CHAPTER IV
RESULTS AND DISCUSSION

4.1 Organizational boundary

In this study, the Department of Environmental Engineering, Faculty of Engineering, Chulalongkorn University was selected as a case study of the academic organization, because a number of activities are normally taken place in a large academic. These activities generate carbon dioxide from various sources. The Department of Environmental Engineering is particularly focused in this research since the department offers two academic activities, i.e., laboratory study and lecturing. Moreover, the department has all complete levels of the study degrees, i.e., doctoral, master, and bachelor study levels. The organizational boundary of this study was set up based on a control approach by all operation and financial control.

4.1.1 Chulalongkorn University

Chulalongkorn University is totally consisted of 41 faculties, departments; academic, research, and service institutes; and academic offices. In 2009, the undergraduate student numbers were 20,419. There are 9,740 students studied for master's degrees and 1,737 studied for doctoral degrees. This means that the university has the total of 32,511 students, while the faculty and staff members including government officials and university personnel are 7,851.

4.1.2 The Department of Environmental Engineering, Faculty of Engineering, Chulalongkorn University

The Department of Environmental Engineering, Faculty of Engineering of Chulalongkorn University was selected as a studied academic organization in this research. The department has 2 buildings located nearby Saraprakeaw as shown in Figure 4.1. The department has been the longest established institute in the field of environmental engineering in Thailand, and offers three degree program. i.e., bachelor's, master's, and doctoral degrees in environmental engineering. Environmental engineering is one of the Engineering Faculties' disciplines. The department provides comprehensive educational and research opportunities in science and engineering, the principal focusing areas include water quality and treatment, wastewater treatment, hazardous and solid waste engineering; ground water modeling and treatment, air quality management, pollution control, and modeling, environmental management, and environmental analysis. This specialty area provides advanced study on the fundamentals, design, and operation of biological, physical, and chemical treatment processes. Applications include the treatment of wastewater and hazardous wastes, development of strategies to improve the quality and safety of drinking water, and management and minimization of solid wastes.

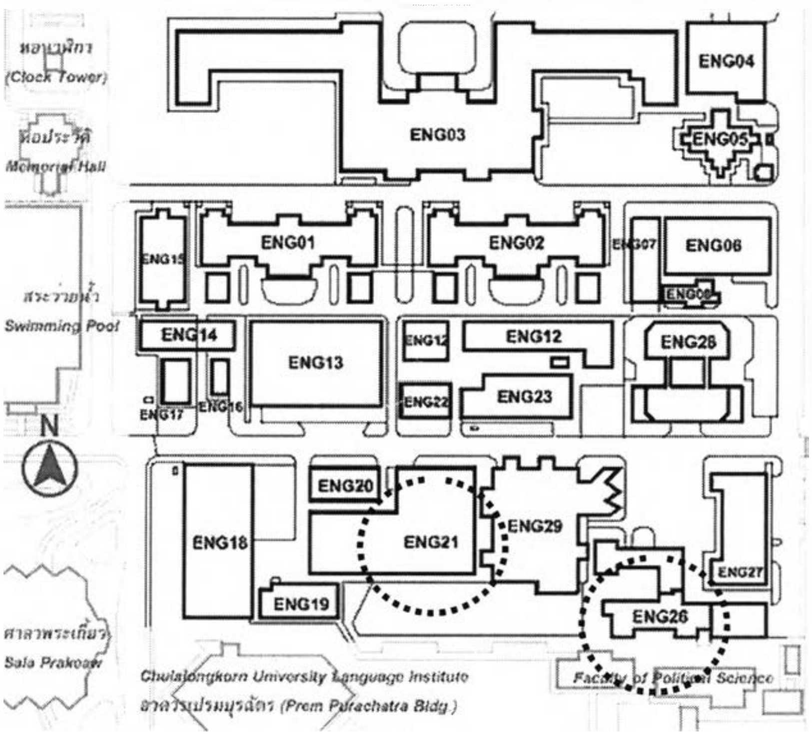

Figure 4.1 Map presenting location of all buildings in the faculty of Engineering, Chulalongkorn University

ENG 21 Civil Engineering and Environmental Engineering Laboratories

ENG 26 Environmental Engineering, Nuclear Technology, Chemical Engineering, Metallurgical Engineering Building

The Department of Environmental Engineering has a number of laboratories, which deal with particular subject areas. The physical facility consists of analytical laboratories and advanced bench and pilot-scale environmental technology assessment laboratories. These laboratories contain various bench-scale experimental systems for educational and research purposes. In addition, they contain a surface area analyzer, portable gas chromatograph, UV/VIS spectrophotometer, microbalance, fume hoods, refrigerators, pH meters, visible spectrophotometers, conductivity meters, centrifuge, autoclave, water purification systems, microscopes and other standard water quality laboratory equipment. The labs also contain an HPLC GC and AAs with various detectors, automated samplers and HP chemstation software for water sample analysis. The laboratories can be classified into 9 main laboratories as follow:

1) Water Laboratory
2) Wastewater Laboratory
3) Biological Laboratory
4) Laboratory for Undergraduates
5) Air Laboratory 1
6) Waste Laboratory
7) OECF Laboratory (Waste Treatment Center)
8) ADB Laboratory (Hazardous Waste Lab)
9) Laboratory for Master's Degree Research

In 2009, there are 35 staff members and 290 students, of which 114 were undergraduates and 166 were master's degree students, and 10 were doctoral degree students (Table 4.1).

Table 4.1 The Environmental Engineering Department's demographic for 2007-2010

Sector	2007	2008	2009	2010
Faculty	18	18	20	20
Other staff	13	13	15	15
- Laboratory teachers	4	4	4	4
- Scientist	1	1	1	1
- Officers	4	4	5	5
- Research assistants	4	4	5	5
Students	179	246	290	243
- Bachelor's degree	77	94	114	112
- Master's degree	99	144	166	126
- Doctoral degree	3	8	10	5
Total	**210**	**277**	**323**	**278**

4.2 Operational boundary

The operational boundary conditions of this study were designated to cover all activities that generated GHGs. The system boundary of this study is illustrated in Figure 4.2. All considered and indirect emissions can be classified into three scopes based on by the greenhouse gas protocol, ISO 14064 parts 1 and TGO guideline as shown in Table 4.2.

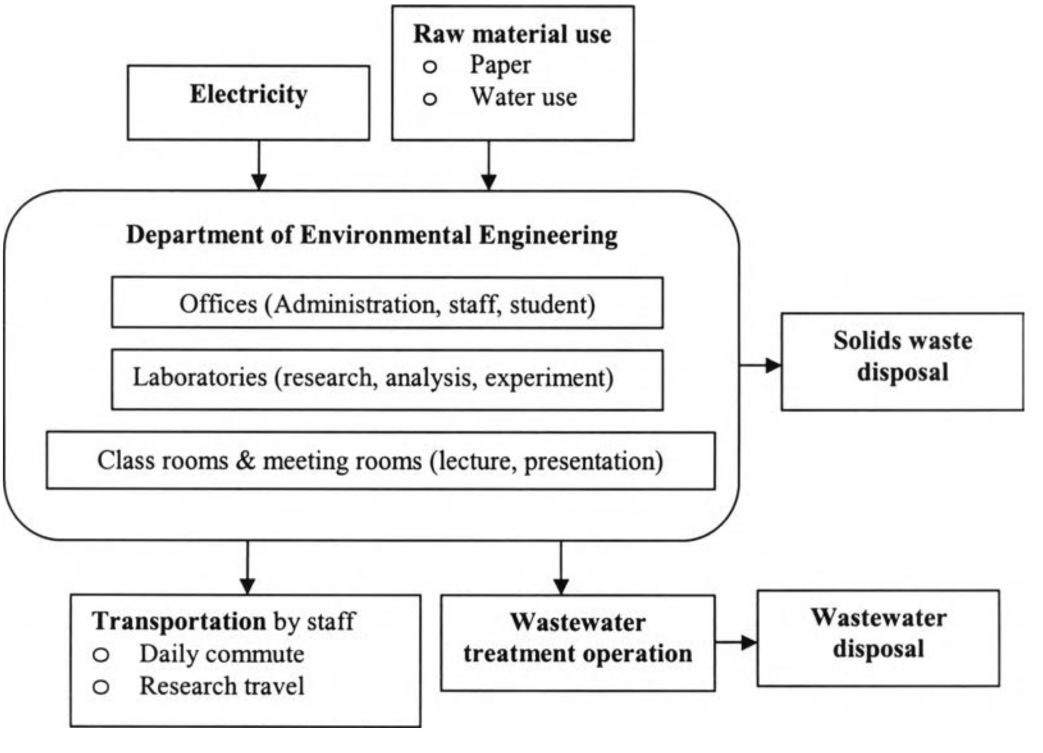

Figure 4.2 System boundary of this study

Table 4.2 The GHG inventory and department scope emission boundaries

Scope description	GHG Protocol's Standard Boundaries (TGO, 2011)	Boundaries of this study	Remark
Scope 1: **Direct emissions**	⊕ Consumption of fuels in vehicles fleet	-	No owned vehicles fleet
	⊕ Production of physical and chemical emissions	-	No data available
	⊕ Leakage of refrigerants and other GHG's (fugitive emissions)	-	No data available (no refrigerator maintenance)
	⊕ Use of fire extinguisher	-	No extinguisher use
	⊕ Use of chemical fertilizer	-	No use of chemical fertilizer
	⊕ Release of GHG's from wastewater operation	Wastewater treatment operation	Owned wastewater treatment plant
Scope 2: **Energy indirect emissions**	⊕ Purchased electricity	Electricity	Purchased electricity
Scope 3: **Indirect emissions**	⊕ Staff commuting	Staff daily commuting	Staff daily commuting
	⊕ Travel between the internal organization by owned vehicles	Staff travelling	
	⊕ Air and organization car travel	Staff travelling	
	⊕ Use of chemicals to clean by contract of service	-	No contract of service
	⊕ Use of tap water	Water use	
	⊕ Use of office equipment and consumable material such as paper	Purchased paper	
	⊕ Use of electricity and LPG in cafeteria and shop leased by the organization	-	No canteen
	⊕ Waste disposal	Solid waste	

For scope 1 Only GHG emissions from the wastewater treatment operation was considered in this study. The other sources of GHG emissions were neglect due to lack of data for the fire extinguisher fugitive emissions, while there were no chemicals that were used in the laboratories and released GHG emissions in FY 2009. The department did not own vehicles so fuel consumption for vehicles was neglect. No chemical fertilizer was used for gardening due to no garden area for which the department was responsible.

For scope 2 Calculation of only energy consumption attributed to the purchased electricity by the department.

For scope 3 Although these indirect emissions are an optional scope, they were included in this study for completeness of this carbon footprint assessment. It was divided into transportation, material use, and landfill waste. For transportation, daily commuting and research travel were taken into account. For material use, only consumable materials, e.g. paper and water use, was included because they were the main type of material regularly used in the department. The last part was landfill waste. The other sources in scope 3 were not covered in this study such as use of chemicals to clean by contract of service and use of electricity and LPG in cafeteria and shop leased by the organization.

The considered GHG emission sources of this study are summarized as follows (Table 4.3):

1) **Direct emission**
   - ➢ Wastewater
     - o Wastewater treatment operation

2) **Energy indirect emission**
   - ➢ Purchased electricity

3) Other indirect emission (everything else that are not in direct and indirect emissions)

- Transportation
  - Research travel
    - Air travel
    - Ground travel
  - Daily Commute
- Material use
  - Paper
  - Water use
- Waste disposal
  - Solid waste

Table 4.3 GHG emission sources classified by scope and emission category

Scope	Emission category	Source	
		Location	**Equipment**
Scope 1: Direct	Wastewater	ENG 21 building	Wastewater treatment operation
Scope 2: Energy indirect	Energy use (Purchased Electricity)	Office -1administrative room - 21 office rooms	Air-Conditioner Light system Office equipment
		Laboratory - 9 laboratories	Air-Conditioner Light system Lab equipment
		Other - 2 student rooms - 2 meeting rooms - 1 library - 10 restrooms - Hallway	Air-Conditioner Light system Fan
Scope 3: Other indirect	Material use	Office - ENG 21 building	Water Paper
		Laboratory - ENG 21 building	Water
	Waste Disposal	2 buildings	Solid waste
	Transportation	Daily Commute	
		Reimbursed Travel - Air - Ground	

4.3 Calculation of the GHG inventory of the department

This part was to quantify the total emission of greenhouse gases (GHGs) from various activities. The GHG inventory of the department was established according to CO_2-originating activities and emission factor. Consequently, the GHG emissions can be calculated as the following equation:

$$\text{GHG emissions} = \text{Activity data} \times \text{Emissions factor} \quad (4\text{-}1)$$

Where:

Activity Data = Activity data in units that will help to calculate the emissions generated (unit of activity)

Emissions Factor = Emission factor for each activity data to converts activity data to emissions values (kgCO2/unit of activity) (see Table 4.3)

Table 4.4 Emission factors used in this study

Type	Unit	Factor ($kgCO_2e$/unit)	Reference	Remarks
Gasoline	L	2.1896	IPCC, 2007	
Diesel	L	2.7080	IPCC, 2007	
Air travel				
- Short flight	pkm	0.18	GHG protocol – mobile guide, 2009	Passenger-Km (pkm)
- Medium flight	pkm	0.126		
- Long flight	pkm	0.11		
Electricity	kWh	0.5610	TGO guideline, 2011	
Paper	kg	0.7350	SimaPro	
Water	m^3	0.0264	Metropolitan Waterworks Authority(Thailand)	File: LCI data source
Wastewater (Anaerobic process)	kgBOD	0.48*25=12	IPCC, 2006 Vol.6	0.48($kgCH_4$/unit) 25=GWP of CH_4
Landfill waste	kg	1.0025	IPCC 2006, Smith et al 2001 and EPA 2008	

4.3.1 Carbon footprint from wastewater treatment

Wastewater generated from people working in the department is mainly composed of organic constituents. The department has installed wastewater treatment plant to treat wastewater from the building. The GHGs emission from organic degradation with an anaerobic treatment unit was considered in this study.

The amount of wastewater can be calculated from the amount of water use as they are taken equally (TGO, 2011). The wastewater treatment of the department is composed of pretreatment process (anaerobic digester) and followed by aerobic treatment. The pretreatment plant has 2 septic tanks and 2 anaerobic tanks. Wastewater generated from toilets and laboratories in the department flows into Septic tanks 1 and 2, anaerobic tanks 1, 2 and then flows to Aeration tank. The microorganism is separated from wastewater in a clarifier tank before discharging into the municipality sewer. Table 4.5 shows BOD concentrations at different sampling points in such a wastewater treatment plant. The GHG emissions from the wastewater treatment were calculated from 2 sources, i.e., the wastewater treatment operation and effluent. The GHG emissions were reported as direct emissions. GHG generated from the wastewater treatment plant was considered only at the anaerobic treatment and digestion process. Since CH_4 from anaerobic operation was released to the atmosphere without capturing, CH_4 emissions from the anaerobic treatment were included in the calculation.

Table 4.5 BOD concentrations of various sampling points in the wastewater treatment process (Tubtimphiroj and Kumwapanitchakul, 2006)

Wastewater treatment plant	**BOD (mg/l)**
Septic tank 1	76.23
Septic tank 2	30.45
Anaerobic tank 1	28.62
Anaerobic tank 2	26.21
Aeration tank	24.21
Clarifier	20.35
Pump Sump	17.92

Calculation of GHG emissions from anaerobic wastewater treatment is based on BOD removal and CH_4 Emissions. Therefore, the GHG emissions due to the studied wastewater treatment can be calculated as given:

(1) Organic constituents in wastewater is calculated in terms of BOD loadings

$$\text{BOD loading}_{removal} = \text{BOD loading}_{input} - \text{BOD loading}_{output} \quad (4\text{-}2)$$

where:

BOD loading $_{input}$ (kgBOD/year) = Water use (m^3) x BOD in effluent (mg/l) x 0.001
= 10,533.6 x 76.23 x 0.001 = 802.93

BOD loading $_{output}$ (kgBOD/year) = Water use (m^3) x BOD from anaerobic tank 2 (mg/l) x 0.001
= 10,533.6 x 26.21 x 0.001 = 276.09

BOD remove by anaerobic treatment unit = A - B
= 802.93 - 276.09 = 526.84 kgBOD/year

(2) CH_4 emission factor

CH_4 emission factor for each domestic wastewater treatment/discharge pathway or system is calculated by the following equation (IPCC, 2006):

$$EF_j = B_o \times MCF_j \quad (4\text{-}3)$$

where:

EF_j = emission factor, kg CH_4/kg BOD

J = each treatment/discharge pathway or system

B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD

MCF_j = methane correction factor (fraction)

Table 4.6 Data requirement for calculation emission factor of wastewater (IPCC, 2006)

Wastewater		
Parameters	**Values**	**Unit**
B	0.6	kg CH_4/kg BOD
MCF	0.8	-
EF	0.48	kg CH_4/kg BOD

(3) Total CH_4 emissions from wastewater is calculated as the following equation (IPCC, 2006):

$$\begin{aligned} CH_4 \text{ Emissions } (kgCH_4/y) &= EF \times \text{Total organics in wastewater} \\ \text{GHG Emissions } (kgCO_2/y) &= CH_4 \text{ Emissions} \times GWP \end{aligned} \tag{4-4}$$

Note: GWP of CH_4 = 25 (IPCC, 2007)

Result from the calculation of GHG emissions from the wastewater treatment plant was found to be 6,324 $kgCO_2e$/year as shown in Table 4.7

Table 4.7 Calculation of BOD removal and GHG emissions

Type of waste	BOD remove in anaerobic tank (mg/l)	Water use (m^3/y)	BOD remove (kgBOD/y)	Emission factor ($kgCO_2e$/kgBOD)	GHG emissions ($kgCO_2e$/year)
Wastewater	50.02	10,533.6	527	$0.48^{(1)} \times 25^{(2)} = 12$	6,324

Note: (1) EF = 0.48 ($kgCO_2e$/kgBOD removed)

(2) GWP of CH_4 = 25

4.3.2 Carbon footprint from electricity consumption

Electricity consumption in the department was collected a primary data from electricity bills of 2 buildings; ENG 21 building and 4^{th} floor of ENG 26 building

4.3.2.1 Electricity consumption of the department

Results collected on the electricity consumption of the department in the fiscal year 2009 (October 2008 – September 2009) showed that the total energy consumption in the department was about 151,955 kWh per year, while the average electricity consumption per month was 12,663 kWh. Figures 4.3 to 4.5 show the monthly electricity consumption of the Department of Environmental Engineering from FY 2007 to 2009.

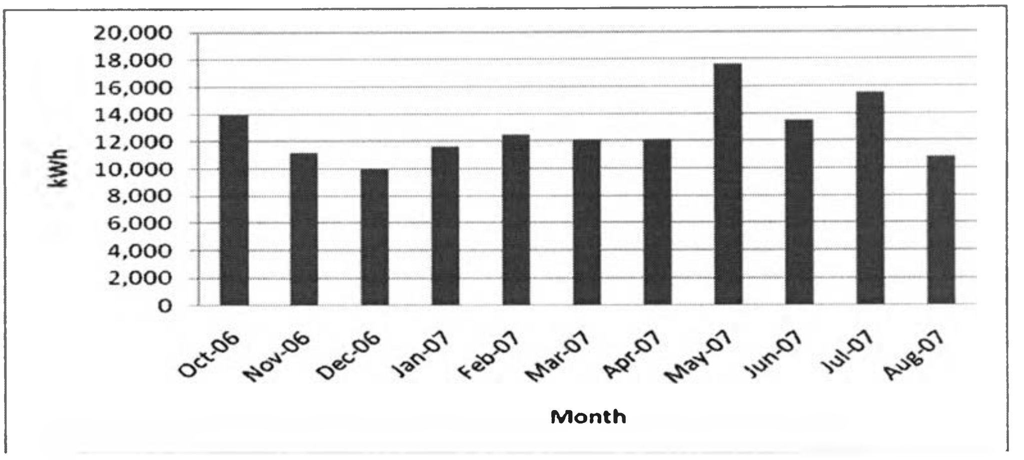

Figure 4.3 Monthly electricity consumption of the Department of Environmental Engineering in FY 2007

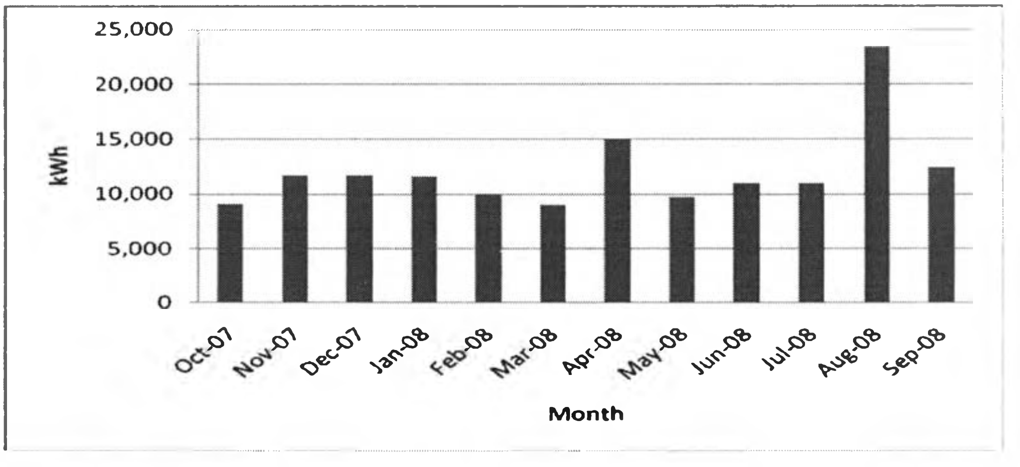

Figure 4.4 Monthly electricity consumption of the Department of Environmental Engineering in FY 2008

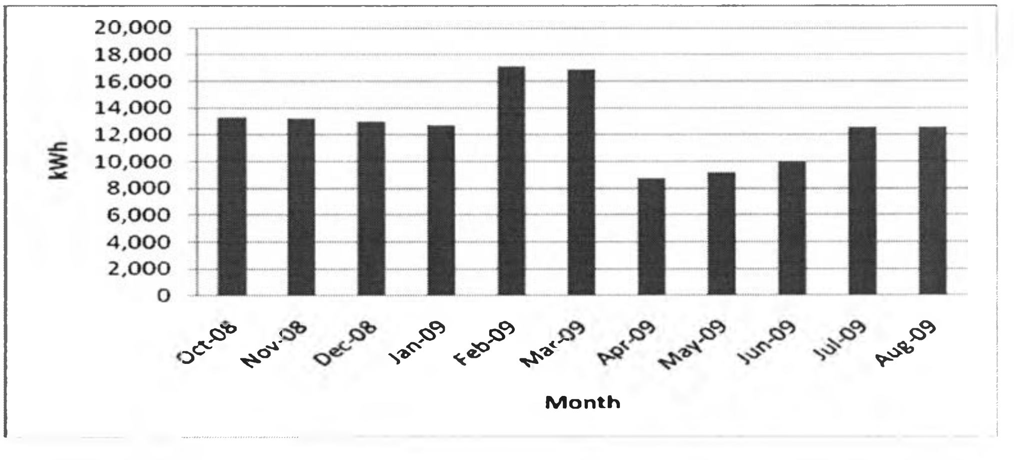

Figure 4.5 Monthly electricity consumption of the Department of Environmental Engineering in FY 2009

Figures 4.3- 4.5 show the similar trend of energy consumption by the department's staff and students. The charts have a similar pattern whereby the consumption was raised at the beginning of the semester and then gradually decreased at the end of the semester. Electricity use varied in each month depending on the weather, working hours, operation and maintenance practices, and people's behaviors. The electricity consumption in the winter was lowest as compared to other seasons. The fully working period has higher energy consumption than other periods.

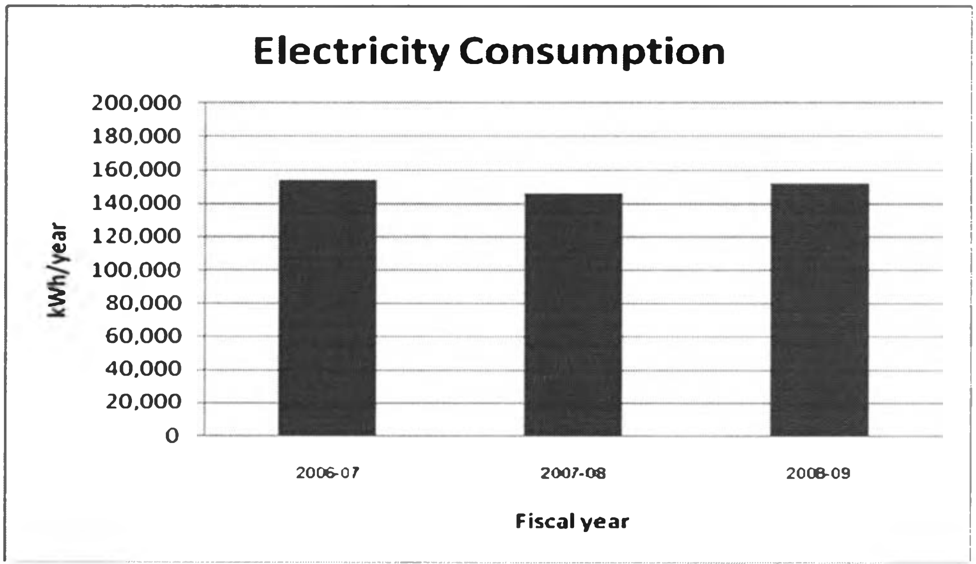

Figure 4.6 The department's electricity consumption from FY 2007-2009

The purchased electricity data from FY 2007 to 2009 shows that electricity consumption remained stable in each year. This is due to the number of staff in the department has been constant over the period, thus resulting in stable use of electricity.

4.3.2.2 GHG emissions from electricity consumption

Emissions from the purchased electricity of the department were calculated by emission factors representing the power pool average for kilowatt hours consumed in Thailand. The use of power pool average emission factors is a standard method and is used by the WRI in their GHG Protocol and TGO guideline. The GHG emissions associated with electricity generation were calculated according to the following equation (TGO, 2011):

$$\text{GHG emissions (kgCO}_2\text{e/y)} = \text{Electricity (kWh/y) x EF (kgCO}_2\text{e/kWh)} \quad (4\text{-}5)$$

where:

GHG emission = GHGs production due to electricity demands ($kgCO_2e$)

Electricity = Electricity consumption (kWh)

EF = GHG emission factor of fuel for producing electricity ($kgCO_2e/kWh$)

Electricity is supplied for all electric equipment in offices, laboratories, and others (classrooms, meeting rooms, restrooms, library, and hallways). In order to estimate the GHG emissions due to electricity generation within the department, it is essential to know the department's total electricity generation. Data of electricity consumption and carbon footprint which were caused by energy consumption within the department from FY 2007 to 2009 were shown in Figure 4.6 to 4.7. Table 4.8 shows the monthly carbon footprint due to the electricity consumption of the department. The average value in FY 2009 was approximately 12,663 kWh per month and the average value in FY 2009 was 7,106.2 $kgCO_2$ per month.

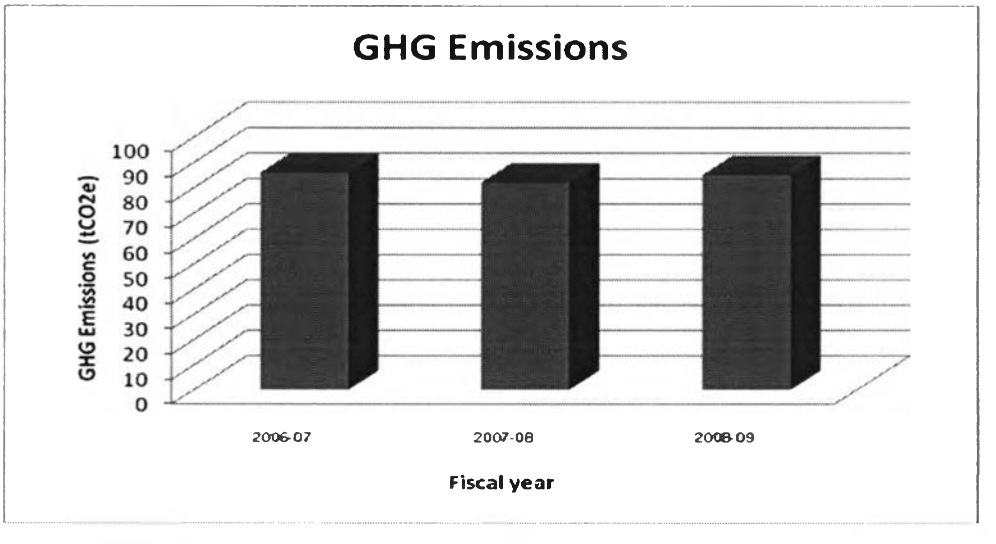

Figure 4.7 GHG emissions from the purchased electricity by the department in FY 2007-2009.

Table 4.8 Calculation of GHG emissions from electricity purchased during FY 2007-2009

Month	**Energy consumption (kWh)**			**GHG Emissions ($kgCO_2e$)**		
	2007	**2008**	**2009**	**2007**	**2008**	**2009**
October	14,003	9,155	13,257	7,856	5,136	7,437
November	11,223	11,760	13,199	6,296	6,597	7,405
December	9,948	11,760	12,984	5,581	6,597	7,284
January	11,615	11,600	12,731	6,516	6,508	7,142
February	12,525	9,995	17,145	7,027	5,607	9,618
March	12,105	9,045	16,910	6,791	5,074	9,487
April	12,105	15,084	8,765	6,791	8,462	4,917
May	17,643	9,711	9,190	9,898	5,448	5,156
June	13,498	11,014	9,975	7,572	6,179	5,596
July	15,553	11,014	12,600	8,725	6,179	7,069
August	10,864	23,352	12,600	6,095	13,101	7,069
September	12,826	12,465	12,600	7,195	6,993	7,069
Total	**153,908**	**145,955**	**151,955**	**86,342**	**81,881**	**85,247**

Emission factor = 0.561 $kgCO_2e/kWh$ (TGO guideline, 2011)

1) GHG emissions by appliance type

The energy power and operation period data can be used to estimate the energy consumption of the appliances in the department. Greenhouse gas emissions, which were generated from the power consumption of the electrical appliances, were evaluated. These appliances included air-conditioners, lights, laboratory equipments, computers, and elevator. The results show that of the department annually produced 85.2 tCO_2e emissions in 2009. It was estimated that approximately 47% of these emissions resulted from energy used by the air-conditioning system, 29% by the lab equipment, 17% by the lighting system, 2% by computers, 4% by all other electric appliances (e.g., copiers and fax machines), and 1% from the elevator (Table 4.9). The laboratories were found to exhibit the highest GHG emissions because they consist of air- conditioners and lab equipment that produce the high portion of GHG emissions.

Table 4.9 GHG emissions by various electrical equipment in 2009

Electricity	Annual Energy Consumption (kWh)	GHG Emissions ($kgCO_2e$)	Percent of the Footprint (%)
Air-conditioner	70,644	39,631	47
Lab equipment	44,156	24,772	29
Lighting system	25,782	14,463	17
Computer	3,183	1,786	2
Elevator	1,890	1,060	1
Other electric appliances	6,075	3,408	4

2) GHG emissions classified by available area

The department buildings consist of 22 staff offices, 9 laboratories, and others such as meeting rooms, restrooms, etc. Each room has different electrical appliances depending on room use purpose. Thus, GHGs emissions from energy consumption in each room can be divided into 3 main sources based on room activities that are an office group, laboratory group, and others. Result shows that the laboratory and office groups are the main contributors to GHG emissions due to electricity consumption. They were accounted for 49% and 43%, respectively as shown in Table 4.10

Table 4.10 GHG emissions divided by available area

Energy Use	Annual Energy Consumption (kWh)	GHG Emissions ($kgCO_2e$)	Percent of the Footprint (%)
Laboratories	74,211	41,632	49
Offices	64,991	36,460	43
Others	12,529	7,029	8

4.3.3 Carbon footprint from material use

Materials can be separated into two types, which are based on the usability. Permanent materials have long lives and strong structures; lab equipment and machines are examples of permanent materials. Consumable materials are things that is used and changed regularly, such as paper. Water is also included in this category. This research focused on consumable materials only.

1) Paper

The consumption of paper products varies widely throughout the department. Administrative offices use paper for report, internal memos, letters, faxes, photocopies, and the like. Meanwhile, in the classrooms and research laboratories paper is generally used to produce teaching and examination sheets, along with other reports or documents. It is usually purchased by the organization and measured in reams. The amount of reams of paper purchased each year by the department was collected from the bill from the administrative office. This information is contained on invoices. The original weight of paper purchased in FY 2009 was 200 reams. However, such paper was consumed only 150 reams that were equal to 375 kg (1 ream = 2.5 kg approximately). The amount of paper consumption was calculated by the equation 4.3.

$$\text{Weight of paper (kg)} = \text{No. ream of paper} \times \text{Weight of one ream} \qquad (4\text{-}6)$$

The GHG emissions from paper were calculated by multiplying the weight of the paper purchased in 2009 with its emission factor. The result showed the GHG emissions from paper were 276 $kgCO_2e$.

2) Water use

Water consumption data were classified into two types of water use that is water used in the laboratories and office building. Water consumption data can be obtained from the water meter of ENG 21 building. Since two departments are located in the same building, allocation was used in this case by the amount of population in two departments. In this study, the water use can be calculated by the formula:

$$\text{Water use } (m^3/y) = \text{No. of staff and student} \times \text{Water consumption rate} \times \text{No. of working day} \qquad (4\text{-}7)$$

where:

The water consumption rate = 0.21 m^3/person/day

The working day = 240 days/year

The water meter recording data of September 2006 were plotted in y-axis against time period in x-axis as shown in Figure 4.7. Therefore, the water consumption rate of the department can be obtained from the slope of the plot by approximately 84 m^3/d or 0.21 m^3/person or 4.1 m^3/square meter. The result shows that water use in 2009 was 10,533.6 m^3/year that equals to 278 $kgCO_2e$.

Table 4.11 Water used within the ENG 21 building recorded in 2006 (Tubtimphiroj and Kumwapanitchakul, 2006)

Date	Meter value (m^3)
1 September 2006	7,498
6 September 2006	7,930
8 September 2006	8,085
11 September 2006	8,370
13 September 2006	8,490
15 September 2006	8,677
18 September 2006	8,930
20 September 2006	9,110
22 September 2006	9,248
25 September 2006	9,497
27 September 2006	9,710
29 September 2006	9,857

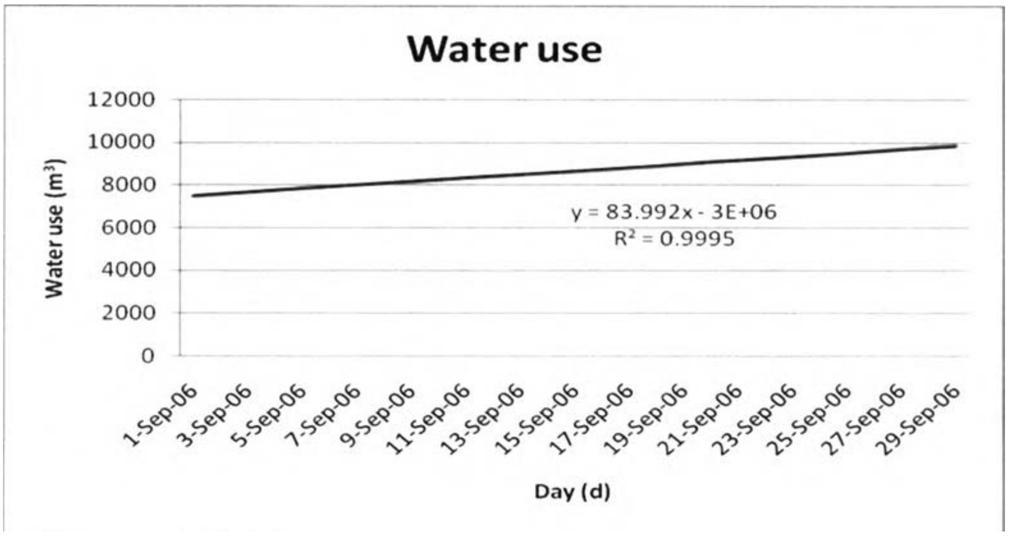

Figure 4.8 Water consumption rate of the Environmental and Civil Engineering building

As a result, the GHG emissions due to material use contributed to the small amount. Paper and water use within the department emitted 276 and 278 $kgCO_2e$, respectively. The total emissions were 554 $kgCO_2e$ as shown in Table 4.8.

Table 4.12 GHG emissions by material use in 2009

Material	Quantity (Unit/year)	GHG Emission Factor ($kgCO_2$/unit of material)	Emissions ($kgCO_2e$)
Paper	375 kg	0.735	276
Water use	10,533.6 m^3	0.0264	278
Total			**554**

4.3.4 Carbon footprint from transportation

In this study only the emissions that resulted from the provision of services was considered. Employees are hired to provide a service, while students are recipients of that service. Thus, transportation in this research referred to the daily commutes of department faculty and staff and department-reimbursed travel (i.e., trips taken by faculty, staff and or graduate students for research purpose that are paid for by the department). Travel by students was not included unless it was paid for by the department or the student worked as an employee of the department, meaning that he or she had to commute to the university to work. The results of GHG emission estimations from transportation should be treated as a grosser approximation than those from Scope 1 and 2 and there are fewer mitigation strategies in some cases.

1) Daily Commuting

GHG emissions due to daily commuting were calculated from the faculty and staff commuting by their private vehicles. The emissions due to mass transit were excluded because of lack of reliable emission factor data. A number of kilometers driven by the staff was obtained from the data in 2009 were used to generate the 2009 GHG emissions. The emissions calculated for the work-related transportation by the department's faculty and staff members that were collected from the survey (Table 4.13). The data were used to calculate commuting distance, fuel consumption, and the number of people per car. This methodology complies with the Greenhouse Gas Protocol and TGO. The emission generated by faculty and staff commuting to work were calculated as the faculty and the staff members were 6,544 and 1,777 liters per year, respectively. Hence, the total distance per year due to commuting of the department was estimated to be 107,610 $kgCO_2e$. The following equations (4-8) were used calculated daily commute as given below:

$$\text{Quantity of fuel (l)} = \frac{\text{Number of days used per year (d)} \times \text{Distance traveled (km/d)}}{\text{Fuel economy (km/l)} \times \text{Number of occupant}} \quad (4\text{-}8)$$

$$\text{GHG Emissions} = \text{Quantity of fuel (l)} \times \text{Emission factor } (kgCO_2/l)$$

Table 4.13 Summary of daily commuting survey results of the faculty and staff members.

Position in the Dept.	No.	Commuting Method % Usage			Fuel type % Usage		Distance (km/day)/People Per Vehicle	Total Fuel used (liter)
		Car	Bike	Mass Transit	Gasoline	Diesel		
Faculty	20	95	0	5	90	10	18.5	6,544
Staff	15	44	0	56	100	0	24.2	1,777

The faculty and staff members of the department are required to participate in any technical conference in order to present their research to the public and to develop knowledge. Most faculty members have to participate in an international conference that is held in other countries. Several staff and graduate students travel to attend a conference in other provinces. They will have to travel either by car or airplane. The emissions due to research travel by car were calculated from traveling distance (in kilometers) or fuel consumption per trip. The traveling data were obtained using a questionnaire and interview. For air travel, it can be separate into 3 categories according to the length of flight. Each length interval has difference emission factors. This methodology is well within the boundary of compliance with the Greenhouse

Gas Protocol and TGO guideline. The distances for research travel by ground and air transportations are shown in Tables 4.14 and 4.15, respectively.

- For ground travel

Table 4.14 Distance of research travel by ground transportation

Travel mode	Total distance travelled (km/year)
Car	10,050
Van	5,400

- For air travel

Table 4.15 Distance of research travel by air transportation

Type of travel	Total distance travelled (km/year)
International air travel	149,400
Domestic air travel	48,000

The result of GHG emissions due to daily commuting and research travel by air and ground transportations are as shown in Table 4.16

Table 4.16 Calculation of the carbon footprint due to transportation

Transportation	Distance (km)	GHG Emissions ($kgCO_2e$)
Daily commute	107,610	14,755
Research travel		
- Air	197,400	25,038
- Ground	15,450	3,504
Total	320,460	43,297

The result shows that GHG emissions by staff transportation in 2009 were 43,297 $kgCO_2e$. The emissions from daily commuting and air travel were 14,755 and 25,038 $kgCO_2e$/year, respectively. Yale Office of Sustainability (2008) reported that a GHG emission from transport was 30% of total GHG emissions from the college.

4.3.5 Carbon footprint of solid waste

Waste in this research was separated into two types that are wastewater (see the detail at 4.3.1) and solid waste. Calculation of carbon footprint from wastewater is based on degradation of organic materials in the wastewater treatment operation, e.g. anaerobic unit, while solid waste calculation includes all wastes from CU facilities that are sent to a the landfill site.

1) Solid waste

Solid waste from the department is sent to a landfill, resulting in the release of methane via the anaerobic decomposition of the organic materials. Methane is 25 times more potent GHG than carbon dioxide. However, landfill methane is a source of energy and some landfills capture and use it for energy. In addition, many materials in landfills do not decompose fully and the remaining carbon is sequestered in the landfill and not released into the atmosphere. Methane emissions from landfills are a function of several factors, including: (1) the total amount of waste in the landfill, which is related to the annual total; (2) the characteristics of the landfill receiving waste (i.e., the composition of waste-in-place, size, climate); (3) the amount of CH_4 that is recovered and either flared or used for energy purposes; and (4) the amount of CH_4 oxidized in the landfill instead of being released into the atmosphere. Therefore, greenhouse gases emission from this part comes from the degradation of solid waste. Greenhouse gases emissions from landfills can be divided into two parts: CO_2 and CH_4 emissions. In this study, the amount of solid waste was collected from the amount of solid wastes everyday within 1 month (Table 4.17). The collected data were then calculated and reported in the average generation rates of the solid waste per day and per year (see the equation 4.6). refer to the amount per year because in the building, mostly is office and laboratory research that have work every day except weekend by average them in generation of solid waste of the department per day, and calculate in the amount per year (see the equation 4.6). The average carbon footprint from the department's solid waste disposal was 3,224 kgCO_2e per year (Table 4.18).

In the study, the amount of solid waste was calculated by 240 working days as given in the following equation:

Landfill waste (kg)	=	No. working day (d) x Landfill waste (kg/d)	(4-9)

Table 4.17 Data collection for the department's solid waste

Week	Mon (kg)	Tue (kg)	Wed (kg)	Thu (kg)	Fri (kg)
1	18.5	13.7	11.1	11.8	20.4
2	12.4	11	13	11.7	14.6
3	13.9	13.7	11.9	11.5	10.8
4	14.9	18.2	11.5	15.2	7.3
Average	14.9	14.12	11.9	12.6	13.3
Total	13.4 kg/day				

Table 4.18 Calculation of the carbon footprint from solid waste

Waste	Quantity (unit/y)	Emission Factor ($kgCO_2e$/unit)	Carbon Emissions ($kgCO_2e$)
Solid waste	3,216 kg	1.0025 (kg)	3,224

The GHG emissions from the wastewater (Table 4.7) and solid waste (Table 4.18) from the department were 9,548 $kgCO_2e$.

4.4 Evaluation of Carbon Footprint in the department

Based on the Greenhouse Gas Protocol, GHG emissions are separated into three categories or "scopes". **Scope 1** includes direct emissions from sources that are owned and controlled by the department. **Scope 2** includes energy indirect emissions resulting from the generation of purchased energy (electricity), and **Scope 3** includes indirect emissions that are a result of activities related to the department, but are not owned or controlled by the department (for example, employee commuting) (Yale Office of Sustainability, 2008). The GHG inventory covers the environmental engineering department for FY 2009, which was from October 2008 to September

2009. The results are from an evaluation of GHG emissions from all activities of the department's emission sources which were classified into 3 scopes. Table 4.19 presents the standard Scope 1, 2 and 3 emissions as well as the emissions from the department that fall under each category. The result indicates that electricity consumption was considered the biggest source of GHG emissions, generating 85.2 tCO_2 annually. Transportation was another significant emission source, as was estimated to produce 43.3 tCO_2annually. GHG emissions from waste and material use equaled 9.5 and 0.6 tCO_2 annually, which account 61.5%, 31.3%, 6.8% and 0.4% of the overall GHG emissions, respectively. Figure 4.9 presents the three emission scopes and their contributions to the overall emission total. From these results, it can be reported the total annual carbon footprint of the department in 2009 was 138.6 tCO_2.

Table 4.19 Carbon Footprint of the Department of Environmental Engineering in 2009.

Scope description	Emission Source	Carbon Emissions (tCO_2e /year)	Percent of the Footprint
Scope 1: Direct emissions	**Wastewater treatment operation**	**6.3**	**4.5%**
Scope 2: Energy Indirect emissions	**Purchased electricity**	**85.2**	**61.5%**
Scope 3: Indirect emissions	Transportation	43.3	31.3%
	• Staff daily commuting	14.8	10.7%
	• Staff travel by airplane and car	28.5	20.6%
	Solid waste	3.2	2.3%
	Material use	0.6	0.4%
	• Paper use	0.3	0.2%
	• Water use	0.3	0.2%
	Total indirect emission	**47.1**	**34.0%**
Total		**138.6**	**100%**

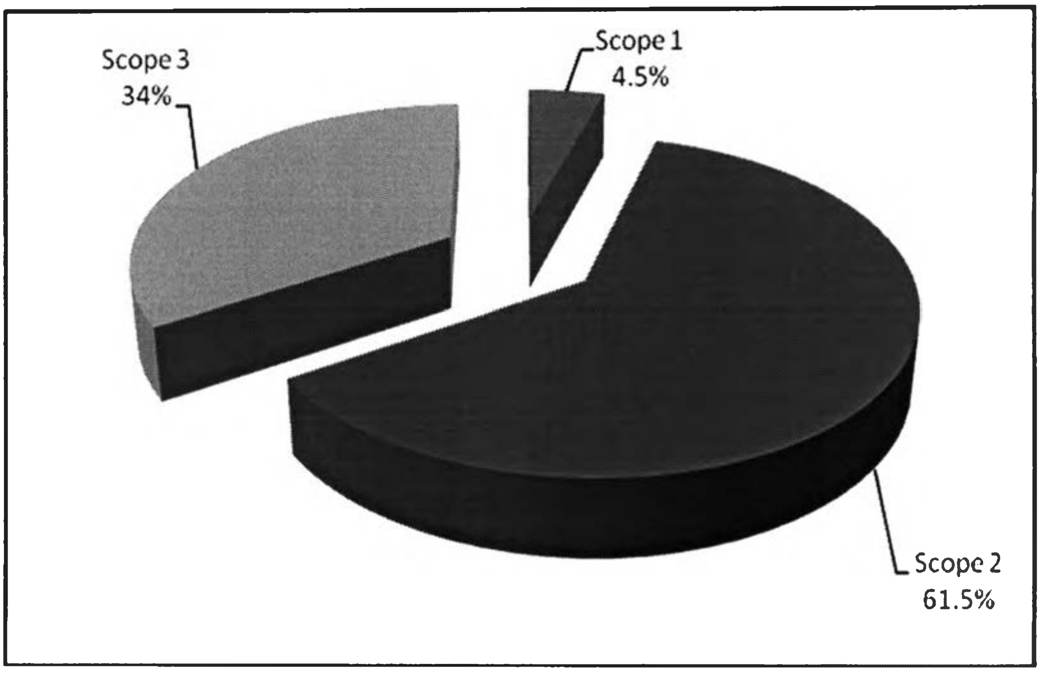

Figure 4.9 Proportion of the carbon footprint from each emission source of the Department of Environmental Engineering.

4.5 Comparison of the GHG emission sources in this study

4.5.1 Carbon footprint classified by scopes

The key factor determining energy use and GHG emissions in the Department of Environmental Engineering is the function of the location, whether it is an office or laboratory. The energy consumption in an office is by various electric equipments such as air conditioners, lighting, computers, notebooks, and copy machines. Research laboratories are also host to high energy use equipment such as autoclaves, furnaces, fume hoods, hot air ovens, TKN analyzers, and pumps. However, such apparatuses are used intermittently. The results from GHG calculations revealed that: For scope 1, in this study; it only one emission source that is wastewater treatment operation in the part of anaerobic process generated 6.3 tCO_2e/year, account 4.5% of overall GHG emissions of the department: For scope 2, it is a largest contributor of GHGs of the department account for of 85.2 tCO_2e/year, the resulted mainly from energy consumption in laboratories, offices, and other space. GHGs calculation revealed that laboratories were the main source of energy consumption accounting for 49% of energy use for academic activities as shown in figure 4.11. The results also demonstrated that air conditioners is the electrical equipment that generated the largest amount of GHGs (Figure 4.10), and then the use of lab equipments due to the research or thesis of student, therefore; that difficult to control or reduce in significant. While air-conditioner has many ways, so it is easiler to reduce than lab equipments. From survey found that mostly air-conditioners in the department are almost 10 year olds and also not being the energy-saving type; consequently, the department should implement several measures to reduce energy consumption from air-conditioners. For instance, they can replace old units with newer energy-efficient model and turn off all equiment when they are not being used: For scope 3, transportation was the second main source of GHG emissions from academic activity. Transportation related emissions equaled to 43.3 tCO_2e per year. It was accounted for 31.3% of the overall GHG emissions. In another aspect, transportation is also the largest contributor in scope 3 (Figure 4.12). The daily commuting and research-related air travel accounted for 84% of scope 3 emissions at 53% and 31%, respectively.

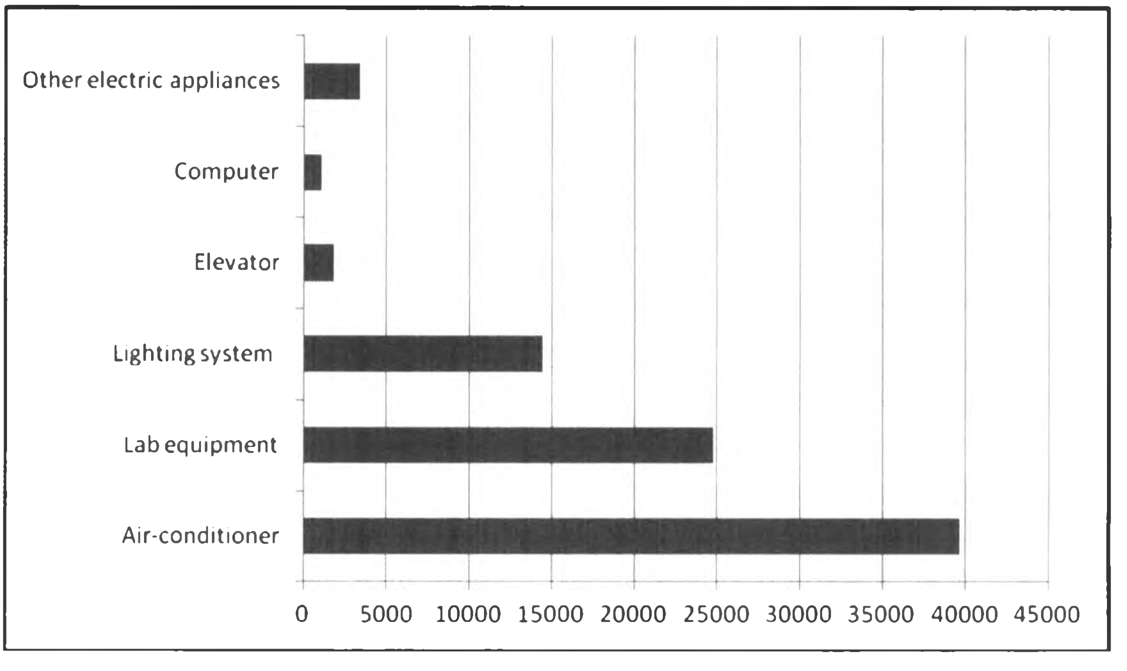

Figure 4.10 Calculation of carbon footprint of scope 2 emission (by electrical equipment)

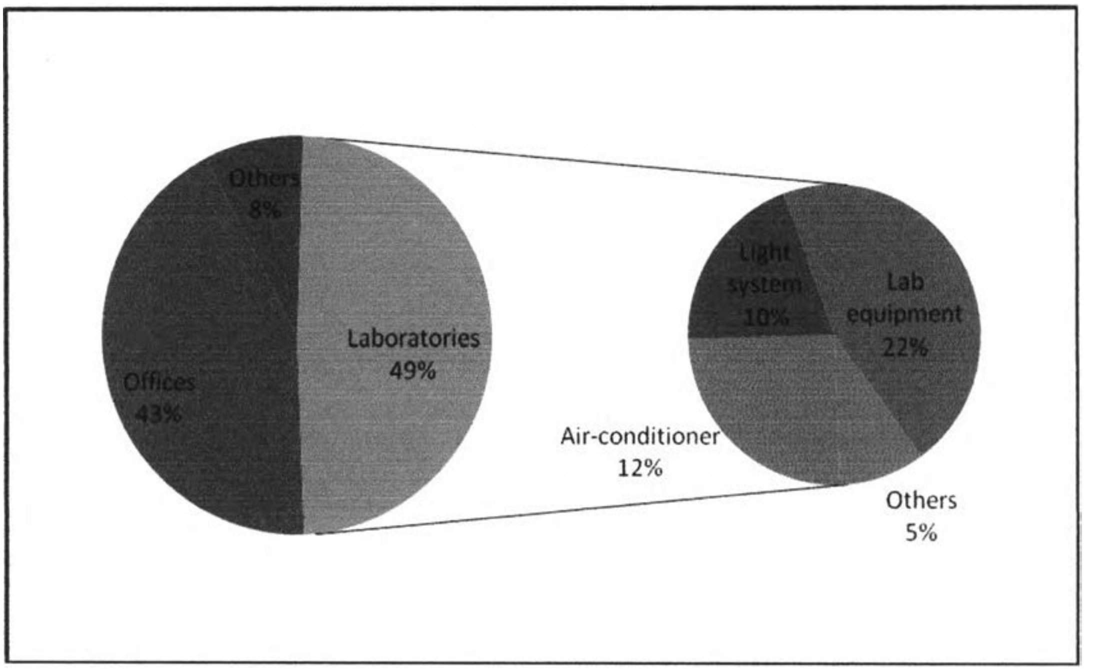

Figure 4.11 Calculate of carbon footprint of scope 2 emission (by equipment and area)

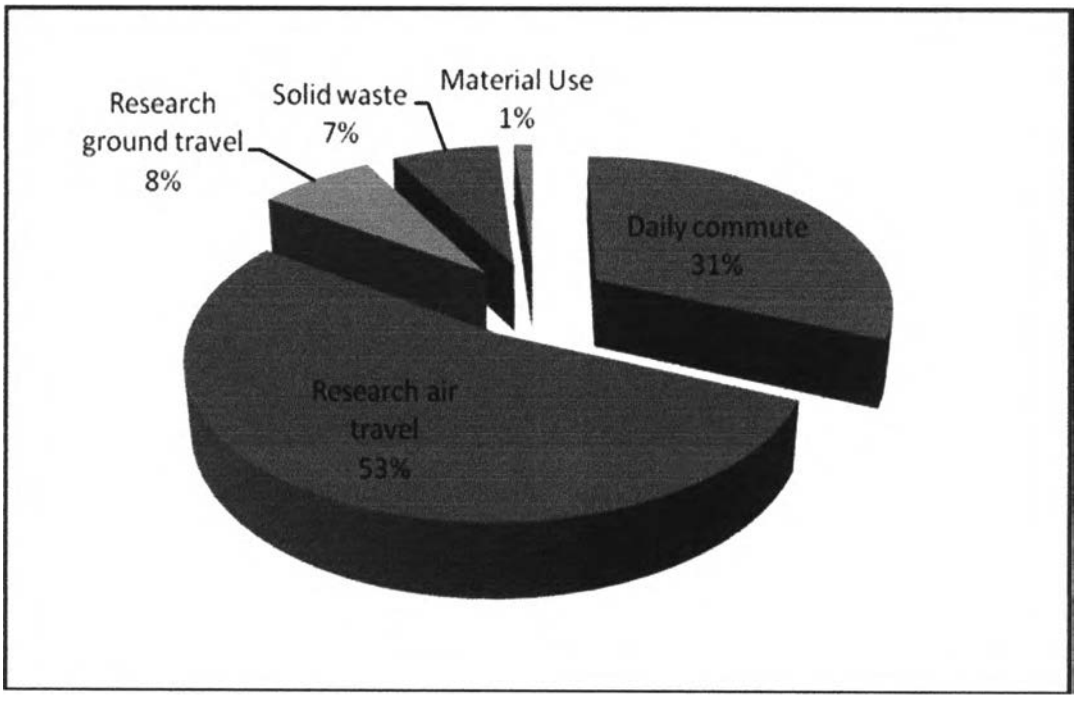

Figure 4.12 Calculation of carbon footprint of scope 3 emission

4.5.2 Comparison with the previous studies

Previous studies on university carbon footprints in the have reported similar trends to those in this study (Pennsylvania, 2007; Purdue, 2007; the Department of Mechanical Engineering, Michigan State University, 2008; Hollins, 2008; Maryland, 2009). These studies classified GHG emission sources differently to match the specific types of sources present at each university, but as a whole, all sources were covered under the same scopes of the Greenhouse Gas Protocol and ISO 14064 part 1. Purdue (2007), Michigan State (2008), and Maryland (2009), have the same major sources of GHG emissions; their on-campus energy use accounts for 57%, 49%, and 41% of their total GHG emissions, respectively. At Pennsylvania (2007), Hollins (2008), and the department in this study, purchased electricity, steam, heat, or/and hot/chilled water accounted 60%, 67%, and 61.5% of the total GHG emissions, respectively. In addition, three studies, namely, the University of Pennsylvania, Purdue University, and the Department of Mechanical Engineering, Michigan State University, reported their carbon footprint in terms of tC per person. The University of Pennsylvania and Purdue University reported a carbon footprint of 1.9 tC per person and 2.1 per person, respectively, while at 2.73 tC per person had a carbon footprint rather higher than those of the university of Pennsylvania and Purdue University. This larger amount can be attributed to the fact that the carbon footprint of Michigan State was only for a single academic, while those of the University of Pennsylvania and Purdue university were for the entire university. For this study, the carbon footprint per person is approximately 1.08 tC. Compare the carbon footprint of this study with those of previous studies are shown in Table 4.20.

Table 4.20 Comparison with the previous studies

University	University Carbon Footprint (CF)		
	CF (tC Per person)	**Major Sources to CF**	**CF (%)**
Purdue University (2007)	2.1	On- Campus Energy, Electricity	57% 26%
University of Pennsylvania (2007)	1.9	Electricity Steam	60% 30%
Hollins University (2003-2007)	-	Electricity On- Campus Energy	67% 27%
Department of Mechanical Engineering, Michigan State University (2008)	2.73	On - Campus Energy, Electricity, Transportation	49% 31% 19%
University of Maryland, College Park (2002-2008)	2.02	On- Campus Energy, Transportation, Electricity	41% 31% 23%
UCSI University, Malaysia (2008)	-	Electricity, Transportation	56% 42%
AIT Campus, Thailand (2009)	2.08	Transportation, Electricity	41% 31%
Department of Environmental Engineering, Chulalongkorn University This study (2009)	1.08	Electricity, Transportation	61.5% 31.3%

Remark: ton Carbon (tC) = ton CO_2 (tCO_2) x 12/44

4.6 Carbon Footprint Reduction

The greenhouse gas (GHG) emissions of the department which were resulted by on-site and off-site activities were estimated in this study. From the results, it can be concluded that the GHG emissions are mainly due to energy consumption of the department. As such, a proper and simple management strategy to reduce GHG emissions in the department should include an energy conservation method. The major electric energy consumer is the air-conditioner. A comprehensive and integrated low carbon sustainability strategy is required in order to achieve a reduction in both energy consumption and GHG emissions a comprehensive and integrated low carbon sustainability strategy is required. There are several measures that can help to achieve significant energy saving. One important strategy is to promote energy efficiency awareness among staff and students in the department. Also, the energy conservation practices are necessary to promote as well.

Energy conservation methods for electric equipment such as turning equipment off when it is not needed and purchasing energy efficient equipment, such as those of "No.5 level," can decrease energy use by as much as 10%. It is also important to make sure that each piece of equipment has its energy management features activated. The installation of timers and occupancy sensors that turn off equipment automatically when they are not needed can also help. Every 1,000 kilowatt-hours (kWh) of electricity saved reduces the amount of carbon dioxide (a greenhouse gas) from entering the atmosphere by about 450 $kgCO_2$ per year. There are many benefits to energy efficiency.

Typically, energy conservation measures are quantified in terms of cost savings. However, there are much more reasons to do an energy conservation than just saving money, it also reduces the amount of fossil fuels that are burned, which results in a decrease in the air pollutants that cause global warming and acid rain.

4.6.1 The possible options for reduce energy consumption and GHG emissions for the department

Since energy consumption is responsible for 61.5% of the department's GHG emissions, a decrease in emissions associated with energy use is critical to reducing the department's footprint. A number of options are available and can be divided into those associated with reducing energy consumption and those associated with reducing carbon emissions during energy generation. The localized implementation of renewable energy generation is a possible option for the department and some examples are explored below. In addition, it can be concluded that GHGs emission are mainly due to electricity consumption come from air-conditioning and light. As such, the proper and simplified management to reduce GHG emissions in the department is energy conservation strategies (Table 4.21). Energy conservation is the practice of decreasing the quantity of energy used. It may be achieved through efficient energy use, in which case energy use is decreased while achieving a similar outcome, or by reduced consumption of energy services. Energy conservation may result in increase of financial capital, environmental value, national security, personal security, and human comfort. Individuals and organizations that are direct consumers of energy may want to conserve energy in order to reduce energy costs and promote economic security. Industrial and commercial users may want to increase efficiency and thus maximize profit.

4.6.1.1 Renewable energy

- Solar energy is an enormous energy source. Energy from the sun is classified as the most important renewable energy. There are two main options: photovoltaic cells for power generation and solar water heating. Clean energy does not have any reaction which would cause environmental toxicity. Solar energy can be transformed into electricity directly. As Thailand is located near the equator, its potential for using solar energy is high level. The daily amount power across the country averages, around 4 to 4.5 kWh per square meter.
- The wastewater and solid waste from the studied department has the potential to be a clean energy source. Most of the waste biomass, such as wood, paper, food waste, and sludge from wastewater, can be used as fuel in power plants that are designed to use waste as fuel, such as in a biogas fermentation tank. In this type of tank, methane gas is recovered as a renewable energy source for electric equipment, which could reduce the carbon footprint of the department.

4.6.1.2 Energy conservation (electricity use)

Since the department does not control the design, maintenance or operation of the physical building that it occupies there is little opportunity for it to choose energy-saving features and devices such as efficient air conditioning (energy saving No.5) and efficient lighting (with electronic ballast, motion sensors, and newer models of fluorescent tubes (such as T5) to reduce energy consumption. However, changing the habits of the members of the departments to reduce consumption is viable over a reasonable period of time and could be achieved with an information campaign based on posters, emails, and the department website announcements.

Table 4.21 Overall of Recommendations in Reduction Methods

Save energy Methods	Reduction strategy
Energy Conservation	• Setting temperature (25°C) and scheduled opening (8.30 -16.30 except 1 hr. for lunch break) of Air-conditioner and Lamp. • Setting room space suitable for natural light. • Setting sleep mode for unused computer • Maintenance of Air-conditioner 2 times per year and 1 time of Lamp.
Energy Efficiency	• Lighting system - T5/Electronic Ballast - Low Loss Ballast - Reflector - Motion or Daylight Sensor - Lighting dimmer - Timer • Air- conditioner - Energy Saving No.5 - Condenser Cooling Unit - Evaporative Cooling • Frame building - Insulator - Double Glazing • Other equipment - Replace desktop to notebook - Use Energy Star equipment

Alternatives for the reduction of energy consumption, greenhouse gases emission and cost by using energy conservation for the electricity. There are many options available for reduce energy consumption in the department such as: Replace save energy no. 5 air-conditioner; use high efficiency lamp; adopt in energy conservation management; etc.

4.6.1.3 Cost-benefit of possible GHGs reduction options

1) Replacing the Energy Label No.5 of Air-conditioner

Since the launch of the first energy efficiency labeling of refrigerators in 1994, Energy Label No.5 has been widely recognized as the designation of energy efficiency. It has also sprawled the introduction of many other high efficiency appliances into the market including air-conditioners in 1995, ballasts in 1998 as well as compact fluorescent lamps and electric fans in 2001. Energy Label No.5 is an innovative alternative for consumers to benefit from their electric appliances while paying less for electricity. The air-conditioner is the appliance that consumes the energy in both the residential sector and the business sector.

Energy Label No.5 is classified by an energy efficiency ratio (EER). EER is the ratio of the cooling capacity of an air conditioner in British thermal units (BTU) per hour, to the total electrical input (in watts) under certain specified tests. Air-conditioners with EER ratings over 10.6 are considered most cost effective (Table 4.22). The higher the ratio, the less the unit will cost to operate. Table 4.23 and 4.24 show the analysis of proposed replacement of new, high energy efficiency air conditioners in the Department of Environmental Engineering.

Table 4.22 Energy Efficiency Rating: Air-conditioner (EGAT, 2006)

Rating No.	EER (Btu/watt)
5	$\geq$ 11.0
4	$\geq$ 10.6
3	$\geq$ 9.6
2	$\geq$ 8.6
1	$\geq$ 7.6

Table 4.23 Description of replacement of the existing air-conditioners in the department with new models

Equipment	Detail of equipment	Amount	Price	
			Price/ unit	Total (Baht)
New Model of Air-conditioner	Energy Label No.5 Brand : York Model : FLCH12 • 13252 Btu FLCH18 • 19199 Btu FLCH30 • 30657 Btu	25 7 4	24,000 33,000 48,000	1,023,000

Table 4.24 Cost-effective of proposed replacement with new air-conditioners in the department

Detail of Equipment	Amount	Power (W)	Working power/year (kWh)
1.Original model			
Old Air-conditioner • 12800 Btu • 18000 Btu • 30000 Btu (EER = 9.6)	25 7 4	1,333 1,856 3,093	70,644
2.New model			
Energy saving No.5 Air-conditioner • 13252 Btu (EER = 11.46) • 19199 Btu (EER = 11.71) • 30657 Btu (EER = 11.93)	25 7 4	1,156 1,640 2,570	58,884
Saving energy/year (kWh)			11,760
Saving cost/year (Baht) (4.03 Baht/kWh)			47,393
Investment cost (Baht)			1,023,000
Payback period (year)			**21.5**

2) Replacing with T5 lamp of lighting

T5 fluorescent lamps are the newest version of florescent lighting available in Thailand. Over ten years ago, 40 watts T12 lamps, called "fat tubes" were widely used. The National Energy Policy Office and the Electricity Generating Authority of Thailand set measures to stop the use off at tubes, and increasing the production and distribution of T8 thin tubes, using 36 watts, which could reduce power consumption by 10% within three years. In Thailand, fat tubes are now obsolete and thin tubes have replaced them. However, more advanced light bulbs continue to be developed. Now, very thin T5 tubes are available that use only 28 watts, when combined the ballast use power only 29.60 watts, compared with 45.40 watts for T8 lamp, since it is economical electricity to 30%. Tables 4.25 and 4.26 present proposed replacement of T8 tubes with T5 tubes in the department.

Table 4.25 Description of proposed replacement with T5 tubes for the lighting system in the department

Equipment	**Detail of equipment**	**Amount**	**Price**	
			Price/ unit	**Total (Baht)**
New Lighting model	T5 • T5 • Electronic ballast Brand : Asia Lamp Model : • T5 - FHE 28T5 • Electronic ballast - 1x28-EBC / 1x14-EBA	511	230	117,530

Table 4.26 Cost-effective of proposed replacement with T5 tubes

Detail of equipment	Amount	Power (W)	Working power/year (kWh)	
1.Original model				
T8 (36 W)	511	45.40	25,782	
2.New model				
T5 (28 W)	511	29.60	16,032	
Saving energy/year (kWh)				9,750
Saving cost/year (Baht) (4.03 Baht/kWh)				39,292
Investment cost (Baht)				117,530
Payback period (year)				**3.0**

4.6.2 Transportation

Transportation was also found to be a significant contributor to 31.3% of the total GHG emissions of the department. Therefore, it should be received particular attention to cope with reduction measures for carbon dioxide emission. Reduction strategies of transportation are shown in Table 4.27

Table 4.27 Strategies for Reducing Transportation Emissions

Emission Sources	Reduction Strategies
Air travel	• Planning for a trip is important, especially the length for the flight (because a high percentage of fuel use and emission are expended in take-off). • Reduction of the department's need for air travel, or reduction of the number of people who go on each trip. Use of virtual meetings (video teleconference or the use of 3G technology).
Daily commuting	• Creation of incentives for employees to use car pool or other alternative methods for work commute, such as walking, cycling, or mass transit. • Allowing for employees to work on home 1 day per week (Telecommuting)

4.6.3 Material use and waste disposal

At last, for the small proportion of GHG emissions that was from waste and material use, the 3R's of reduce, reuse, and recycle define the main strategy that should be implemented whenever possible to reduce emissions.

The use of materials within the department is unlikely to decrease, but emissions can be reduced by using predominately recycled materials. The majority of the department's material emissions resulted from its use of paper, of which only 3% was post-consumer recycled. The production of 1 ton of paper, it requires 17 tons of trees, 20 m^3 of water, 300 liters of baby oil, and 1,000 kW – hr of electric power. The recycled paper uses less 30% farmed trees than normal paper. It was calculated that using one ream of recycled paper helps saves enough trees to absorb 2.75 kilograms of carbon dioxide from the air, which equals to the amount of carbon dioxide emitted from driving a car 9 km. Reduction strategies of material use and waste disposal is shown in Table 4.28

Table 4.28 Strategies for Reducing Material Use and Waste Emissions

Emission Sources	Reduction Strategies
Material use	• Paper : - Adopt the 3R's (reduce, reuse, and recycle) approach - Contact via e-mail rather than on paper. - Use both sides of paper before sending it to be recycled - Use recycling paper - Awareness raising for staff and student in the 3R's strategy • Water use: - Use water saving devices (Sure Save) - Install rain water collecting system - Reduce the processing time of the motor/pump - Install water meter in each floor
Waste disposal	• Solids waste disposal - Establish Recycling Bank for waste management.

4.6.4 Management Strategy of Chulalongkorn University

For this report, it is aimed to create a list of options to reduce the carbon footprint of Chulalongkorn University's Department of Environmental Engineering. The previous three sections outline a diverse array of viable options for the reduction of the department 's carbon impact. The ambitious scope of such an objective requires a measured approach, however, and the implementation of a plan with manageable incremental and intermediate goals is essential for success. The options outlined in this document present an opportunity to reduce the carbon footprint of the Department of Environmental Engineering of Chulalongkorn University over a range of timescales and with varying levels of emissions reduction, thereby facilitating movement at a variety of possible speeds and initial costs. Possible options have been developed to reduce the amount of carbon-intensive energy that the department produces and/or purchases, as well as the amount of energy required and utilized throughout the department. In the future, it will be expanded to the development of a plan with incremental steps to reduce the university's carbon emissions along a manageable timeline. The university could realistically adopt carbon mitigation goals to be achieved in the next 2, 5, 10, or 20 years, and pursue steps to reach those benchmarks. The list of options approach provides an excellent introduction to the carbon mitigation strategies available to Chulalongkorn University.

The carbon footprint of the entire university may be reduced using the same carbon footprint reduction strategies recommended to the department, but on larger scale. The university may launch both short-and long-term carbon footprint reduction strategies.

1) The short-term strategic plan should be about stimulating energy conservative awareness among the staff, faculty, and students of the university
    - Reduction strategies should be widely promoted using information campaigns and educational programs, which update and inform people on regular basis to encourage environmentally friendly habits.

Seminars, posters, webpages, brochures, pamphlets and the like can be helpful in raising awareness.

- Launch interceding projects that encourage energy saving in ways that make it easy for everyone to participate in, such as a recycling bank.
- Stimulate people in the organization to participate with reduction of carbon footprint program by trading with commensurate things such as gratuity or reward for staff/faculty, or special point for student.

2) The long-term strategic plan may have higher capital cost, but it can be seen a worthwhile investment due to it has long term period of lifetime for a investment.

- Green purchasing which is the affirmative selection and acquisition of products and services that most effectively minimizes negative environmental impacts over their life cycle of manufacturing, transportation, use and recycling or disposal, for example, appliances "No. 5 level" such as air-conditioner, fluorescent tube, fan, and refrigerator.
- Green energy is energy that is produced in a manner that has less of a negative impact to the environment than energy sources like fossil fuels, which are often produced with harmful side effects. "Greener" types of energy that often come to mind are solar, wind, geothermal and hydro energy. There are several more, nuclear energy, for example, that are sometimes considered green energy sources because of their lower waste outputs relative to energy sources such as coal or oil. Green energy source that can be tapped by the university include solar cells and biogas from canteen waste or wastewater plant.
- Green Building is a structure that is environmentally responsible and resource-efficient throughout its life-cycle: from its design, construction, operation, maintenance, and renovation, until its demolition.