install solar cells on the building's roof (Solar Rooftop), which helps save fossil energy consumption. Scopes 2 and 3 did not show significant reductions in carbon dioxide emissions. However, the combined effects of all three scopes showed significant reductions. Renewable energy from waste can mitigate greenhouse gas as the same in other researches (Achiraya et al., 2017; Nanthiya et al., 2016; Ruenrom et al., 2021; Thierry et al., 2015; Tharinya et al., 2017).

Considering 2022 and 2023, the reductions in greenhouse gas emissions were similar as the original measures from 2021 were still in place.

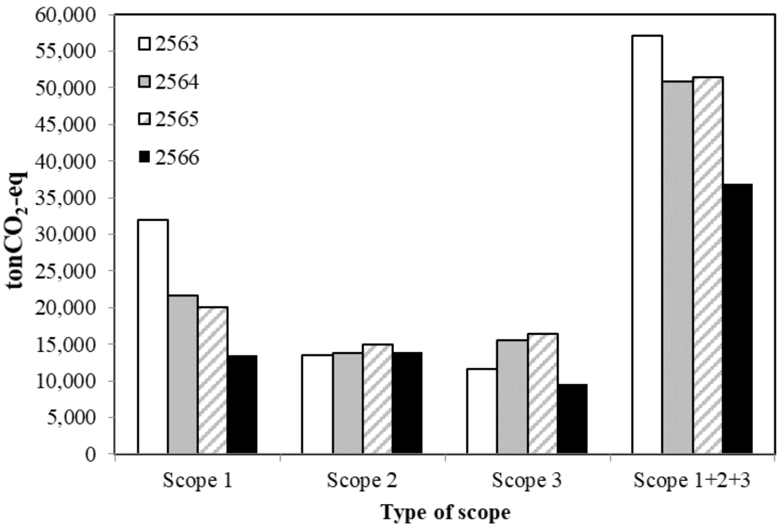


Figure 5. Carbon dioxide emissions of scope 1, 2, 3 and the sum of all three Scopes during 2020–2023.

3.6. Economic and environmental suitability assessment of appropriate GHG mitigation

Economic growth is related to the environment, which is a key issue of the sustainable development goals. Economic activities can lead to environmental problems, negatively affecting sustainable development. It is necessary to analyze and understand the impact of economic growth on environmental degradation. It is proposed that there is a non-linear relationship between economic growth and environmental degradation, represented by an inverted U-shaped Kuznets curve. Environmental Kuznets curve According to the EKC hypothesis, the initial increase in real GDP per capita leads to an increase in CO_2 emissions. In the early stages of economic growth, the consumption of fossil fuels eventually leads to a decrease in CO_2 emissions. The turning point is the adoption of green technologies, policies, and the demand for clean energy. Studies indicate that the use of renewable energy plays an important role in reducing CO_2 emissions, which is good for the environment. A country's economic and energy policies may be unsustainable for various reasons, such as the wrong implementation of economic and energy policies (Cem et al., 2023). There are also studies that focus on economic policy uncertainty, stating that the economy is sensitive and related to the policy decisions of the government and stakeholders. The culprit that causes the overall scale of economic activity to decrease under increased uncertainty. Policy uncertainty will affect the economy and is not an accepted economy. In this study, the Economic Policy Uncertainty Index (EPU) reveals that the EPU is a significant predictor. Due to the increase in the EPU index (Cem et al., 2020).

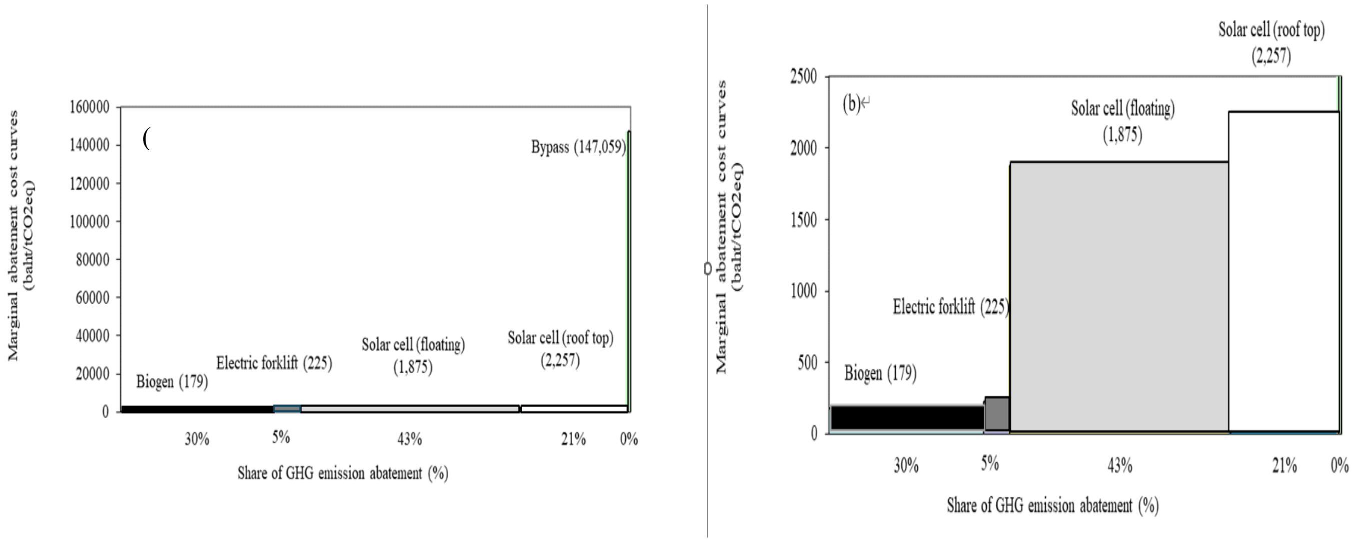
The implementation of the project to reduce greenhouse gas emissions involves the cost of operation. Therefore, in order to compare which project is the best, an economic graph will be created to analyze the cost of greenhouse gas reduction, including the marginal abatement cost curve, which is a graph showing the proportion of investment to the amount of greenhouse gas emission reduction and the amount of greenhouse gas reduction per year. It can be displayed in order of cost from least to most for 5 projects as follows:

1) Biogas electricity generation project;
2) Electric forklift project;
3) Rooftop solar installation project;
4) Floating solar farm installation project;
5) Wastewater bypass project from the treatment system to grow new plants.

From the MACC of all projects, the data is shown in **Figure 6** and the annual emission data is shown in **Table 2**.

Table 2. Cost per unit of greenhouse gas emissions and annual greenhouse gas emissions of each project.

Project	**Marginal abatement cost (baht/TCO$_2$eq)**	**GHG emission abatement (TCO$_2$eq/year)**
Biogen	179	839
Electric forklift	225	144
Solar cell (floating)	1875	1200
Solar cell (roof top)	2257	591
Bypass	147,059	14



(**a**) (**b**)

Figure 6. Marginal abatement cost curve (**a**) GHG abatement costs of five projects and (**b**) an extension of (**a**).

In this case the *x*-axis is modified in form of project sharing in percent. Bypass is Bypass is the diversion of wastewater to plant fast-growing trees. From the data of all 5 projects, it is possible to mitigate greenhouse gas emissions in scope 1 and 2. From **Figure 6**, the sample factory mainly uses fuel from solar cells and secondly uses fuel from biogas.

4. Discussion

The policy and guidelines for reducing greenhouse gas emissions in organization are short-term (3 years), medium-term (5 years), and long-term (7 years or more) with the following measures:

(1) Management of the readiness of electrical appliances: Maintain electrical appliances in an efficient working condition according to energy conservation measures, change light bulbs and lamps to be efficient in lighting, and clean air conditioners regularly.

(2) Reducing the use of fossil energy: Energy conservation measures, replaceing fossil fuels by using renewable energy. Renewable energy includes wood chips and biogas. Electricity produced from biogas is used instead of LPG in forklifts, using a 900-kilowatt solar rooftop, and floating solar farms.

(3) Reducing greenhouse gas emissions at the source: Bypass anaerobic energy to send to new planting areas, reducing the use of wood chips.

(4) Planting forests to absorb carbon

Currently, the cassava starch industry lacks policies and measures to promote the recycling of waste from the production process to be reused as renewable energy instead of fossil energy, which has been continuously increasing in price, resulting in an increase in energy costs for product production in the same direction and increase carbon dioxide (CO_2) emission. Likewise, other researches Achiraya (2017); Cem et al. (2024) and Tharinya (2017) have used renewable energy. The current waste solution in the cassava starch industry is to release water from the production process into a wastewater pond and treat it and release the treated water into natural water sources. The sludge is left to dry in the pond without reusing both wastewater and sludge. In addition, most of the machinery and equipment used in the production process are old and use a lot of fossil energy. As a result, the production process itself also creates a lot of waste and releases carbon. In addition to releasing carbon and waste from the production process, the raw materials in the cassava starch industry, which are cassava roots that have been cultivated using chemical fertilizers and transported using machinery, and the equipment used for cultivation and transportation that uses energy from fossils also releases carbon dioxide. Therefore, it can be concluded that the cassava starch industry from the beginning to the end of the process creates waste and releases carbon dioxide, which is part of the greenhouse gas that is the main cause of global warming.

Here, the solution to improve the problem of carbon dioxide (CO_2) emissions. Most cassava starch industries use fossil energy and create waste (by-product), such as starch scraps, cassava peels, etc. Most cassava starch factories lack a way to recycle waste, such as using wastewater to produce methane gas (CH_4) to produce heat instead of using energy from fossils. This may be due to the large investment and the long payback period, which makes most entrepreneurs not give it importance.

If looking at the development of the cassava industry to be a green industry and linked to solving the problem of global warming This may be possible because Thailand has 3 important laws for waste management from the cassava starch industry: the National Environmental Quality Promotion and Conservation Act 1992, the Public Health Act 1992, and the Hazardous Substances Act 1992, which have been in use for a long time and have not been updated, making them in time for the waste situation and global warming problems, especially the development of innovation and promotion of waste utilization, which is a type of pollution and hazardous waste with different components and sources from general waste, as well as the lack of policies and management guidelines, causing existing policies and management guidelines to be outdated and should be revised. In the short term, while there is a lack of specific policies and laws, the author proposes to improve existing policies and laws to be applied to solving problems, establish additional policies to promote the utilization of hazardous waste, and enact secondary laws on a case-by-case basis to facilitate management guidelines, using environmental principles such as the polluter-pays principle, the principle of shared environmental responsibility, the principle of extended producer liability (EPR), the principle of shared and differentiated responsibility, the principle of precaution, the principle of environmental surveillance, and other related principles. Apply to additional policy formulation to promote the recycling of hazardous waste and create a systematic linkage in the management of waste from the cassava starch industry and create management standards.

5. Conclusion

This research showed GHG emission of organization in year range from 2020–2023 of cassava factory which has covered more than 50% of share market in Thailand. Data of GHG can demonstrate which activity made the highest GHG emission mainly fossil fuel usage. The effective project for mitigating GHG emission was the highest GHG mitigation with the lowest investment cost according to MACC. This research has found that biogas generation and solar cell can mitigate greenhouse gas in range of 591–1200 tons of carbon dioxide equivalent.

Conflict of interest: The authors declare no conflict of interest.

References

CB. (2022). Imports and Export Merchandise Trade Statistics. Available online: https://usatrade.census.gov/data/Perspective60/View/dispview.aspx (accessed on 2 June 2024).

Chaichaloempreecha, A., Winyuchakrit, P., Limmeechokchai, B. (2017). Assessment of renewable energy and energy efficiency plans in Thailand’s industrial sector. Energy Procedia, 138, 841–846.

Energy Policy and Planning Office, Ministry of Energy. (2023). Carbon dioxide (CO_2) emissions from energy use in 2023. Available online: https://www.eppo.go.th/ (accessed on 2 June 2024).

Greenhouse Gas Management Organizatio. (2023). Project requirements Types of greenhouse gases. Available online: https://tver.tgo.or.th/index.php/th-standard/std-th-project-development/std-th-project-specification/std-th-types-of-greenhouse-gases (accessed on 2 June 2024).

Hansupalak, N., Piromkraipak, P., Tamthirat, P., et al. (2016). Biogas reduces the carbon footprint of cassava starch: A comparative assessment with fuel oil. Journal of Cleaner Production, 134, 539–546.

Huang, Y.-H., Wu, J.-H., Liu, T.-Y. (2022). Bottom-up analysis of energy conservation and carbon dioxide mitigation potentials by extended marginal abatement cost curves for pulp and paper industry. Energy Strategy Reviews, 42, 100893.

Isik, C. (2013). The importance of creating a competitive advantage and investing ininformation technology for modern economies: An ARDL test approach from Turkey. Journal of the Knowledge Economy, 4, 387–405.

Isik, C., Dogru-Dr. True, T., Sirakaya-Turk E. (2018). A nexus of linear and non-linear relationships between tourism demand, renewable energy consumption, and economic growth: Theory and evidence. Inter. J. Tourism Res, 20(1), 38–49.

Isik, C., Ongan, S., Islam, H., et al. (2024). ECON-ESG factors on energy efficiency: Fostering Sustainable development in ECON-growth-paradox countries. Gondwana Research, 135, 103–115.
Isik, C., Ongan, S., Ozdemir, D., et al. (2024). Renewable energy, climate policy uncertainty, industrial production, domestic exports/re-exports, and CO_2 emissions in the USA: A SVAR approach. Gondwana Research, 127, 156-164.
Isik, C., Simionescu, M., Ongan, S., et al. (2023). Renewable energy, economic freedom and economic policy uncertainty: New evidence from a dynamic panel threshold analysis for the G-7 and BRIC countries. Stochastic Environmental Research and Risk Assessment, 37, 3367–3382.
Isik, C., Sirakaya-Turk, E., Ongan, S. (2020). Testing the efficacy of the economic policy uncertainty index on tourism demand in USMCA: Theory and evidence. Tourism Economics, 26(8), 1344–1357.
Kesicki, F. (2013). Marginal Abatement Cost Curves: Combining Energy System Modelling and Decomposition. Analysis Environ Model Assess, 18, 27–37.
Lerdlattaporn, R., Phalakornkule, C., Trakulvichean, S., Songkasiri, W. (2021). Implementing circular economy concept by converting cassava pulp and wastewater to biogas for sustainable production in starch industry. Sustainable Environment Research, 31(20), 1–12.
Piyachomkwan, K., Tanticharoen, M. (2011). Cassava industry in Thailand: Prospects. The Journal of the Royal Institute of Thailand. The Journal of the Royal Institute of Thailand, 3, 160–170.
Prasara-A, J., Gheewala, S. H. (2021). An assessment of social sustainability of sugarcane and cassava cultivation in Thailand. Sustainable Production and Consumption, 27, 372–382.
Research and Development Institute of Kasetsart University. Cassava The importance of cassava. Available online: https://www3.rdi.ku.ac.th/?p=17872 (accessed on 2 June 2024).
Ritchie, H., Rosado, P., Roser, M. (2024). Breakdown of carbon dioxide, methane and nitrous oxide emissions by sector. How much does electricity, transport and land use contribute to different greenhouse gas emissions? Available online: https://ourworldindata.org/emissions-by-sector (accessed on 2 June 2024).
Sathitbunanan, S., Ritthong, W. (2017). Techno-Economy analysis by green abatement cost curve for pulp and paper industry. Energy Procedia, 138, 734–738.
Supasa, T., Hsiau, S.-H., Lin, S.-M, et al. (2017). Sustainable energy and CO_2 reduction policy in Thailand: An input–output approach from production- and consumption-based perspectives. Energy for Sustainable Development, 41, 36–48.
Tarntip, S. (2016). The synthesis of life cycle assessment of carbon and water footprints in native starch Industry. NIDA Development Journal, 56(3), 221–252.
Tran, T., Da, G., Moreno-Santander, M. A., et al. (2015). A comparison of energy use, water use and carbon footprint of cassava starch production in Thailand, Vietnam and Colombia. Resources, Conservation and Recycling, 100, 31–40.
Van Giau, V., Van Thanh, T., Liu, T. L., et al. (2024). Environmental engineering research, application of linear programming for cassava starch production optimization in Vietnam within a circular Economy framework toward zero emission. Environmental Engineering Research, 28(4), 220214.