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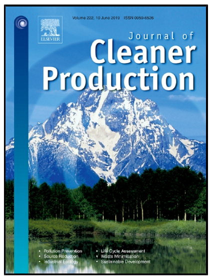

GHG Evaluation and Mitigation Planning for Low Carbon City Case Study: Dan Sai Municipality

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Abstract

In the era of globalization, the economy has expanded, leading to an increase in population and the growth of the city dramatically. The municipalities as local administrators for the being and the quality of life of people in the city. However, the activities in the city such as fuel consumption of housing and transportation, electricity use, waste management like wastewater and waste produce both direct and indirect greenhouse gases, increasing many impacts of climate change. The concept of "low carbon city" has been applied to local government in Thailand. This research aims to evaluate city's greenhouse gas emissions in a case study of Dan Sai municipality based on the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories guideline (GPC), divided into three scopes are scope 1, direct greenhouse gas emissions, scope 2, indirect greenhouse gas emissions from the electricity use and scope 3, other indirect greenhouse gas emissions. According to the study of the city's greenhouse gas emissions in year 2016, was found that Dan Sai municipality had a greenhouse gas emission of 22,925.66 tCO_2eq, equivalent to 5.95 tCO_2eq/person/year of the amount of greenhouse gas emissions per capita, The amount of greenhouse gas emissions per household is 11.84 tCO_2eq/household/year and the amount of greenhouse gas emissions per area is 2,999.82 tCO_2eq/square kilometer/year. And from the assessing results of the alternative options to reduce greenhouse gases by analyzing the final cost of the three options, that are increasing the number of solar rooftops, increasing the use of household LED bulbs and refining waste management using RDF technology, found that the final cost was -175.48, 87.53 and -61.72 Baht/ $kgCO_2eq$, respectively. This project model is a sustainable city developed into a low carbon city in the future.

Keywords: Life Cycle Assessment, Carbon Footprint, Low Carbon City, Forecasting, GHG Mitigation Options, Municipality.

1. Introduction

Nowadays, the world is experiencing the problem of climate change which is a major environmental problem in the world, causing serious, spacious and long-lasting impacts. One of the main causes is global warming. It can be seen that the rising temperatures impact on many climate changes, such as more serious natural disasters, earthquakes, floods, severe storms, including new epidemic. These are all the result of increased greenhouse gas emissions from human activities such as the energy consumption, the development and expansion of the industrial sector, the transportation, the gases of nitrogen oxide from using of nitrogen fertilizers, methane from rice cultivation, the decomposition of organic substances by piles of garbage and sewage, including the destruction of natural resources and the environment in other ways (Sununta N. et al., 2017) for the development of the country hastily in the past 100 years with rapid economic development, lifestyle change and consumption growth (Hubacek et al., 2011). This has led to an increase in greenhouse gas emissions and atmospheric greenhouse gas concentrations that affect the energy balance and patterns of climate on a global scale. The International Energy Agency estimates that CO_2 emissions from energy use in cities will grow by 1.8% per year between 2006 and 2030, with the share of global CO_2 emissions rising from 71% to 76%. As a result of urbanization, the world's urban population grew from 220 million in 1900 (3% of the world's population) to 3530 million in 2011 (52% of the world's population) (Shan et al., 2017). From the problem caused awakening, many agencies have created requirements to help reduce the global warming issue of the city level by encouraging the developing countries to prepare a strategy or plan for development in the Low Carbon Society in the context of sustainable development.

The literature review disclosed many researchers that have reported the valuable application of a carbon footprint in the environmental management of urban. Some studies have been conducted in terms of the carbon footprint of the city, for example, The study of sustaining the low-carbon emission development in Asia and beyond: sustainable energy, water, transportation, and low-carbon emission technology. The results are of energy, water conservation, green transportation, and low emission technology can significantly promote the development of low-carbon emission. The energy sector is the key contributor to GHG emission. The dependency of non-renewable energy in Asia countries remains high despite the various mitigation plans (Lee et al., 2017). Recently, The study of carbon footprint accounting in support of city water supply infrastructure siting decision making: a case study in Ningbo, China. This study suggests that the benchmark discount rate for the water supply infrastructure average incremental economic cost accounting should be decreased from 6% to 4.5 - 4.0% (Wu L. et al., 2015). The evaluated the carbon footprint of Xiamen City in 2009 by a hybrid approach. Besides carbon emissions from the end-use sector activities (called scope1+2) in normal research, carbon emissions from the cross-boundary traffic and the embodied energy of key urban imported materials (namely scope3) were also included. The results are carbon emissions within scope1+2 only take up 66.14% of the total carbon footprint, while emissions within scope 3 account for 33.84%. The industry is the most carbon-intensive end-use sectors which contribute 32.74% of the total carbon footprint and 55.13% of energy use emissions in scope1+2. Overall, Xiamen is relatively a low-carbon city with characters of industrial carbon-intensive and high embodied emissions. This highlight the importance of managing for scope 3 emissions in the developing cities (Lin J. et al., 2013). In Asia, the initiative was launched in Japan in the 2050 Low Carbon Society Scenarios which aims to make each country realize and reduce greenhouse gas emissions by preparing the City Carbon Footprint (CCF) to show the greenhouse gas emissions data from various activities in the city, leads to the guidelines for reducing greenhouse gas emissions, which represent social responsibility. For Thailand has bring the City Carbon Footprint to study the amount of greenhouse gases in 3 municipalities are Chiang Rai municipality, Lampang municipality and Nong Samrong municipality which analyzes the amount of greenhouse gas emissions in the base year 2012 and analyzes to find the appropriated approach to reduce greenhouse gas emissions, using marginal abatement costs to decide on a project or technology that would be appropriate for the investment worthiness and able to reduce greenhouse gas emissions.

Evaluate City Carbon Footprint (CCF) of Dan Sai Municipal area in Loei province of northeastern Thailand and the prediction of greenhouse gas emissions of the city was calculated from the year 2015 as the base year (BAU: business as usual) to the year 2030 by using mathematical forecasting model. As the results, the total of CCF value of Dan Sai Municipal area is 8,528.04 tCO_2eq. The greatest contributor is fossil fuel consumption in the section of trade and industries that occupies is about 39.77% of the total, followed by electricity consumption in the city, solid waste treatment in which accounting for 25.37% and 13.17%, respectively. According to the forecasting model, it was found that carbon emissions could be increased to 11,662.39 tCO_2eq (26.87%) (Sununta N., et al., 2017). Regarding the previous literature review, there were only greenhouse gas evaluations of the city in foreign countries; it can be seen that no previous analytical work had been reported on the deeply CCF evaluation from Thailand. Therefore, the aim of the study was to evaluate the carbon footprint for Dan Sai Municipality. This is an extension of the research results (Sununta N., et al., 2017), which will collect primary data from all study areas and prediction of GHG emission of the city is calculated from 2016 as the base year (BAU: business as usual) to 2030 by using mathematical forecasting model for analyzing the Mitigation Options Planning Survey for Low Carbon City. Finally, the results are interpreted and discussed.

2. The evaluation Carbon Footprint for cities

The evaluation Carbon Footprint for cities is a way of displaying emission data of greenhouse gas from the cities, it helps to prepare in reporting greenhouse gas emissions by showing the amount of emissions in the unit of tons of each gas then sum it in tons of carbon dioxide equivalent. Within the city, there will be various activities that contribute a lot of greenhouse gas both direct, indirect and other indirect ways. The guidelines for preparing the city greenhouse gas emission data will be assessed according to the method of IPCC (2006) (IPCC, 2006) and calculate carbon footprint referenced from Global Protocol for Community-Scale Greenhouse Gas Emission (GPC) (GPC, 2012). By evaluating the amount of the city greenhouse gas emission activities in 3 scopes as follow: scope 1 is direct emission and removal caused by the activities in the subdivision of the city, scope 2 is indirect emission and removal caused by the importing of energy in various ways, both produce and supply from the outside of the city and scope 3 is another indirect emission and removal caused by activities beyond scope 1 and scope 2, such as the amount of waste that takes place within the city's area, and then eliminated outside the city. Main activities that cause greenhouse gas emissions can be identified as shown in Table 1.

Table 1
Main activities that cause greenhouse gas emissions

Sectors	sub-sectors	Scope 1	Scope 2	Scope 3
Stationary combustion	Residential buildings	✓	✓	✓
	Commercial and institutional buildings and facilities	✓	✓	✓
	Manufacturing industries and construction	✓	✓	✓
	Energy industries	✓	✓	✓
	Energy generation supplied to the grid	✓		
	Agriculture, forestry, and fishing activities	✓	✓	✓
	Non-specified sources	✓	✓	✓
	Fugitive emissions from mining, processing, storage, and transportation of coal	✓		
	Fugitive emissions from oil and natural gas systems	✓		
Transportation	On-road	✓	✓	✓
	Railways	✓	✓	✓
	Waterborne navigation	✓	✓	✓
	Aviation	✓	✓	✓
	Off-road	✓		
Waste management	Disposal of solid waste generated in the city	✓		✓
	Disposal of solid waste generated outside the city	✓		
	Biological treatment of waste generated in the city	✓		✓
	Biological treatment of waste generated outside the city	✓		
	Incineration and open burning of waste generated in the city	✓		✓
	Incineration and open burning of waste generated outside the city	✓		
	Wastewater generated in the city	✓		✓
	Wastewater generated outside the city	✓		
Industrial Process and Product Use (IPPU)	Industrial process	✓		
	Product use	✓		
Agriculture, Forestry and Other Land Use (AFOLU)	Livestock	✓		
	Land	✓		
	Aggregate sources and non-CO2 emission sources on land	✓		

3. Materials and methods

3.1 Background of Dan Sai municipality

Dan Sai municipality, one of the popular tourist destinations located in northeastern Thailand. Phi Ta Khon, sometimes known as ghost festival, is the most common name for a group of festivals held in Dan Sai. The events take place over three days between March and July, the dates being selected annually by the town's mediums, more than 50,000 tourists arrive each year. So that is increasing amounts of energy use, solid waste generated by the local population and tourists as well. This study focused on Dan Sai located in the north of Loei province, northeastern Thailand (17°16'53.37"-17°28'15"N, 101°08'46.08"-101°14'61"E) with a total administrative area of 7.3 km^2, the total population is 3,679 persons and 1,850 households in 2016. Geography is different from the northeast, which is usually the plateau completely opposite the Dan Sai, the physical condition is flat in the middle of the valley and the river is flowing, making it abundant never faced problems with natural disasters.

3.2 Goal and scope definition

In the first step of this study, the goal and the scope should be defined. The goal of this study is to evaluate the carbon footprint of the city and forecasting for analyzing the mitigation options is applied. This study has focused on accounting of the amount of three types of GHG emissions, namely, carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2O). The global warming potential (GWP) factors are 1, 25, and 298, respectively (IPCC, 2007). We referred to the Global Protocol for Community-scale Greenhouse Gas Emission Inventories (GPC) guideline (Greenhouse Gas Protocol, 2015).

The scope of this study is calculated the amount of greenhouse gas emission occurred administrative boundary of the city, both direct and indirect, and scale as ton of tCO_2 equivalent (tCO_2eq), by the survey and collect data on greenhouse gas emission activities of Dan Sai Municipality, according to the scope 1, scope 2 and scope 3, as illustrated in Fig. 1. The period for collecting the data is in the fiscal year 2016 or between January 1, 2016, to December 31, 2016, for calculating the amount of greenhouse gas emission of local government.

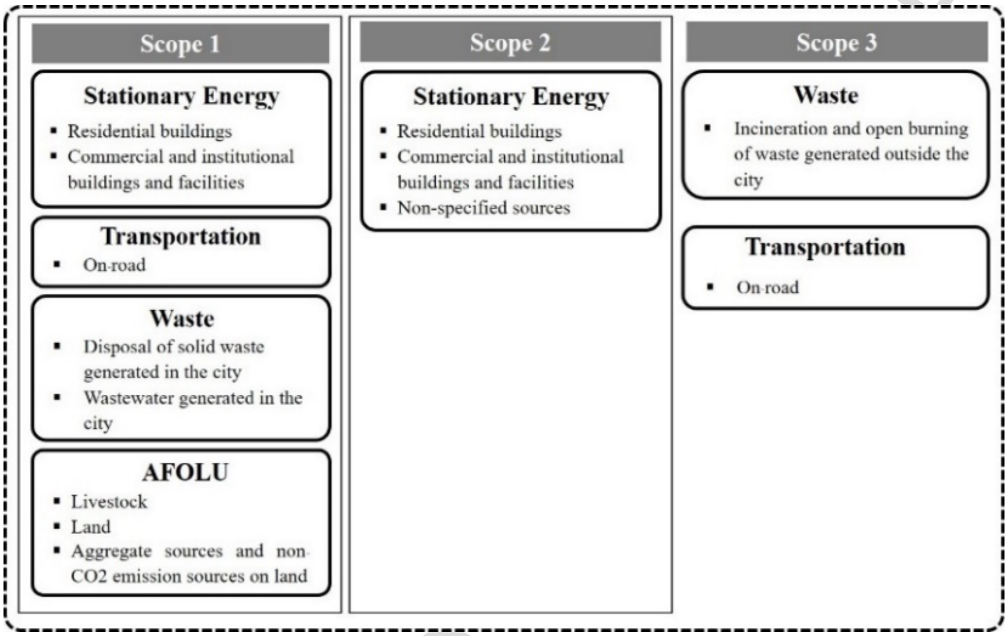


Fig. 1. The System boundary of Dan Sai Municipal Carbon footprint in 2016.

From the data in Fig. 1, Scope 1 include residential energy consumption, commercial and institutional buildings, and facilities energy consumption and non-specified sources energy consumption, energy consumption in road transportation, disposal of solid waste generated in the city, wastewater generated in the city, livestock, land and aggregate sources and non-CO_2 emission sources on land, scope 2 includes residential energy consumption, commercial and institutional buildings and facilities energy consumption and non-specified sources energy consumption and scope 3 include Incineration and open burning of waste generated outside the city and energy consumption in road transportation.

3.3 Data sources and inventory

The data sources of inventory in Dan Sai Municipality in this study were from primary data such as household questionnaire, commercial and institutional buildings and facilities questionnaire, provincial waterworks, provincial agriculture, department of livestock, the office of municipal and provincial electricity. The inventories of Dan Sai Municipality are mentioned in Table 2.

Table 2
Data sources and Inventory of Dan Sai Municipal in 2016.

Scope	Sectors	Sub-sectors	Quantity	Unit	Source of data
Scope 1	Stationary Energy	Residential buildings ▪ fuel combustion within the city boundary Commercial and institutional buildings and facilities	65,310	kg	Residential, Commercial and institutional buildings and

		▪ fuel combustion within the city boundary	1,442,492	kg	facilities
	Transportation	On-road			
		▪ fuel combustion on-road transportation occurring within the city boundary	5,749,538	liter	Petrol station
	Waste	Disposed in open dumps within the city boundary	18,123	ton waste	Municipal
		wastewater generated and treated within the city boundary	3,022	$kgCH_4$	Provincial Waterworks
	AFOLU	Livestock	189	$kgCH_4$	Department of Livestock Development
		Land	1,007	$kgCH_4$	Provincial Agricultural
		Aggregate sources and non-CO2 emission sources on land	49	ha	Provincial Agricultural
Scope 2	Stationary Energy	Residential buildings			
		▪ grid-supplied energy consumed within the city boundary	2,450,000	kWh	Provincial electricity
		Commercial and institutional buildings and facilities			
		▪ grid-supplied energy consumed within the city boundary	1,576,566	kWh	Provincial electricity
		Non-specified sources			
		▪ grid-supplied energy consumed within the city boundary	33,955	kWh	Provincial electricity
Scope 3	Waste	Incineration and open burning of waste generated outside the city	7.20	ton waste	Municipal
	Transportation	On-road	11,815	liter	Bus station

3.4 Evaluation of city carbon footprint

The CCF process is carbon accounting, it can be used to evaluate a larger number of emissions and impact factors using the quantify referred from GPC. The steps of a CCF: (1) determine the goal and scope of greenhouse gas assessment in the municipalities (2) identify greenhouse gas emissions and removal activities (3) create a basis for distributing data of GHG emission and removal source in the municipalities (4) survey and collect the activities data source of GHG emissions and removal source in the municipalities both quantitatively and qualitatively (5) calculate the city's carbon footprint from activities that emitted and removed greenhouse gases and the last is the interpretation. To prepare a database of GHG emissions and removal, according to the guideline for city greenhouse gas data preparation of Thailand Greenhouse Gas Management Organization (Public Organization: TGO) (TGO, 2015). The calculation of the amount of greenhouse gas emissions for city level can be calculated from this Eq (1).

$$GHG_{ES} = \sum_{Category} A \times EF \qquad (1)$$

where GHG_{ES} is the emissions of given gas from all its source categories (tCO_2eq); A is the amount of individual source category utilized which generates emissions of the gas under consideration (unit) and EF is the emission factor of giving type by type of source category ($kgCO_2eq$/unit). Emissions from combustion of fuels such as diesel, liquefied petroleum gas (LPG), and fuel oil were calculated from the emission factors for refuse derived-fuel-fired combustors (uncontrolled), US Environmental Protection Agency (EPA) (EPA, 1995) and were obtained from the Intergovernmental Panel on Climate Change (IPCC) report (IPCC, 2006) and European Environment Agency (EEA) guidelines (EEA, 2013). Heating values of various fuels were retrieved from the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy (DEDE, 2015).

The GHG emissions in the energy sector from stationary combustion energy consumption, which include household energy consumption, industrial sector energy consumption, public and private sector energy consumption and transportation are in scope 1 and cross-boundary transport (road transport) in scope 3 can be calculated from amount of individual energy consumption category (unit) multiply emission factor of giving type by type of energy consumption category (kgCO_2eq/unit) can be calculated from this Eq (2) and the GHG emissions from electricity consumption are in scope 2 can be calculated from this Eq (3).

$$GHG_{ES,\mathrm{fuel}} = A_{Fuel_a} \times EF_a \tag{2}$$

where $GHG_{Emissions,\mathrm{fuel}}$ is the emissions of energy consumption from source categories (tCO2eq); A_{Fuel_a} is the amount of fuel used (unit) and EF_a is the emission factor of each fuel type and is each fuel type (kgCO_2eq/unit).

$$GHG_{ES,\mathrm{elec}} = Elec \times EF_{elec} \tag{3}$$

where $GHG_{ES,\mathrm{elec}}$ is the emissions of electricity consumption (tCO_2eq); $Elec$ is the amount of electricity consumption (kWh) and EF_{elec} is the emission factor of electricity consumption (kgCO_2eq/kWh). The GHG emissions from waste sector, wastewater management and discharge can be calculated from the volume of water to be supplied or used multiply 80% of supplied or used water multiply biochemical oxygen demand (BOD) multiply GHG emission factor and GHG emissions from solid waste (waste management by open dump) can be calculated from this Eq (4)

$$GHG_{ES,\mathrm{waste}} = A_{waste} \times \left[\left[\sum_X CH_4 generated_{X,T} - R_T \right] \times (1 - R_T) \right] \times 25 \tag{4}$$

Where $GHG_{ES,\mathrm{waste}}$ is the emissions of waste management by open dump (tCO_2eq); A_{waste} is the amount of solid waste (ton); $CH_4 generated$ is the amount of methane generated (tCH_4/year); X is the component of solid waste; T is the year of calculate; R_T is methane oxidation on landfill cover and 25 is the global warming potential (GWP) of methane.

In the agriculture sector, which include livestock farming and management could be calculated from CH_4 emissions (the number of animals multiply with GHG emission factors for each species 10^{-6}) and N_2O emissions of dung management (the number of animals multiply with average nitrogen of weight of each species multiply by 365 multiply by nitrogen fraction in dung multiply by GHG emission factor of nitrous oxide multiply by 44/28). Finally, GHG emissions from forestry and other of land use could be calculated from CO_2 reabsorption by above-ground biomass of stem plus of above-ground biomass of branch and plus of above-ground biomass of leaves.

3.5 Forecasting and GHG Mitigation Options Planning Survey

In the forecasting section, estimated the CCF of Dan Sai municipality from the base year (2016) to 2030 by using mathematical forecasting model according to statistics or mathematics, there are many ways, depending on the expansion of the community and the periods in the future. The important data is the amount of population, the number of households and per capita income gross municipal product (GMP) of the present and the past of the municipality's population. In this study, polynomials were used in the forecasting model. The slope and R-square are higher than 0.9

and an independent variable could be displayed in the following from Eq (5) and linear regression analysis used to be forecasting the number of households and GMP values of the municipality that can be calculated from this Eq (6).

$$Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \varepsilon \tag{5}$$

$$P_n = P_o \left(1 + \left(\left(P_n - \left(P_{n-1}\right)\right) / \left(P_{n-1}\right)\right)\right)^n \tag{6}$$

Where P_n is population in n years that calculated from the present period to the future (person); P_0 is the present population or year of initial calculation (person); n is period required to calculate change from the present year (year) and P_{n-1} is the present population or year of initial calculation (person).

After evaluating the city's greenhouse gas emissions forecasts, then fine the GHG mitigation options planning survey. In this research, have analyzed the method/activity/technology to reduce greenhouse gas emissions by assessing the potential and feasibility of reducing greenhouse gas emissions that are appropriate and consistent to reciprocate the demand of the local municipalities under the consultation between the consultant and the stakeholders in the municipal area by focusing on greenhouse gas reduction activities that benefit the community in terms of environmental, social, and impacts, include technical limitations of each activity/technology that use to reduce greenhouse gas emissions. The suggested long list of GHG mitigation sectors, sub-sectors and activity/technology for Dan Sai Municipality are mentioned in Table 3.

Table 3
Suggested long list of GHG mitigation sectors, sub-sectors and activity/technology for Dan Sai Municipality.

Sectors	Sub-sectors	Activity/Technology	Description
Private buildings (residential & commercial)	**Energy efficiency - Existing Buildings**	Lighting	Replacement of existing electric lighting fixtures with more energy-efficient ones. Under CDM methodology AMS-II. N, this activity also includes installation of lighting control systems, such as occupancy sensors, timers, daylighting or dimming controls in order to reduce electric lighting lamp operating hours.
		Cooling	Installation of new energy efficient air cooling equipment for buildings (air conditioners, fans, chillers, refrigerators) or replacement of old equipment with new, more energy efficient.
		Appliance & electronics	Promoting the use of less carbon intensive appliances and electronic devices in the building (e.g. fridges, ovens)
Municipal buildings & public lighting	**Energy efficiency - Existing Buildings**	Lighting	Replacement of existing electric lighting fixtures with more energy-efficient ones. This could also include installation of lighting control systems, such as occupancy sensors, timers, daylighting or dimming controls in order to reduce electric lighting lamp operating hours. New construction (greenfield) projects are not included.
		Cooling	Efficiency improvement of ventilation and air conditioning systems (e.g. evaporative, ground cooling).
		Appliance & electronics	Promoting the use of less carbon intensive appliances and electronic devices in the building (e.g. fridges, ovens)
	On-site RE systems	RE systems (on-grid)	Installation of RE systems for buildings (e.g. rooftop solar PV, wind turbines) to displace electricity from the grid (on-grid)
		RE systems (off-grid)	Installation of RE systems for buildings (e.g. rooftop solar PV, wind turbines) to displace electricity from the grid (off-grid)
	Street & Other Public Lighting	Streetlights and traffic signals	Installation of more energy efficient lights, including solar-powered street lights.
Solid waste management	**Waste management**	MSW segregation	Waste segregation from MSW (plastics, metals, paper and cardboard, etc.) including through upscaled network of waste banks
		Development of integrated waste management system	
	Alternative fuels production	Biodiesel production from waste cooking oil	The use of waste cooking oil from municipality (e.g. from hotels, restaurants) for production of biodiesel for motorized vehicles instead of more carbon intensive fossil fuel diesel.
		Plastic waste to oil	Plastic waste from municipality (e.g. HDPE, LDPE and PET) is collected, separated from MSW, processed into petroleum fuels similar to diesel and gasoline

		Refused Derived Fuel (RDF) production from MSW	Treatment of waste to produce refuse-derived fuel (RDF) to be used as fuel for electricity or heat production.
		Use of biomass as an alternative fuel	
	Waste composting and production of organic fertilizer	Organic waste composting	Controlled aerobic treatment of organic waste resulting in production of organic fertilizer or soil conditioner. Due to this, the organic material will not be decayed anaerobically and, thus, emissions of methane will be avoided. This activity applies for the organic fraction of MSW. CDM methodologies extend the boundaries to include biomass waste from agricultural or agro-industrial activities, including manure.
	Waste-to-energy	Landfill gas capture for energy generation	Capturing and combustion of methane gas from landfills (i.e. solid waste disposal sites, SWDS) or sites for anaerobic fermentation of waste (T-VER methodology), which would otherwise be emitted in the atmosphere. Recovered methane could be used for power generation
		Biogas generation from organic waste	Anaerobic digestion of organic waste with capture of methane and its use for energy production (this includes processing and upgrading biogas and then its distribution via a natural gas distribution grid). This could include: tapioca starch, palm oil, ethanol.
		MSW incineration	Incineration of landfill waste for energy generation. CDM methodology specifies the types of wastes (glass, aluminum, ferrous metals from waste sorting stages, inert materials, run-off wastewater); applicable incineration technologies (rotary kiln, rotating fluidized bed, circulating fluidized bed, hearth or grate type) and a condition that the fraction of energy generated by auxiliary fossil fuels should not be more than 50% of the total energy generated in the incinerator.

In consultation with stakeholders in the municipality, administrators and municipal officials, found that for private buildings (residential & commercial) sector, the stakeholders have chosen only LED replacement activities to reduce their greenhouse gas emissions, for municipal buildings & public lighting sector, the stakeholders have chosen the rooftop solar PV activity to reduce their greenhouse gas emissions and for the solid waste management sector, the stakeholders have chosen have chosen to reduce their greenhouse gas emissions from waste segregation from MSW and treatment of waste to produce refuse-derived fuel (RDF). Then, the activities/ technologies selected by the stakeholder meetings will be evaluated for the final unit cost for reducing greenhouse gas emissions to calculate the amount of greenhouse gas that can be reduced by changing each technology. The saving result of the reduced greenhouse gases will be converted into an annual value that shows a financial perspective in the unit of money per equivalent carbon dioxide. The project or technology to be considered is fuel production of waste, solar rooftop and replacing LED household bulbs from this Eq (7).

$$MAC = \left(\frac{\mathrm{OP}_t + \mathrm{M}_t + \mathrm{E}_t + \sum CC_t}{AEF}\right) \tag{7}$$

Where MAC is the final unit cost of a project or technology (Baht/tCO_2eq), OP_t is the investment cost in the first year of the project or technology t (Baht), M_t is the cost of operating and maintaining the project or technology t (Baht), E_t is the cost savings of the project or technology t (Baht), $\sum CC_t$ is other expenses incurred throughout the project or installation and use of technology t (Baht), AEF is the annual reduction in greenhouse gases (tCO_2eq)

4. Results and Discussion

4.1 City carbon footprint of Dan Sai Municipality

The CCF of Dan Sai Municipal area in 2016 was 22,925.66 tCO_2eq. The emissions of sectors and sub-sectors were as table 4. The fuel combustion the on-road transportation occurring within the city boundary in on-road transportation sector is the largest source of the total (15,111.00 tCO_2eq). The fuel combustion within the city boundary in Commercial and institutional buildings and facilities sector takes the second place (2,877.56 tCO_2eq). The third largest source is grid-supplied energy consumed within the city boundary in Residential buildings (1,426.14 tCO_2eq). Finally, disposed in open dumps within the city boundary sector contributes to 1,066.95 tCO_2eq, grid-supplied energy consumed within the city boundary in commercial and institutional buildings and facilities sector (917.72 tCO_2eq), the fuel combustion within the city boundary in the residential buildings sector (214.17 tCO_2eq), wastewater generated and treated within the city boundary in waste sector (75.57 tCO_2eq), on-road out of boundary in the transportation sector (32.43 tCO_2eq), land in AFOLU sector (25.20 tCO_2eq), Incineration of waste generated outside the city in waste sector (11.90 tCO_2eq), livestock and Aggregate sources and non-CO_2 emission sources on land in AFOLU sector are 4.72 and 0.02 tCO_2eq, respectively. The amount of greenhouse gas emissions per capita is 5.95 tCO_2eq/person/ year, the amount of greenhouse gas emissions per household is 11.84 tCO_2eq/household/ year and the amount of greenhouse gas emissions per area is 2,999.82 tCO_2eq/square kilometer/year.

Table 4
City carbon footprint of Dan Sai Municipality in 2016.

Scope	Sectors	GHG emissions (tCO_2eq)	Sub-sectors	GHG emissions (tCO_2eq)
Scope 1	Stationary Energy	3,091.73	Residential buildings	
			▪ fuel combustion within the city boundary	214.17
			Commercial and institutional buildings and facilities	
			▪ fuel combustion within the city boundary	2,877.56
	Transportation	15,111.00	On-road	
			▪ fuel combustion on-road transportation occurring within the city boundary	15,111.00
	Waste	1,142.52	Disposed in open dumps within the city boundary	1,066.95
			wastewater generated and treated within the city boundary	75.57
	AFOLU	29.94	Livestock	4.72
			Land	25.20
			Aggregate sources and non-CO2 emission sources on land	0.02
Scope 2	Stationary Energy	2,363.62	Residential buildings	
			▪ grid-supplied energy consumed within the city boundary	1,426.14
			Commercial and institutional buildings and facilities	
			▪ grid-supplied energy consumed within the city boundary	917.72
			Non-specified sources	
			▪ grid-supplied energy consumed within the city boundary	19.76
Scope 3	Waste	11.90	Incineration of waste generated outside the city	11.90
	Transportation	32.43	On-road	32.43

4.2 Forecasting result of city carbon footprint in Dan Sai Municipality

The prediction of city-level greenhouse gas emissions from year 2016 to 2030 indicated that GHG emissions in 2030 will be increased up to 36.64% (2016 as 22,925.66 tCO_2eq and 2030 as 36,184.01 tCO_2eq) due to the growth of the city and the population, based on statistical theory by mathematical model with the relating variables, including the growth rate of the population, the number of households and per capita income of the municipality of the current and the past was implemented. Mitigation options will be applied and projected the potential to reduce greenhouse gas emissions of the municipality in the future. The results can be shown in Fig. 2.

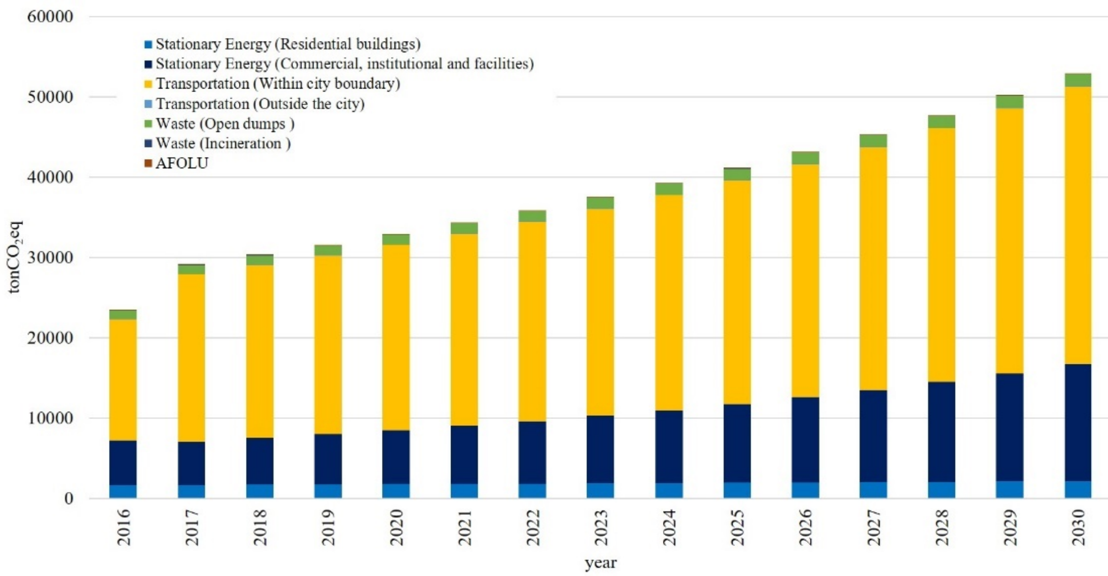
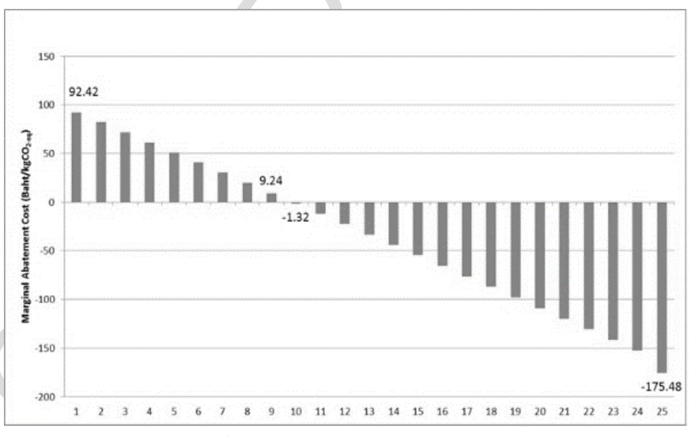


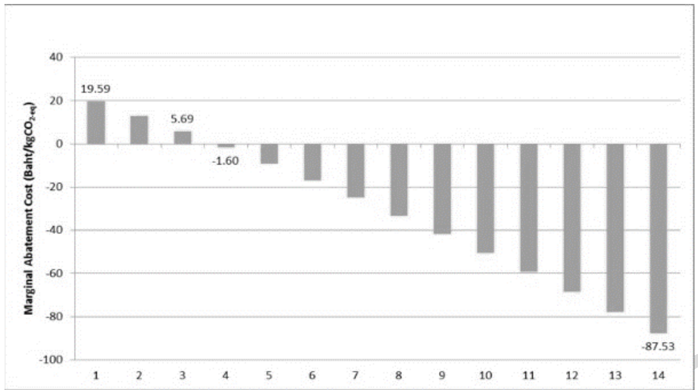
Fig. 2. Forecasting of CCF in Dan Sai Municipality in year 2016 to 2030.

4.3 GHG Mitigation Options Planning Survey for Dan Sai Municipality

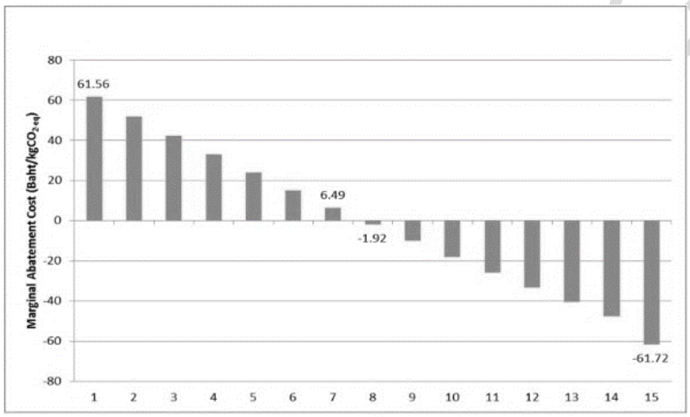
Based on the final cost analysis of greenhouse gas reduction in three projects, which are fuel production of waste, solar rooftop and replacing LED household bulbs, in Fig.3 has shown the final cost of a solar rooftop, LED household bulbs and RDF waste fuel throughout the life cycle, which the life of the solar cell lasts 25 years, LED bulb life is 14 years, based on the bulb lifetime is 30,000 hours, 6 hours a day and the life of the machine producing RDF waste fuel is 15 years. Determined the solar rooftop installs 50% of the total households, 1 kW per household, the LED bulb is replaced one bulb by one household and RDF waste fuel is based on the amount of waste generated in 2012, the proportion of waste that can be used to produce RDF waste fuel is plastic, paper, and scrap leaves.



(a) Marginal abatement cost of rooftop solar PV



(b) Marginal abatement cost of replacing LED



(c) Marginal abatement cost of refuse-derived fuel (RDF)

Fig. 3 The mitigation Options Planning Survey for Dan Sai Municipality

In Fig. 3, to start a project investment the final cost of the installation of solar rooftop, the replacement of LED household bulbs and RDF waste fuel is 92.42, 19.59 and 61.56 Baht/ kgCO_2eq, respectively, which are a positive value that also requires additional costs to reduce greenhouse gas emissions and the final unit cost in the last year of life of the installation of solar rooftop, the replacement of LED household bulbs and RDF waste fuel is -175.48, 87.53 and -61.72 Baht/kgCO_2eq, respectively, which are a negative value that shows no cost to reduce greenhouse gas emissions and is also profitable.

5. Conclusion

In the year 2016, the amount of greenhouse gas emissions of the Dan Sai municipality from various activities, had a greenhouse gas emission of 22,925.66 t$CO_{2\text{-eq}}$, equivalent to 5.95 tCO_2eq/person/year of the amount of greenhouse gas emissions per capita, the amount of greenhouse gas emissions per household is 11.84 tCO_2eq/ household/year and the amount of greenhouse gas emissions per area is 2,999.82 tCO_2eq/square kilometer/year. From the analysis of the first year final cost of the installation of solar rooftop, the replacement of LED household bulbs and RDF waste fuel is 92.42, 19.59 and 61.56 Baht/kgCO_2eq, respectively, which are a positive value that also requires additional costs to reduce greenhouse gas emissions and the final unit cost in the last year of life of the installation of solar rooftop, the replacement of LED household bulbs and RDF waste fuel is -175.48, 87.53 and -61.72 Baht/kgCO_2eq, respectively, and can also reduce the greenhouse gas emissions of the municipality by 12,171.49, 17,835.48, and 4,872.50 tCO_2eq, respectively. The results from this analysis of greenhouse gas emissions make it possible to know which sources or activities contribute the high greenhouse gas emissions, in order to be able to manage or find a way to reduce greenhouse gas emissions occur at that point and analyze to find the final unit cost that can be used to indicate any technology or project which can generate profits and reduce greenhouse gas emissions. This study could lead to better solutions for maximizing the potential of low carbon city and minimizing the climate change problem issues. However, it should be noted that this study focused on evaluation of only GHGs that is related to the impact of global warming. To be getting better comprehensive results, other negative effects such as other environmental impacts and economic and social aspects should be considered in the evaluation.

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