CHEMICAL ENGINEERING TRANSACTIONS
VOL. 63, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Jeng Shiun Lim, Wai Shin Ho, Jiří J. Klemeš

ISBN 978-88-95608-61-7; **ISSN** 2283-9216
DOI: 10.3303/CET1863047

City Carbon Footprint Evaluation and Forecasting Case Study: Dan Sai Municipality

Netchanakan Sununta[a], Surat Sedpho[b], Sate Sampattagul[c,d,*]

[a]Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand,
[b]School of Energy and Environment, University of Phayao, Phayao, Thailand
[c]Center of Excellent on Energy, Economic and Ecological Management, Science and Technology Research Institute, Chiang Mai University
[d]Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Thailand
sate@eng.cmu.ac.th

In this research, City Carbon Footprint)CCF(of Dan Sai municipality was evaluated according to the Global Protocol for Community-scale Greenhouse Gas Emission Inventories)GPC(guideline. Related activity data in 2015 were collected and analyzed which presented into 3 scopes (Scope1, 2, 3). As the results, the total CCF of Dan Sai Municipality is 8,528.04 tCO_2eq which contributed from scope 1, scope 2 and scope 3 of 5,524 tCO_2eq, 2,164 tCO_2eq, 1,140 tCO_2eq, respectively. Fossil fuel combustion from industrial sub-sector in scope 1 showed the greatest contribution of 40% of the total, followed by electricity consumption in scope 2, solid waste treatment in scope 1 accounting for 25% and 13%, respectively. The data of CCF in 2015 was used as baseline (Business as Usual: BAU) in order to predict city emissions in 2030 using mathematical forecasting model. The result indicated that CCF of Dan Sai can be reach up to 11,662.39 t CO_2eq (27%). Consequently, applying mitigation options to reduce the emission for Dan Sai has been proposed. It was found that implementation of reduction projects including installation of solar rooftop, composting organic waste, producing RDF from waste and convert waste to energy by using RDF hybrid ORC could reduce CCF accounting for 20%, 0.53%, 1% and 3%, respectively. This study can provide benefits and offer better solutions for maximizing the potential of low carbon city and minimizing the climate change problem issues for municipality in the near future.

1. Introduction

Rapidly increasing greenhouse gas)GHG(in the atmosphere has resulted in climate change with negative impacts on both natural and socio-economic systems)Parks, 2009(. More than half of world's population are living in cities, a number expected to increase to more than 5 billion representing about 60% of the population by 2030)Alhamwi et al., 2017(. Other human activities are the major cause of increased GHG in the atmosphere 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)TGO, 2015(. Thailand is one of the impacted regions in the world under the current prediction of climate change. Accordingly, the management concept of reducing greenhouse gas emissions by the creation of the society, Low-carbon City, based on the carbon footprint of the city was developed in order to evaluate and planning the reduction of GHG. Evaluation of GHG emission in the city was studied by many researchers. Some studies have been conducted in terms of the carbon footprint of the city.

Xi et al. (2011) studied a contributing to local policy making on GHG emission reduction through inventorying and attribution in Shenyang, China by carbon footprint of the city approach. It found that the analysis on GHG emissions at the city level can help to identify the major industries and societal sectors for reducing efforts to

Please cite this article as: Netchanakan Sununta, Surat Sedpho, Sate Sampattagul, 2018, City carbon footprint evaluation and forecasting case study: dan sai municipality, Chemical Engineering Transactions, 63, 277-282 DOI:10.3303/CET1863047

facilitate low-carbon policy making)Xi et al., 2011). City carbon footprint also applied for special economic zone, Xiamen City in 2009 by adding carbon emissions from the cross-boundary traffic and the embodied energy of key urban imported materials in the evaluation together with carbon emissions from the end-use sector activities in normal research. The results indicated that further analysis indicates that the urbanization and industrialization in Xiamen cause more material consumption and industrial emissions than normal city area)Lin et al., 2013). Recently, in 2015, Ramachandra evaluated the GHG footprint of major cities in India through quantification of sector wise GHG emissions and computation of carbon dioxide equivalent)CO_2eq(. GHG footprint of all the major cities in India helps in improving national level emissions inventories)Ramachandra et al., 2015(and Wang and Ho (2017) studied a carbon and energy use reporting being incorporated in the existing reporting practices by facility managers for government office buildings in Putrajaya. The findings conclude that this high level of reporting status is expected to give positive impact on future mandatory reporting and to demonstrate as new instrument for building sector CO_2 mitigation in Putrajaya (Wang and Ho, 2017). Regarding the previous literature review, there were only greenhouse gas evaluations of city in foreign countries; no previous analytical work had been reported on the deeply CCF evaluation from Thailand. Therefore, the aim of the study was to evaluate and predict the carbon footprint for Dan Sai Municipality from 2015 to 2030. In addition, mitigation options were applied to reduce GHG in the future. Finally, the results are interpreted and discussed.

2. Site of study

Presently, Thailand is the early tourist destination. Many places were promoted as the new tourism city, including Dan Sai. Dan Sai, one of the popular tourist destinations 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. In 2015, total population is 3,691 persons and 1,841 households. 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 more than 50,000 tourists arrive each year. The growth of population may cause increasing of emission which contribute from energy consumption such as electricity, fossil and industry. Consequently, developing and evaluating of city carbon footprint for Dan Sai municipality are needed in order to manage and reduce the emissions release from city activities which can used as the prototype model for tourist city.

3. Methodology

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 city carbon footprint according to Global Protocol for Community-scale Greenhouse Gas Emission Inventories)GPC) guideline)Greenhouse Gas Protocol, 2015(and reduce the emission by applying mitigation options. This study has focused on three gases released, 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, 2006(. System boundary is defined along with the administrative boundary of the city, GHG emissions released from the city activity in 2015 are collected and expressed as ton CO_2 equivalent)tCO_2eq(. According to GPC guideline, GHG emissions are classified in to three scopes as showed in Figure 1.

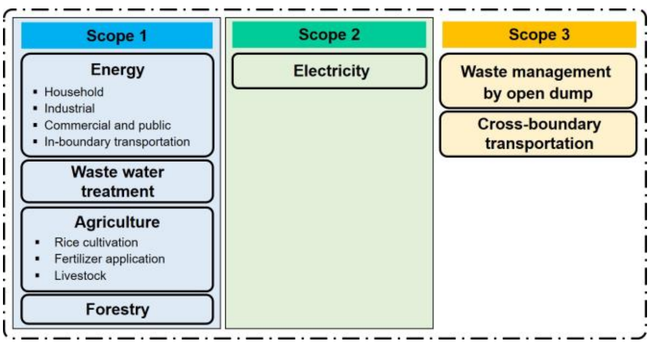

Figure 1: *Classification of GHG in City Carbon Footprint*

Scope 1 refers to direct and fugitive emissions which include: direct emissions of fossil fuel combustion from household, industry, commercial and public as well as in-boundary transportation (excluded electricity); methane released from waste water treatment; fugitive emissions from agricultural activities such as rice cultivation, fertilizer application and livestock; and carbon dioxide emissions from forestry and other land use. Scope 2 refers to indirect emissions from electricity consumption, whereas scope 3 refers to others emissions such as waste management and cross-boundary transportation.

3.2 Data sources and inventory

Table 1 shows the collected inventory data from various data sources expressed by the scope of Dan Sai Municipality.

Table 1: Inventory of Dan Sai municipality in 2015

Scope	Sector	Sub-sector	Item	Quantity	Unit	Data source
1	Energy	Household	LPG	74,154.55	kg	Questionnaire
		Industry	Natural gas	11,121.55	m^3	Questionnaire
			Diesel	273,973.12	L	Questionnaire
			LPG	91,694.62	kg	Questionnaire
			Fuel oil	43,956.87	L	Questionnaire
			Gasoline	2,244.97	L	Questionnaire
		Commercial and public	Diesel	284,544.06	L	Questionnaire
			Gasoline	32,484.81	L	Questionnaire
		In-boundary transportation	Diesel	94,800.96	L	Questionnaire
			Gasoline	155,230.56	L	Questionnaire
	Waste	Waste water treatment	Waste water	332,784.00	m^3	Provincial Waterworks Authority
	Agriculture	Rice cultivation	Field emission (CH_4)	814.60	kg CH_4	District of Agricultural Extension Office
		Fertilizer application	Urea	438.23	kg	District of Agricultural Extension Office
		Livestock	Manure management	94	kg CH_4	Livestock Office
	Forestry	Forestry	Carbon absorption	78,649.26	kg	Dan Sai municipality
2	Electricity	Electricity	Electricity	3,722,564.73	kWh	Provincial Electricity Authority
3	Others	Waste management	Solid waste	1,374.16	t	Dan Sai municipality
		Cross-boundary transportation	Diesel	11,802.95	L	Questionnaire
			Gasoline	168.80	L	Questionnaire

3.3 Evaluation of city carbon footprint

In this section, city carbon footprint can be calculated from inventory data of Dan Sai municipality as showed in Table 1 according IPCC guideline)IPCC, 2006(by multiplying activity data with its emission factor as follows:

$$GHG_{Emissions} = \sum_{Categories} A_i \times EF_i \tag{1}$$

where $GHG_{Emissions}$ 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_i is the emission factor of give 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).

GHG emissions from solid waste management)open dump(can be calculated as follows:

$$GHG_{Emissions,\mathrm{waste}} = A_{waste} \times \left[\left[\sum_{X} CH_4 generated_{X,T} - R_T \right] \times (1 - R_T) \right] \times 25 \tag{2}$$

Where $GHG_{Emissions,waste}$ is the emissions of waste management by open dump)tCO_2eq(, A_{waste} is the amount of solid waste)t), CH_4generated 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.

The data of waste water from Dan Sai municipality was not available, thus, waste water was estimated around 80 % of tap water used. GHG emissions from wastewater management can be calculated by multiplying waste water with biochemical oxygen demand)BOD) and its emission factor.

In the agricultural sector, GHG emissions related to field emission (CH_4) from rice cultivation, nitrogen application from fertilizer application, enteric emissions and manure management from livestock were evaluated. CH_4 emissions from rice cultivation were estimated by multiplying daily emissions factor (kgCH_4 per hectare per year) with cultivation period of rice for conditions (number of days) and harvested area of rice for conditions (hectares per year) (IPCC, 2006). Nitrous oxide emissions from fertilizer application could be estimated from amount of urea fertilization (tonnes urea per year) multiply with emission factor (tonne of C per tonne of urea) multiply with 44/28 (conversion of C stock changes to CO_2 emissions) (IPCC, 2006). Furthermore, CH_4 emissions from enteric fermentation and manure management were estimated by multiplying the number of animals (head) with its emission factor for enteric fermentation (kg of CH_4 per head per year) (IPCC, 2006). In addition, N_2O emissions from livestock could be estimated by multiplying number of animals for each livestock category with annual N excretion for livestock category (kg N per animal per year multiply with fraction of total annual nitrogen excretion managed in MMS for each livestock category) and emission factor for direct N_2O-N emissions from MMS (kg N_2O-N per kg N in MSS) (IPCC, 2006). Finally, GHG emissions from forestry could be calculated from CO_2 absorption by above-ground biomass of stem plus of above-ground biomass of branch and plus of above-ground biomass of leaves. CO_2 absorption by the forest will be reported in the research. However, the absorption was not accounted in CCF.

3.4 Forecasting of city carbon footprint

In the section, estimated the CCF of Dan Sai municipality from base year)2015(to 2030 by using mathematical forecasting model according to statistics or mathematics. Forecasting is the alternative implement depend on the expansion of the community and the periods in the future. For Dan Sai municipality, related data including amount of population, number of households and per capita income gross municipal product)GMP(of the present and past of municipality's population are considered. In this study, polynomials were used in forecasting model. The slope and R-square are higher than 0.9 and an independent variable and linear regression analysis forecasting the number of households and GMP values of the municipality can expressed as follows:

$$Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \varepsilon \tag{3}$$

$$P_n = P_o \left(1 + \left(\left(P_n - \left(P_{n-1}\right)\right) / \left(P_{n-1}\right)\right)\right)^n \tag{4}$$

Where P_n is population in n years that calculated from the present period to the future)people), 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(.

4. Results and discussion

4.1 City carbon footprint of Dan Sai Municipality

The overall GHG emissions or CCF were evaluated entire all sectors according to the framework as showed in Figure 1 via the data in 2015 calendar year. CCF of Dan Sai municipality is 8,528.04 tCO_2eq as expressed in Table 2.

Scope 1 showed the greatest GHG emissions of 5,524 tCO_2eq accounting around 61% of the total CCF which contributes from fossil fuel consumption from energy sector, especially on industry, released GHG up to 40% of the total CCF. The results indicated that the growth of tourism industry caused the increasing of the number of persons in high season. Small industry and commercial will be growth along with the population in order to produce the commodity the demand in consumption lead to the requirement of energy such as natural gas, diesel and LPG to serve the demand. GHG emissions related to electricity consumption showed the contribution of 25% of the total CCF.

Similarity to the results in scope 1, GHG emissions are related to the number of person who live and stay in the municipal area at the time. Municipal solid waste management in scope 3 showed the interested proportion around 13% of the total CCF. The conventional operation for waste management in Dan Sai municipality is open-dumped, thus GHG emissions from solid waste is strongly related to the fermentation of organic matter in solid waste. In-boundary and cross boundary transportation showed fair significant on CCF results which influenced by the public transport route which arranged by the policy of the government. Other sectors showed insignificant results.

Table 2: *City carbon footprint of Dan Sai Municipality in 2015*

Scope	Sector	Sub-sector	Item	GHG emissions (tCO_2eq)	Proportion (%)
1	Energy	Household	LPG	225.79	2.65
		Industry	Fossil fuels (natural gas, diesel, LPG, fuel oil, gasoline)	3,391.98	39.77
		Commercial and public	Diesel & Gasoline	853.65	10.01
		In-boundary transportation	Diesel	625.29	7.33
	Waste	Waste water treatment	Waste water	99.84	1.17
	Agriculture	Rice cultivation	Field emission (CH_4)	20.36	0.24
		Fertilizer application	Nitrogen application	2.19	0.03
		Livestock	Manure management	5.07	0.06
	Forestry	Forestry	Carbon removal	-39.37*	-
		Scope 1 sub-total		5,524.17	61.26
2	Electricity	Electricity	Electricity	2,163.93	25.37
		Scope 2 sub-total		2,163.93	25.37
3	Others	Waste management	Solid waste	1,123.55	13.17
		Cross-boundary transportation	Diesel	16.39	0.19
		Scope 3 sub-total		1,139.94	13.37
		Total		8,528.04	100

* This value is excluded in the total CCF.

4.2 Forecasting result of city carbon footprint in Dan Sai Municipality

The prediction of city level greenhouse gas emissions from year 2015 to 2030, 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 are shown in Figure 2.

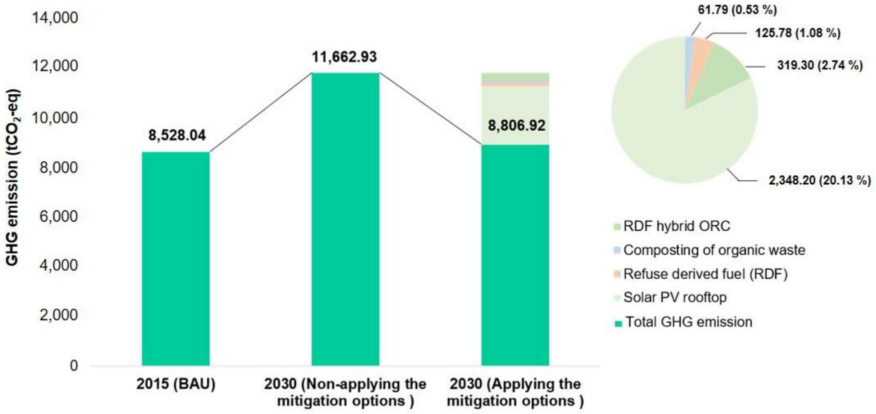

Figure 2: *Forecasting and applying the mitigation options of CCF in Dan Sai Municipality*

According the evaluation in Figure 2, the results indicated that GHG emissions in 2030 will be increased up to 27% from 2015 due to the growth of the city and the population. In order to mitigate the GHG emissions in the future, various activities/technologies need to be applied. Installation of solar rooftop can produce electricity to substitute national gird consumption. In 2030, solar rooftop will be reduced GHG emissions up to 20% of the total. GHG related to fermentation of organic waste will be resolved via composting which could be reduce around 0.53% of the total. Applying waste to energy technologies, RDF and RDF hybrid ORC, will be convert waste as fuel for RDF and convert waste to electricity for RDF hybrid ORC. Both of technologies could be decreased GHG emissions in 2030 between 1-3% of the total CCF.

5. Conclusions

CCF is the framework in order to evaluate the amount of GHG emissions for the city which can applied according to the context of the city. In 2015, the total CCF of Dan Sai Municipality is 8,528.04 tCO_2eq. The major contribution is fossil fuel consumption industry sub-sector, accounted 40% of the total, followed by electricity consumption, solid waste treatment, accounted 25% and 13, respectively. In 2030, GHG emissions of Dan Sai municipality will be increased up to 26.87% comparison to 2015. Mitigation activities/technologies were applied to offer the guideline for reduction. Installation of solar PV rooftop could be decreasing the CCF around 20%, composting of organic waste could reduce CCF of 1.29%, RDF and RDF hybrid ORC could reduce between 1-3%. 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.

Acknowledgments

This study has been supported by Dan Sai Municipality, Loei Province of Thailand, Thailand Greenhouse Gas Management Organization)Public Organization(, The Thailand Research Fund)TRF(, The Graduate School Chiang Mai University and Center of Excellent on Energy, Economic and Ecological Management, Science and Technology Research Institute, Chiang Mai University.

References

Alhamwi A., Medjroubi W., Vogt T., Agert C, 2017, GIS-based urban energy systems models and tools: Introducing a model for the optimisation of flexibilisation technologies in urban areas, Applied Energy, 191, 1-9.

DEDE (Department of Alternative Energy Development and Efficiency Ministry of Energy), 2015, Energy situation of Thailand January - September 2015, Department of Alternative Energy Development and Efficiency, Ministry of Energy <www.dede.go.th/download state_58/sit_57_58/frontpage_sep58% 20)1(.pdf> accessed 31.01.2016.

EPA (United States Environmental Protection Agency), 1995, Complication of air pollutant emission factors Vol. 1: Stationary point and area sources, Office of Air Quality Planning and Standards & Office of Air and Radiation, US Environment Protection Agency.

EEA (European Environment Agency), 2013, EMEP/EEA air pollutant emission inventory guidebook 2013: Technical guidance to prepare national emission inventories, European Environment Agency, Publications Office of the European Union, Luxembourg.

Greenhouse Gas Protocol, 2012, Global Protocol for Community – Scale Greenhouse Gas Emission)GPC(.

IPCC (Intergovernmental Panel on Climate Change), 2006, IPCC Guidelines for National Greenhouse Gas Inventories, prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T., Tanabe K.)Eds(, IGES, Japan.

Lin J., Liu Y., Meng F., Cui S., Xu L., 2013, Using hybrid method to evaluate carbon footprint of Xiamen City, China, Energy Policy, 58, 220-227.

Parks N., 2009, UN update: climate change hitting sooner and stronger, Environmental Science & Technology, 43, 8475–8476.

TGO (Thailand Greenhouse Gas Management Organization))Public Organization(, 2015, Guidelines for assessing the carbon footprint of city, Thailand Greenhouse Gas Management Organization, Thailand.

Ramachandra T.V., Aithal B.H., Sreejith K., 2015, GHG footprint of major cities in India, Renewable and Sustainable Energy Reviews, 44, 473-495.

Wang T.W., Ho C.S., 2017, Carbon and Energy Use Reporting for Buildings in Putrajaya: Implementation Status and Drive Factors, Chemical Engineering Transactions, 56, 415-420.

Xi F., Geng Y., Chen X., Zhang Y., Wang X., Xue B., Dong H., Liu Z., Ren W., Fujita T., Zhu, Q., 2011, Contributing to local policy making on GHG emission reduction through inventorying and attribution: A case study of Shenyang, China, Energy Policy, 39, 5999-6010.