Assessing GHG Emission Reductions for Organization through the Installation of Solar PV Rooftop On-grid System

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Abstract

The Earth's surface temperature is steadily increasing due to the accumulation of greenhouse gases, a phenomenon known as global warming. Human activities are the root cause of this significant global issue. Reducing greenhouse gas (GHG) emissions is one of the most critical actions in climate change mitigation. Organizations can engage in activities that promote change and reduce greenhouse gases by acknowledging the significance of addressing climate change. By reducing GHG emissions and promoting the use of renewable energy, organizations can begin to address environmental issues. Therefore, the purpose of this investigation is to assess the reduction of GHG emissions in an educational institution by substituting electricity consumption from the electrical grid with renewable energy in the form of a solar PV rooftop on-grid system. The School of Renewable Energy's GHG emissions were assessed, covering three scopes of GHG emissions activities: direct emissions, indirect emissions, and other indirect emissions. The organization's activity data were collected over a 12-month period. Without installing a solar panel system, the organization reported total GHG emissions of 310.40 tCO2e, relying solely on imported electricity for internal use. The highest GHG emissions were from Scope 2, amounting to 239.38 tCO_2e, primarily due to electricity importation. Scope 3 had the second highest GHG emissions, totaling 65.76 tCO_2e, resulting from employee commuting and the use of purchased goods such as paper and tap water. Scope 1 had the lowest GHG emissions at 5.26 tCO_2e, produced by the combustion of diesel and gasoline in both stationary and mobile sources, as well as CH_4 emissions from the septic tank. The percentage of GHG emissions from Scope 2 activities was 77.12%, which was considered to have a significant environmental impact and contribute to global warming. This was because 478,851 kWh of electricity were imported. The installation of on-grid solar cells for power generation reduced imported electricity to 113,120 kWh. Consequently, GHG emissions from Scope 2 decreased to 56.55 tCO_2e, leading to an overall reduction in the organization's GHG emissions to 127.57 tCO_2e. The organization's GHG emissions decreased by 182.83 tCO_2e as a result of using alternative energy to generate electricity. This assessment can serve as a database for educational institutions and prepare the government to report greenhouse gas emissions. Furthermore, it can serve as carbon credits for trading and exchanging carbon with other organizations to offset GHG emissions from various activities. In addition, it endorses the government's goal of achieving carbon neutrality and net zero emissions in the future.

Keywords: Carbon footprint for organization, Greenhouse gases, Solar rooftop, Global warming potential, Carbon dioxide

1. Introduction

Climate change [1] refers to long-term changes in weather patterns and temperatures, which are characterized by an increasing severity and impact. Human activities, both direct and indirect, are the primary drivers that increase the amount of greenhouse gas in the atmosphere. The Earth's surface temperature increases as a result of this increase in greenhouse gas, a phenomenon known as global warming. Fuel combustion from vehicles, [2] machinery, energy consumption, waste disposal, refrigerant leaks, and a variety of industrial processes, including cement production and food and beverage processing, are all factors that contribute to greenhouse gas emissions (GHG emissions). Public electricity and heating, manufacturing, transportation, and construction are the top four sources of GHG emissions [3–5]. Many countries are increasingly concerned about the impact of GHG emissions on the environment. One of the most effective actions to mitigate global warming is to reduce GHG emissions [6–7].

The 27th session of the Conference of the Parties (COP27) to the United Nations Framework Convention on Climate Change (UNFCCC) is currently underway with the objective of promoting international collaboration in the reduction of GHG emissions. The primary objective, in accordance with the Paris Agreement, is to maintain the global temperature increase at or below 2°C above pre-industrial levels and to make concerted efforts to limit the temperature increase to 1.5°C by 2100. Thailand places considerable importance on environmental impacts and has signed agreements to regulate GHG emissions. At present, the nation emits more than 300 $MtCO_2e$ of greenhouse gases. Thailand has established policies and objectives to achieve carbon neutrality by 2050 and net zero emissions by 2065.

Consequently, the starting point in addressing environmental concerns is to evaluate GHG emissions from various activities. The Carbon Footprint for Organization (CFO) is an important tool used to measure the emissions and removals of greenhouse gases resulting from an organization's or office's activities, including production processes and services. The educational institutions can utilize the organization's carbon footprint values to inform their planning and establish a database and inventory.

This calculation serves to initiate effective greenhouse gas reduction strategies for organizations in Thailand. According to a study, the CFO of the Department of Ordnance Engineering, Academic Division, Chulachomklao Royal Military Academy had 79.027 tCO_2e, with the highest emissions from electricity consumption [8]. Hayiwangoh, et al. [9] outlined the assessment process as follows: the establishment of organizational and operational boundaries, data collection, greenhouse gas calculation, summarization and reporting of results, and result verification.

The organization's boundaries are defined using the control approach, which includes operational control and financial control, and the equity share approach, as evaluated in accordance with ISO14064-1 standards. The identification of direct greenhouse gas (GHG) emissions from organizational activities includes indirect GHG emissions from external energy use and other sources. The evaluation covers seven categories of greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

A systematic approach is required to measure, analyze, and report the GHG emissions that result from an organization's operations in order to assess its GHG emissions. **Figure 1** illustrates the steps involved in this procedure.

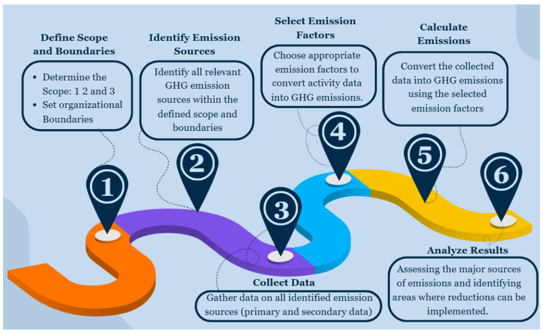

Figure 1 The step of GHG emissions assessment.

The organization's GHG emissions are assessed in three distinct categories [10]. The organization directly regulates direct GHG emissions, which include the combustion of machinery, vehicle operation, and wastewater treatment. The organization imports energy, such as electricity, heat, and steam, resulting in indirect greenhouse gas emissions. Eastern Asia University's research on greenhouse gas assessments of electricity consumption revealed emissions of approximately 4,383.47 tCO_2e [10]. Other indirect greenhouse gas emissions include emissions from the use of materials and equipment and employee travel. The GHG emissions are quantified in terms of carbon dioxide equivalent (CO_2e) [5]. A study of carbon footprints in four areas-electricity use, fuel and transportation, waste disposal, and other activities-found that higher education institutions emitted 3,469.14 tCO_2e, with most of these emissions resulting from the use of air conditioning electricity in academic buildings [11]. Consequently, Southern Rajabhat Universities' carbon footprint assessments revealed Scope 2 GHG emissions of 2,160 tCO_2e out of a total of 2,435 tCO_2e, with most of these emissions resulting from electricity consumption [9]. In 2014, Thammasat University reported a total carbon footprint of 34,533 tCO_2e, with Scope 2 emissions at 31,271 tCO_2e and Scope 1 emissions at 1,693 tCO_2e [12]. A feasibility study revealed that installing a hybrid solar PV system in an apartment with electricity consumption of 2,207.40 MWh could potentially reduce greenhouse gas emissions by up to 1,256.45 tCO_2e [12].

According to prior reports, electricity consumption is the primary source of GHG emissions. The increase in CO_2e levels is caused by the demand for and consumption of electricity. The energy use sector presents a significant barrier to achieving carbon-neutral objectives and net-zero greenhouse gas emissions [13]. As a result, this paper demonstrates how educational institutions can reduce GHG emissions by utilizing renewable energy sources. Therefore, this research aims to assess the GHG emissions of a college by comparing the GHG emissions generated by conventional electricity consumption with those generated by renewable energy sources, specifically through the installation of solar panels. Establishing a comprehensive database on renewable energy use is crucial for mitigating environmental impacts and supporting Thailand's efforts to achieve carbon neutrality and net zero emissions in the future.

2. Organization and Operational Boundaries

The assessment of greenhouse gases was divided into two parts: 1) the assessment of greenhouse gas covering the organization's activities in three scopes, with Scope 2 evaluating the total electricity consumption of the organization, and 2) the assessment of the specific reduction in greenhouse gas resulting from the installation of solar cells for electricity generation. Therefore, the research aims to evaluate the GHG emissions from the organization's operations and compare the greenhouse gas emissions from solar PV panel installation with those from external electricity purchases.

The GHG Protocol and the ISO 14064-1 standard and requirements for calculating and reporting the carbon footprint of organizations in Thailand (CFO) were implemented as a guideline for assessing the GHG emissions of the School of Renewable Energy in Chiang Mai, Thailand. The study focused on the responsibilities of the School of Renewable Energy, including lecture halls, laboratories, offices, green spaces, residential hotel, and operational buildings (a four-story school building). Over a 12-month period, from May 2023 to April 2024, the study collected data, calculated the amount of greenhouse gases from both direct and indirect sources, and defined the operational control for assessment.

We evaluated the organization's GHG emissions for both individual activities and the organization as a whole, dividing them into three scopes. The evaluation examined GHG emissions in three distinct scopes:

Scope 1: Direct GHG emissions and removals include emissions from sources owned or controlled by the organization, such as stationary combustion, mobile combustion, fugitive emissions, and others.

Scope 2: Energy indirect GHG emissions from imported energy, heat, or steam consumed by the organization were referred to as energy indirect GHG emissions.

Scope 3: Indirect emissions were GHG emissions resulting from an organization's activities but derived from sources owned or controlled by other organizations. Other indirect GHG emissions included various additional sources.

The GHG emissions were assessed in accordance with the Kyoto Protocol, covering CO_2, CH_4, N_2O, HFs, SF_6, NF_3, and PFCs, as shown in **Figure 2**. Activity data, comprising secondary data, was obtained from the provincial electricity authority (PEA) of Chiang Mai, while primary data was recorded to compile the organization's electricity consumption data. **Table 1** shows the classification of activities that produced GHG emissions into three scopes.

The calculation of GHG emissions was conducted using activity data from the organization, greenhouse gas emission factors (EF), and the Global Warming Potential (GWP). The criteria specified in Eq. (1) and (2) [5] of the GHG Protocol were applied to determine the relative equivalent emissions of each category, and presented the results in terms of CO_2 equivalent.

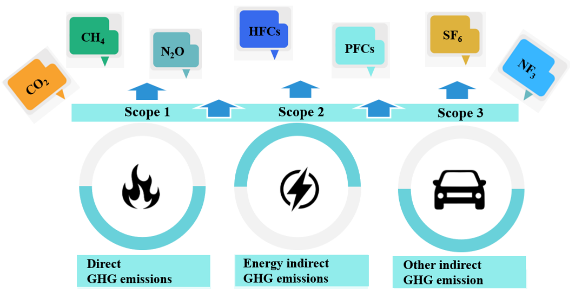

Figure 2 Scope of carbon footprint for organization.

$$GHG_{emissions} = Emission\ data \times GWP100 \quad (1)$$

$$GHG_{emissions} = Activity\ data \times EF \quad (2)$$

Where:

The activity data quantifies the activities that result in the emission or removal of greenhouse gas [5].

The emission factor is a coefficient that correlates GHG emissions with GHG activity data [5].

Table 1 Sources for activity data.

Categories	Resource	Source of GHG emissions
Scope 1: Direct GHG emissions and removals		
Stationary combustion	Liquid fuel	Lawnmowers and power generators.
Mobile combustion	Liquid fuel	vehicles
Septic tank		CH_4 emissions from septic tank
Scope 2: Energy indirect emissions		
Imported electricity	Electricity	Purchased electricity
Scope 3: Other indirect GHG emissions		
Purchased products and services	Paper, tap water	Purchased goods and services
Transport of waste and disposal	Management	Waste disposal
Employee commuting	Liquid fuel	Consumption by vehicles

The global warming potential values of each greenhouse gas were used for the calculations, as shown in **Table 2**.

Table 2 Global warming potential (GWP) values for 100-year time horizon (IPCC Fifth Assessment Report (AR5) 2014).

Common name/ chemical formula	GWP100 values
Carbon dioxide (CO_2)	1
Methane (CH_4)	28
Fossil methane (CH_4)	30
Nitrous oxide (N_2O)	265
Sulfur hexafluoride (SF_6)	23,500
Nitrogen trifluoride (NF_3)	16,100
Hydrofluorocarbons (HFCs)	4–12,400
Perfluorocarbons (PFCs)	6,630–11,100

Total methane emissions from the septic tank were calculated based solely on employee data, without accounting for the number of students. Equation 3 was used for this calculation [14].

$$CH_4Emissions = [\textstyle\sum_{i,j}(U_i \times T_{i,j} \times EF_j)]\,TOW - S) - R \quad (3)$$

Where:
CH_4 emissions: Methane emissions in the inventory year, kg CH_4/yr.
TOW: Total organic content in wastewater in the inventory year, kg BOD/yr.
S: Organic component removed as sludge in the inventory year, kg BOD/yr.
U: Fraction of the population group in the inventory year (U = 1).
T: Degree of utilization of treatment/discharge pathway (T = 1).
EF: Emission factor derived from maximum methane producing capacity (0.6 kg CH_4/kg COD) and methane correction factor (MCF) of septic tank (MCF = 0.5)
R: Amount of methane recovered in the inventory year, kg CH_4/yr.
i: Income group.
j: Each treatment/discharge pathway.

To evaluate greenhouse gas emissions, we collected data from 358 students using the buildings, 25 full-time staff members, and one business pickup vehicle. We specifically collected Scope 3 data (employee commuting) for the full-time personnel. The complex included three educational and workshop buildings and one residential hotel with sixteen rooms.

3. The Installation of a Solar PV Rooftop On-grid System

Polycrystalline solar panels, composed of silicon, achieved an efficiency of 13% to 16%. These panels were interconnected in series to form arrays and arranged in parallel to optimize sunlight capture, efficiently converting it into electrical energy. **Figure 3** illustrates the installation of the panels on the rooftops of laboratories and school buildings. The system was on-grid, allowing it to connect to the power grid. The design integrated two power supply systems: electricity generated from the solar panels and electricity from the grid. However, the on-grid system could not operate independently when grid electricity was unavailable. Therefore, it remained reliant on grid electricity, even while generating power from the solar panels for internal use. During periods of insufficient solar power generation, the system drew electricity from the grid.

The installation of solar panels on Building A, Building B, and Building C, each with capacities of 100 kW, 200 kW, and 300 kW, respectively, achieved a total production capacity of 600 kW. The on-grid system included six 50 kW and twelve 25 kW grid-tie inverters. These inverters convert direct current (DC) electricity, produced by the solar panels, into alternating current (AC) power used by the electrical grid.

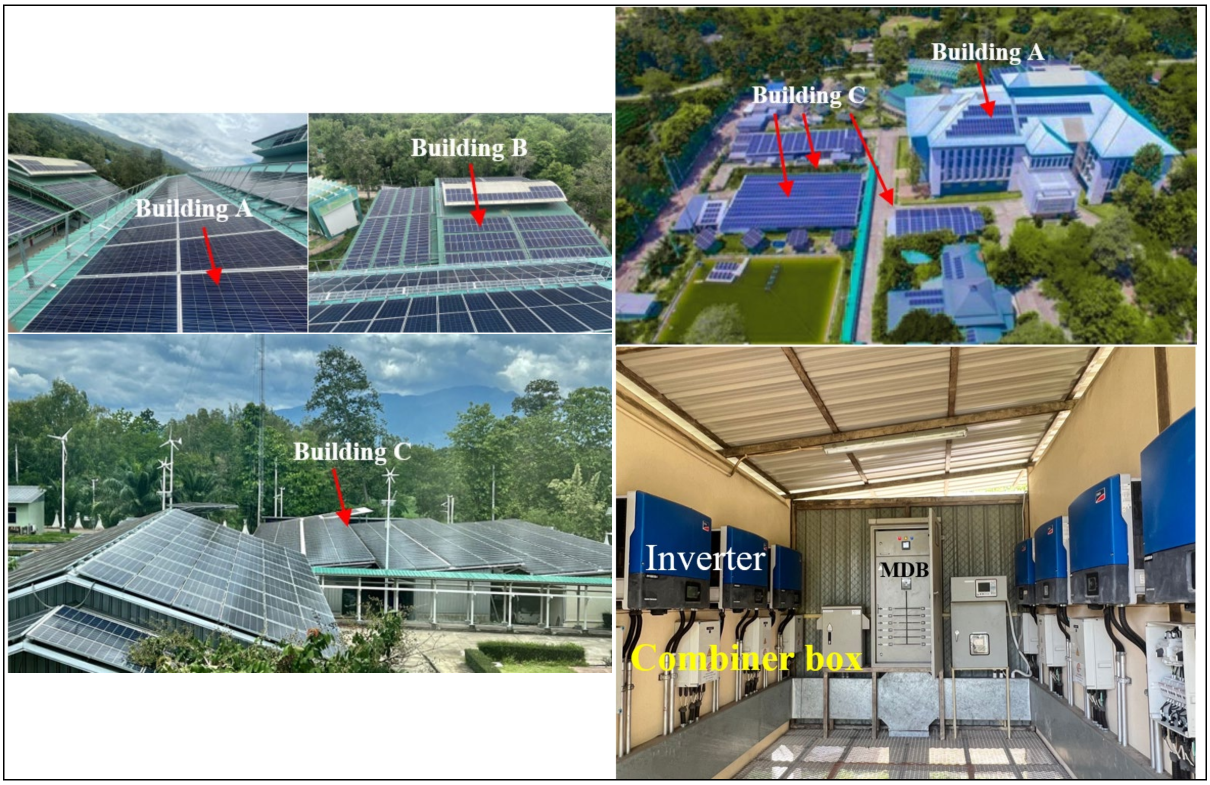

Figure 3 The installation of solar panels on Building A, Building B, and Building C and Powerhouse.

Based on data recorded by the solar cell electricity generation system and energy imported from the Provincial Electricity Authority (PEA) over a 12-month period, as shown in **Table 3**, monthly electricity generation from the solar cell system exceeded usage from the electricity authority. This underscores the solar cell electricity generation system's role as the primary energy source for supplying power to the building's equipment.

The total amount of electricity generated from solar cells was 365,731 kWh, whereas 113,120 kWh of electricity was imported from the Provincial Electricity Authority. The organization's total electricity consumption amounted to 478,851 kWh.

Table 3 Data recorded from the solar cell system and PEA energy import over 12 months.

Solar cell (kWh)	PEA (kWh)			Total
	On peak	Off peak	Holiday	
MAY-DEC-23				
35,222	2,440	3,760	2,680	8,880
34,042	2,500	4,020	2,540	9,060
39,511	3,060	4,060	3,800	10,920
26,899	3,560	4,680	2,840	11,080
28,017	3,740	4,340	2,780	10,860
31,113	2,451	3,078	3,071	8,600
37,068	2,420	3,520	1,940	7,880
28,027	2,660	4,220	3,360	10,240
JAN- APR 24				
16,787	2,280	4,320	2,520	9,120
27,826	1,980	3,840	2,600	8,420
29,018	2,620	4,460	3,280	10,360
32,201	1,640	2,800	3,260	7,700
Total (kWh)				
365,731	**31,351**	**47,098**	**34,671**	**113,120**

4. GHG Emissions from the Organization

4.1 Direct GHG Emissions from Scope 1

The GHG emissions from Scope 1 included direct emissions from stationary combustion and mobile combustion. The use of generators and lawnmowers powered by diesel and gasoline resulted in stationary combustion. Pickup trucks and cars, which also use diesel and gasoline, produced mobile combustion emissions. Additionally, the septic tank system emitted CH_4 as GHG emissions. With 25 full-time employees, the calculation was based on actual working days to determine the CH_4 emissions in kilograms from the septic tank system, using an emission factor (EF) of 28 $kgCO_2e/kg\ CH_4$. Scope 1's total GHG emissions were calculated at 5.26 tCO_2e. CH_4 emissions from the septic tank system were the highest, amounting to approximately 2.07 tCO_2e. Diesel combustion in mobile sources was the second largest contributor, generating 1.62 tCO_2e. GHG emissions from gasoline use in mobile and stationary combustion were comparable, at 0.51 and 0.53 $kgCO_2e$, respectively.

4.2 Indirect GHG Emissions from Scope 2

Scope 2 defined GHG emissions as indirect emissions from imported electricity. During the 12-month recording period, the organization sourced electricity from PEA. The amount of electricity imported varied, ranging from 7,700 kWh to 11,080 kWh, as indicated by the invoice data. The consistent import of electricity for building illumination, air conditioning, and other equipment indicated that average nighttime electricity consumption remained stable each month. Electricity was required to be imported from the power grid during the night as a result of the absence of batteries.

In January 2024, the total electricity consumption amounted to 25,907 kWh, with 9,120 kWh imported from the PEA and 16,787 kWh generated by solar cells. The cold season led to a reduced demand for air conditioning and cooling devices, resulting in the lowest electricity consumption of the year. This led to a decrease in electricity imports from the PEA, especially when residential hotel switched off their air conditioning at night. However, refrigeration equipment and lighting, both inside and outside the buildings, remained operational. Consequently, the energy consumption led to a total GHG emissions of 12.95 tCO_2e and GHG emissions were 4.57 tCO_2e when solely considered imported energy.

The academic year commenced in July 2024, accompanied by a range of activities that necessitated the use of electrical equipment, leading to high GHG emissions from energy consumption. After July, the organization moved some classes to facilities outside of its premises. The calculation of GHG emissions from monthly electricity imports utilized an emission factor of 0.4999 $kgCO_2e/kWh$ (Thai National LCI Database, TGO electricity 2016-2018).

Table 4 details the calculation of GHG emissions, focusing specifically on the electricity imported from external sources.

Table 4 GHG emissions comparison of imported electricity and solar cell generation.

Month	Emission Factor	PEA value	GHG emissions	
		(kWh)	$kgCO_2e$	tCO_2e
MAY23– APR 24	0.4999 $kgCO_2e/kWh$	8,880	4,439.11	4.44
		9,060	4,529.09	4.53
		10,920	5,458.91	5.46
		11,080	5,538.89	5.54
		10,860	5,428.91	5.43
		8,600	4,299.14	4.30
		7,880	3,939.21	3.94
		10,240	5,118.98	5.12
		9,120	4,559.09	4.56
		8,420	4,209.16	4.21
		10,360	5,178.96	5.18
		7,700	3,849.23	3.85
Total (PEA)		**113,120**	**56,548.69**	**56.55**
Month	Emission Factor	Solar power (electricity)	GHG reduction	
		(kWh)	$kgCO_2e$	tCO_2e
MAY23–APR 24	0.4999 $kgCO_2e/kWh$	35,222	17,607.48	17.61
		34,042	17,017.60	17.02
		39,511	19,751.55	19.75
		26,899	13,446.81	13.45
		28,017	14,005.70	14.01
		31,113	15,553.39	15.55
		37,068	18,530.29	18.53
		28,027	14,010.70	14.01
		16,787	8,391.82	8.39
		27,826	13,910.22	13.91
		29,018	14,506.10	14.51
		32,201	16,097.28	16.10
Total (Solar power (electricity))		**365,731**	**182,828.93**	**182.83**

The data on the organization's electricity consumption from external energy imports were sourced from an on-grid system that operated alongside electricity generated from rooftop solar cells, supplemented partly by electricity imports from the Provincial Electricity Authority (PEA). **Table 4** depicted the organization's total electricity consumption and the corresponding GHG emissions. Without the installation of solar panels, the organization would have imported all its electricity.

The organization's electricity consumption, including both imported electricity from PEA and that generated from solar cells, peaked in July 2023, leading to the highest GHG emissions of 25.21 tCO_2e. November 2023 recorded the second-highest GHG emissions at 22.47 tCO_2e, while January 2024 had the lowest emissions, totaling 12.95 tCO_2e.

4.3 Indirect GHG Emissions from Scope 3

The assessment of GHG emissions in Scope 3 encompassed the organization's indirect activities beyond Scope 1 and Scope 2. These activities include:

1. Purchased goods and services, such as uncoated paper and tap water.
2. Waste generated in operations, specifically landfill disposal of solid waste.
3. Employee commuting, which involved employees traveling between the organization and their residences using personal vehicles.

The EF used for calculating greenhouse gas was as follows: 2.1020, 0.5410, 2.3200, 2.2719, and 2.7406 $kgCO_2e$/unit. These EFs were sourced from three references: the Thai National LCI Database, IPCC Vol. 2, and the TGO Guidebook.

4.3.1 GHG Emissions from Employee Commuting

The organization's activities for purchased goods in Scope 3 Category 1 included the use of 842 kg of uncoated paper for office purposes and 44,738 m^3 of tap water. The assessment revealed that these activities generated 25.97 tCO_2e in GHG emissions. Interestingly, the consumption of tap water resulted in relatively higher GHG emissions compared to the use of paper.

4.3.2 GHG Emissions from Employee Commuting

Under Scope 3, employees of the School of Renewable Energy commuted to work using personal vehicles, round-tripping from their residences. They used gasoline and diesel fuels, with data collection based on the distance traveled. The total distance traveled by vehicles (km), the average fuel consumption rate for vehicles of all sizes, and the emission factor for the vehicles used were utilized to calculate GHG emissions from employee commuting for the reporting year involving 25 employees by private vehicles). The total distance traveled was divided by the average fuel consumption rate for vehicles of all sizes to determine the amount of diesel and gasoline consumed. The EF for each fuel type was then multiplied by this result (IPCC 2014, and the TGO Guidebook). **Table 5** presents the total distances by fuel type. The calculations indicated that employee travel resulted in a total of 36.47 t CO_2e in GHG emissions. Diesel use accounted for 23.48 tCO_2e, while gasohol 91 use generated 12.99 tCO_2e.

Table 5 The total distances and the average fuel consumption rate.

Types of fuel oils	Total distance	Fuel consumption
	km	L
Gasoline	84,384	5,716
Diesel	95,188	8,567
The average fuel consumption rate (km/L)		
Gasoline	14.7630 (Pollution Control Department, 2551)	
Diesel	11.1110 (American Petroleum Institute, 2004)	

5. The Calculated GHG Emissions of The School of Renewable Energy

The assessment results of GHG emissions from the activities of the School of Renewable Energy are presented in **Table 6**. It was found that without the installation of solar cells for electricity generation, the organization's electricity consumption would account for the highest GHG emissions in Scope 2, amounting to approximately 239.38 tCO_2e. The GHG emissions assessment by Hayiwango, et al. [9], which highlighted that educational institutions typically have significant GHG emissions from electricity use in Scope 2, aligns with these findings.

Table 6 GHG emissions of an organization.

Activity data	Value	EF	$kgCO_2e$	tCO_2e
SCOPE 1 (Direct emissions)				
1.Stationary Combustion (L)				
Generator (diesel)	200	2.7078	541.56	**0.54**
Lawn mower (gasoline)	240	2.1894	525.46	**0.53**
2. Mobile Combustion (L)				
Diesel	591.5	2.7406	1,621.06	**1.62**
Gasoline	224	2.2719	508.91	**0.51**
3. Septic tank ($kgCH_4$)	73.8	28.0000	2,066.40	**2.07**
SCOPE 2 (Indirect emissions) Electricity consumption within the organization (without the installation of an on-grid solar panel system)				
Electricity (kWh)	365,731	0.4999	182,828.93	**182.83**
SCOPE 2 (Indirect) Imported energy				
Imported electricity from PEA	113,120	0.4999	56,548.69	**56.55**
SCOPE 3 (Other indirect emissions)				
Paper (kg)	842	2.1020	1,769.88	**1.77**
Water usage (m^3)	44,738	0.5410	24,203.26	**24.20**
Waste (kg)	1,432	2.3200	3,322.24	**3.32**
Employee commuting (gasoline)	5,716	2.2719	12,986.18	**12.99**
Employee commuting (diesel)	8,567	2.7406	23,478.72	**23.48**
Total GHG emissions for organization			**310,401.29**	**310.40**

6. GHG Emissions Reduction with Solar PV Rooftop On-grid System Installation

Over a 12-month period, the organization consumed 478,851 kWh of electricity. **Table 7** shows that the installation of an on-grid solar PV system reduced electricity imports to 113,120 kWh by generating 365,731 kWh from solar cells. Initially, without electricity generation from solar cells, GHG emissions were measured at 239.38 tCO_2e. However, GHG emissions from Scope 2 decreased to 56.55 tCO_2e as a result of daytime electricity generation from solar cells, consistent with the findings of Pongvijarn, et al. [15]. The organization achieved a GHG emissions reduction of 182,83.2 tCO_2e.

This reduction in GHG emissions indicated that the organization had mitigated its environmental impact, thereby reducing the greenhouse gases that contribute to global warming. This data serves as the foundation for carbon credits, which are used to support government policies in the preparation for net zero emissions and carbon neutrality. The organization must engage in activities that reduce greenhouse gas by up to 90% independently in order to achieve the net zero target.

Table 7 GHG emissions reduction in the inventory year.

Inventory year (kWh)		EF	tCO_2e
PEA	113,120	0.4999	56.55
Solar cell	365,731		182.83
Total electricity consumption	478,851		239.38
GHG emission reduction	182.83 tCO_2e		

The GHG emissions were calculated as percentages across all three scopes. Scope 2 emerged as the predominant contributor to global warming, accounting for the highest percentage of GHG emissions at 77.12%, mainly attributed to the import of electricity from external sources. Scope 3 followed with 21.19%, primarily due to employee travel [16] and purchased goods. Scope 1, which includes emissions from stationary and mobile combustion sources, as well as CH_4 emissions from septic tanks, contributed the lowest GHG emissions, at 1.70%, as depicted in **Figure 4**.

The organization installed a solar PV rooftop to generate electricity and reduce its reliance on external sources for electrical energy. Initially, the imported electricity totaled 478,851 kWh per year, contributing to a total of 77.12% across all three scopes. The installation of solar cells reduced the import of electrical energy to 113,120 kWh. As a result, the percentage of GHG emissions decreased from the initial 77.12% to 23.62% due to the reduction in energy imports in scope 2.

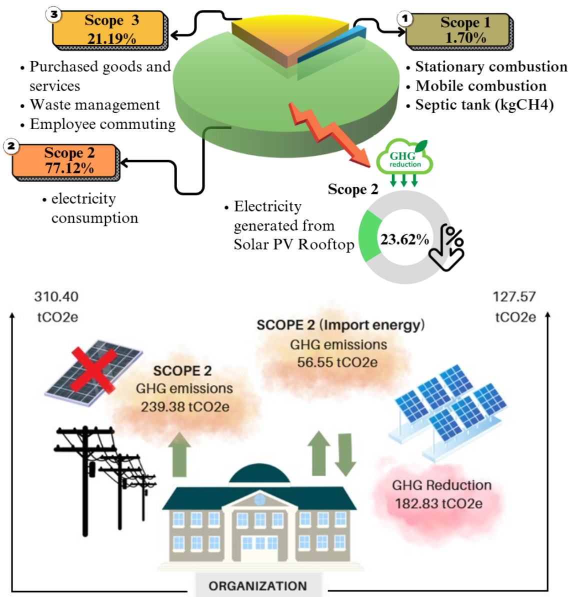

Figure 4 GHG emissions reduction in the inventory year.

Figure 4 illustrates the reduction in GHG emissions. Without the solar PV rooftop installation, the organization's GHG emissions would have been 310.40 tCO_2e. However, installing a 600 kW on-grid solar PV rooftop reduced the organization's greenhouse gas emissions to 127.57 tCO_2e. This reduction in GHGs, amounting to 182.83 tCO_2e, was primarily due to a decrease in electrical energy imports. Specifically, the imported electrical energy accounted for only 56.55 tCO_2e of GHG emissions.

The organization's assessment of GHG emissions showed that using electricity from rooftop solar cells, as opposed to imported fossil fuel-based electricity, reduced emissions. Nevertheless, GHG emissions persisted in a variety of forms. We recommend the following strategies to further reduce these emissions:

- Encourage sustainable transportation: To encourage employees to use low-carbon transportation systems, provide incentives such as free bus passes, preferred parking for hybrid or alternative fuel vehicles, or mass transit options.
- Implement power management: to reduce energy consumption, implement strategies such as turning off unnecessary equipment, utilizing low-power modes, and implementing occupancy sensors and task lighting.
- Convert to energy-efficient lighting and appliances: reduce energy consumption, reduce costs, and reduce GHG emissions by transitioning to energy-efficient lighting and appliances (e.g., LED bulbs).
- Improve insulation, seal air leaks, and upgrade to energy-efficient heating and cooling systems; these measures will reduce energy consumption and associated emissions. To enhance insulation, reduce energy consumption for heating and ventilation, and absorb CO_2, incorporate green roofs

or walls to foster a more sustainable organization environment.

- Encourage sustainable behaviors: develop a sustainability policy, establish specific objectives, and incentivize sustainable behaviors among stakeholders and employees. It is crucial to provide training and education to employees on sustainable practices, including sustainable transportation, waste reduction, and energy conservation.
- Solar-powered Charging Stations: Install solar-powered charging stations across the organization, enabling students and staff to recharge electronic devices while promoting the use of renewable energy. Moreover, introduce anaerobic digestion to transform organic waste into biogas, a valuable resource for heating or electricity production.
- The pyrolysis technology used to produce pyrolysis oil from plastic waste involves thermal decomposition at high temperatures, resulting in oil with diesel-like components. Conducting research and development to improve the quality of engine-use oil can serve as a substitute for fossil fuels, thereby reducing greenhouse gas emissions from diesel consumption. Furthermore, the technology aids in the reduction of greenhouse gas emissions associated with landfill refuse disposal [17].
- Paper reduction: encourage the use of digital documentation to further reduce emissions by minimizing paper consumption.
- Rainwater Harvesting and Reuse: Implement rainwater harvesting systems to collect and reuse water for non-potable purposes, such as irrigation and toilet flushing, reducing the demand on tap water and associated energy use.
- Encourage employees to participate in sustainability initiatives: Ensure that staff actively participate in sustainability initiatives to achieve long-term emission reductions through consistent and collective actions.

7. Conclusion

The School of Renewable Energy's GHG emissions assessment aimed to illustrate the organization's GHG emissions from using alternative energy rather than importing energy from external sources. The assessment covered all three scopes, revealing that the organization emitted a total of 310.40 tCO_2e. This emission breakdown included 5.27 tCO_2e for Scope 1, 239.38 tCO_2e for Scope 2, and 65.76 tCO_2e for Scope 3. It was clear that the primary contributor to the highest GHG emissions in Scope 2 was the import of electrical energy from outside the organization, accounting for 77.12% of the total.

The installation of a 600 kW on-grid solar PV rooftop system, which generates electricity during daylight hours, reduced electrical energy imports from 478,851 kWh to 113,120 kWh. This reduction led to a decrease in Scope 2 GHG emissions from 239.38 tCO_2e to 56.55 tCO_2e. Overall, this resulted in a comprehensive decrease in GHG emissions, reducing from 310.40 tCO_2e to 127.57 tCO_2e. The installation of the solar PV rooftop system thus contributed to a reduction of the organization's GHG emissions by 182.83 tCO_2e. Future organizations can market these emission reductions as carbon credits or use them for carbon offsetting. However, the use of solar rooftops for electricity generation without batteries presents a number of challenges, including intermittent power due to reliance on sunlight, no power at night or during low sunlight, increased grid dependency, wasted excess energy without storage, reduced efficiency from real-time usage, and higher initial costs if batteries are subsequently applied.

Organizations with policies aimed at achieving carbon neutrality and net zero emissions can use data from GHG emissions assessments as a baseline (base year). Additionally, other organizations can use this data as a guideline for reducing GHG emissions within their own operations.

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9. References

[1] K. H. D. Tang, “Climate Change in Malaysia: Trends, Contributors, Impacts, Mitigation and Adaptations,” *Science of the Total Environment*. vol. 650, pp. 1858–1871, 2019, doi: 10.1016/j.scitotenv.2018.09.316.

[2] K. Iempremjit, “Effect of Biodiesel-ethanol Fuel Blends on Performance and Combustion Characteristics in a Small Diesel Engine during Start of Engine,” *Ladkrabang Engineering Journal*, vol. 38, no. 3, pp. 24–32, 2020.

[3] M. Pazzini, C. Lantieri, V. Vignali, A. Simone, G. Dondi, G. Luppino and D. Grasso, “Case Studies in the Emilia Romagna Region in Support of Intermodality and Accessibility of Public Transport,” in *Proc. 5th Conference on Sustainable Urban Mobility, Virtual CSUM2020*, Greece, Jun. 17–19, 2021, pp. 65–74.

[4] F. Censorii, L. Cotignoli, V. Vignali and A. Bartoli, “Sustainable and Resistant Road Infrastructures: The Role of the Envision Framework as a Guide to a New Design Approach,” *coatings*, vol. 12, no. 2, 2022, Art. no. 236, doi: 10.3390/coatings12020236.

[5] R. Battistini, F. Passarini, R. Marrollo, C. Lantieri and V. Vignali, “How to Assess the Carbon Footprint of a Large University? The Case Study of University of Bologna’s Multicampus Organization,” *energies*, vol. 16, no. 1, 2023, Art. no. 166, doi: 10.3390/en16010166.

[6] IPCC, “Climate Change 2014: Synthesis Report,” IPCC, Geneva, Switzerland, Fifth Assessment Rep., 2014.

[7] J. Kiehle, M. Kopsakangas-Savolainen, M. Hilli and E. Pongracz, "Carbon footprint at institutions of higher education: The case of the University of Oulu," *Journal of Environmental Management*, vol. 329, 2023, Art. no. 117056, doi: 10.1016/j.jenvman.2022.117056.

[8] K. Chaivanich, "Carbon Footprint of an Organization: A Case Study of the Department of Ordnance Engineering Academic Division, Chulachomklao Royal Military Academy," *Science and Technology Nakhon Sawan Rajabhat University Journal*, vol. 12, no. 15, pp. 48–57, 2020.

[9] N. Hayiwangoh, P Pradabphetrat, V.Rangpan, S. Jijai and E. Saniso, "Carbon Footprint Assessment and Actions to Promote Green University of Rajabhat Universities in Southern Thailand," *Interdisciplinary Research Review*, vol. 18, no. 4, pp. 1–6, 2023.

[10] T. Maimun, S. Teekasap, A. Sareephattananon and B. Rattanatai, "Organization Carbon Footprint Assessment of Eastern Asia University," *EAU Heritage Journal Science and Technology*, vol. 12, no. 2, 195–209, 2018.

[11] S. Sudha and D. Hirunl, "Carbon Footprint of an Organization Case Study of Chaiyaphum Rajabhat University," *Engineering Journal Chiang Mai University*, vol. 26, no. 1, pp. 227–233, 2019.

[12] P. Usubharatana and H. Phungrussami, "Carbon Footprint of Organization: Case Study for Thammasat University," *Thai Science and Technology Journal*, vol. 22, vol. 1, pp. 1–12, 2014.

[13] S. Tangprasert and N. Leeprechanon, "The Mechanism to Drive Carbon Neutrality Policy and Net-Zero Emissions for the Building Sector in Thailand," *Science & Technology Asia*, vol. 28, no. 2, pp. 75–87, 2023, doi: 10.14456/scitechasia.2023.28.

[14] C. A. Tu, L. V. Quy and N. D. Toan, "Estimation of Methane Emission from Domestic Wastewater in Cau river Basin by 2023," *Journal of Climate Change Science*, no. 23, pp. 69–76, 2022.

[15] C. Pongvijarn and S. Klongboonjit, "The Feasibility Study of Installing Hybrid Solar PV Systems for Residential Building: A Case Study of an Apartment with 26 Rooms," *Ladkrabang Engineering Journal*, vol. 39, no. 3, pp. 167–180, 2022.

[16] C. J. L. Balsas, "Sustainable transportation planning on college campuses," *Transport Policy*, vol. 10, no. 1, pp. 35–49, 2003, doi: 10.1016/S0967-070X(02)00028-8.

[17] S. Sommai, C. Jutaporn, P. Sarawut, J. Chawaroj and P. Panuwit, "The Testing of Pyrolysis Reactor with Separation of Condenser for the Production of Liquid Biofuel from Plastic Waste and Economic Evaluation," in *The 23th Transfer of Heat and Mass Energy in Thermal Devices and Processes*, Phetchaburi, Thailand, Mar. 14–15, 2024, pp. 273–280.