City-wide greenhouse gas mitigation options to support global climate goals:
Case studies of Bangkok, Chiang Mai, and Rayong, Thailand

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A Dissertation Submitted in Partial Fulfillment of the Requirements
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ศักยภาพการลดก๊าซเรือนกระจกระดับเมืองของประเทศไทยเพื่อสนับสนุนเป้าหมายการ
เปลี่ยนแปลงสภาพภูมิอากาศระดับโลก:
กรณีศึกษากรุงเทพมหานคร จังหวัดเชียงใหม่ และจังหวัดระยอง

นายสิทธิศักดิ์ สุขใสสาคร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาศิลปศาสตรดุษฎีบัณฑิต
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สิทธิศักดิ์ สุขใสสาคร : ศักยภาพการลดก๊าซเรือนกระจกระดับเมืองของประเทศไทยเพื่อสนับสนุนเป้าหมายการเปลี่ยนแปลงสภาพภูมิอากาศระดับโลก: กรณีศึกษากรุงเทพมหานคร จังหวัดเชียงใหม่ และจังหวัดระยอง. (City-wide greenhouse gas mitigation options to support global climate goals: Case studies of Bangkok, Chiang Mai, and Rayong, Thailand) อ.ที่ปรึกษาหลัก : ผศ. ดร.สุทธิรัตน์ กิตติพงษ์วิเศษ

ปัจจุบันภาคส่วนเมืองมีความสำคัญต่อการบรรลุเป้าหมายการควบคุมอุณหภูมิของโลกไม่เกิน 1.5 องศาเซลเซียส ภายในปี พ.ศ. 2643 งานวิจัยนี้ได้ทำการประเมินการปล่อยก๊าซเรือนกระจกและแนวทางในการจัดทำแผนการลดการปล่อยก๊าซเรือนกระจกในกรณีศึกษาของประเทศไทย ได้แก่ กรุงเทพมหานคร เชียงใหม่ และระยอง อาศัยแนวทางที่ระบุในแผนที่นำทางการลดก๊าซเรือนกระจกของประเทศและเป้าหมายในการควบคุมอุณหภูมิของโลกไม่เกิน 1.5 องศาเซลเซียส ผลการวิจัยพบว่าภาคพลังงานมีสัดส่วนปล่อยก๊าซเรือนกระจกมากที่สุดทั้ง 3 จังหวัด ขณะที่ ภาคขนส่งปล่อยก๊าซเรือนกระจกมากที่สุดเป็นอันดับที่ 2 ในกรุงเทพมหานครและจังหวัดเชียงใหม่ และ ภาคอุตสาหกรรมการผลิตมีสัดส่วนสูงเป็นอันดับ 2 ในจังหวัดระยอง ทั้งนี้ กรุงเทพมหานครปล่อยก๊าซเรือนกระจกประมาณ 41.25 ล้านตันคาร์บอนไดออกไซด์เทียบเท่า ในปี พ.ศ. 2558 และคาดการณ์เพิ่มขึ้นถึง 112.53 ล้านตันคาร์บอนไดออกไซด์เทียบเท่า ในปี พ.ศ. 2593 ภายใต้การดำเนินการปกติ ผลการศึกษาเสนอเป้าการลดการปล่อยก๊าซเรือนกระจกของกรุงเทพมหานครที่ร้อยละ94.98 ในปี พ.ศ. 2593 เพื่อให้สอดคล้องกับเป้าหมายในการควบคุมอุณหภูมิโลกที่ 1.5 องศาเซลเซียส โดยศักยภาพการลดการปล่อยก๊าซเรือนกระจกส่วนใหญ่ได้แก่ ภาคพลังงาน ภาคขนส่ง และการจัดการของเสีย อย่างไรก็ตามข้อจำกัดด้านงบประมาณและบทบาทหน้าที่ของหน่วยงานภายในกรุงเทพมหานครอาจเป็นอุปสรรคในการดำเนินงานลดการปล่อยก๊าซเรือนกระจก ขณะเดียวกันจังหวัดเชียงใหม่ปล่อยก๊าซเรือนกระจกทั้งสิ้น 6.83 ล้านตันคาร์บอนไดออกไซด์เทียบเท่า ในปี พ.ศ. 2558 และคาดว่าจะเพิ่มขึ้นเป็น 12.47 ล้านตันคาร์บอนไดออกไซด์เทียบเท่าในปี พ.ศ. 2593 เพื่อให้สอดคล้องกับเป้าหมายการควบคุมอุณหภูมิของโลกไม่เกิน 1.5 องศาเซลเซียส จังหวัดเชียงใหม่ควรตั้งเป้าหมายลดก๊าซเรือนกระจกลงร้อยละ 91.38 ในปี พ.ศ. 2593 ซึ่งภาคส่วนที่มีศักยภาพการลดก๊าซเรือนกระจก ได้แก่ ภาคพลังงาน ภาคการขนส่ง และภาคการเกษตร ทั้งนี้ การจัดสรรงบประมาณ ความร่วมมือระหว่างหน่วยงานระดับท้องถิ่นและข้อจำกัดด้านองค์ความรู้เชิงเทคนิคนับเป็นข้อจำกัดในการดำเนินโครงการลดก๊าซเรือนกระจก ขณะที่ จังหวัดระยองปล่อยก๊าซเรือนกระจก 21.25 ล้านตันคาร์บอนไดออกไซด์เทียบเท่าในปี พ.ศ. 2558 และคาดการณ์เพิ่มสูงขึ้น 36.02 ล้านตันคาร์บอนไดออกไซด์เทียบเท่า ในกรณีการดำเนินงานปกติ โดยจังหวัดระยองควรตั้งเป้าหมายเพื่อจำกัดการปล่อยก๊าซเรือนกระจกที่ระดับ 0.90 ล้านตันคาร์บอนไดออกไซด์เทียบเท่า ในปี พ.ศ. 2593 เพื่อบรรลุเป้าหมายการควบคุมอุณหภูมิโลกที่ 1.5 องศาเซลเซียส โดยเฉพาะภาคส่วนที่มีศักยภาพสูงในการลดก๊าซเรือนกระจกได้แก่ ภาคพลังงาน ภาคอุตสาหกรรมการผลิต และภาคขนส่ง ทั้งนี้ ภาคอุตสาหกรรมการผลิตต้องอาศัยเทคโนโลยีระดับสูงและความร่วมมือจากภาคเอกชนภายในจังหวัดในการมีส่วนร่วมจัดทำแผนการลดก๊าซเรือนกระจกระยะยาวในภาพรวม งานวิจัยนี้เสนอแนะให้รัฐบาลพิจารณาประเด็นสนับสนุนงบประมาณด้านการบรรเทาปัญหาสภาพภูมิอากาศและเสริมสร้างศักยภาพและความรู้แก่หน่วยงานระดับเมืองโดยเฉพาะการจัดเตรียมระบบการวัดผล รายงาน อย่างเป็นระบบและมาตรฐานเพื่อนำไปสู่การขับเคลื่อนสังคมคาร์บอนต่ำต่อไป

สาขาวิชา	สิ่งแวดล้อม การพัฒนา และความยั่งยืน	ลายมือชื่อนิสิต ....
ปีการศึกษา	2563	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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Sittisak Sugsaisakon : City-wide greenhouse gas mitigation options to support global climate goals: Case studies of Bangkok, Chiang Mai, and Rayong, Thailand. Advisor: Asst. Prof. SUTHIRAT KITTIPONGVISES, Ph.D.

The action of city on climate mitigation becomes a crucial role. The aims of this study were to quantify greenhouse gases (GHGs) emission, identify feasibility of mitigation options in selected provinces, and to evaluate the performance of local capacity to support Thailand's Nationally Determined Contributed (NDC) and 1.5°C limit pathway. Three provinces, including Bangkok, Chiang Mai and Rayong of Thailand were selected as case studies. The results revealed that stationary energy was the greatest contribution to the city's GHGs emissions in all case studies. Transportation was the second largest emitter in Bangkok and Chiang Mai, whereas IPPU was the second major GHG source in Rayong. Bangkok's GHGs emissions were 41.25 million tones carbon dioxide equivalent ($MtCO_2eq$) in 2015 and was projected to increase to 112.53 $MtCO_2eq$ in 2050 as in business-as-usual (BAU). To align with 1.5°C global pathway, Bangkok should set limits on their GHGs reduction for 94.98% compared to BAU in 2050. Stationary energy, transportation, and waste are high-potential sectors for mitigating GHGs emissions. Lack of financial supports and clarity regarding local government's mandate and authority are limitations of climate policies implementation. In Chiang Mai, total GHGs emissions were 6.83 $MtCO_2eq$. in 2015 and projected to 12.47 $MtCO_2eq$ in 2050. Chiang Mai need to consider limiting GHGs emissions for 91.38% from BAU in 2050 to fit with the global target, especially the implementation in stationary energy, transportation and AFOLU sectors. Collaborative governance at the local level is a key success factor in driving climate change mitigation. Further, Rayong should limit their GHGs emissions in 2050 at 0.90 $MtCO_2eq$ to achieve 97.50% of emissions reductions to achieve the 1.5°C global pathway. Rayong was projected to increase GHGs emissions from 21.25 $MtCO_2eq$ in 2015 to 36.02 $MtCO_2eq$ in 2050. Stationary energy, IPPU and transportation are high-potential sectors for lowering GHGs. IPPU sector could be challenge for driving climate mitigation policies in Rayong due to advanced technologies and long-term collaboration with private sector is required. Overall, this research suggests that national government has to provide technical and financial support, especially climate mitigation fund, monitoring, reporting and verification system. National climate mitigation policies should be more also holistic integrated and aligned with the roadmap of local policies in the long run.

Field of Study:	Environment, Development and Sustainability	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....

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INTRODUCTION

1.1 Background

Climate change is one of the most serious environmental tasks to face humanity and continues to be a crucial challenge to the global community. The United Nations Framework Convention on Climate Change (UNFCCC) defines the term climate change as "A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in additional to natural climate variability observed over comparable time periods" (UN, 1992). The United States Environment Protection Agency (USEPA) also described climate change as "any significant changes in the measures of climate lasting for an extended period of time" (US EPA, 2017). Climate change therefore includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer. The following explanation of climate change is given by Intergovernmental Panel on Climate Change (IPCC):

> "*Warming of the climate system is unequivocal, as is now evident from observation of increase in global average air and ocean temperature, widespread melting of snow and ice and rising global average sea level*" (IPCC, 2007).

Over the past century, the global average temperature has risen by 1.0^{o}C from 1880 until 2020. Scientists are projecting another 0.5^{o}C rise by 2037 and 2.0^{o}C by 2063, as demonstrated in **Figure 1**.

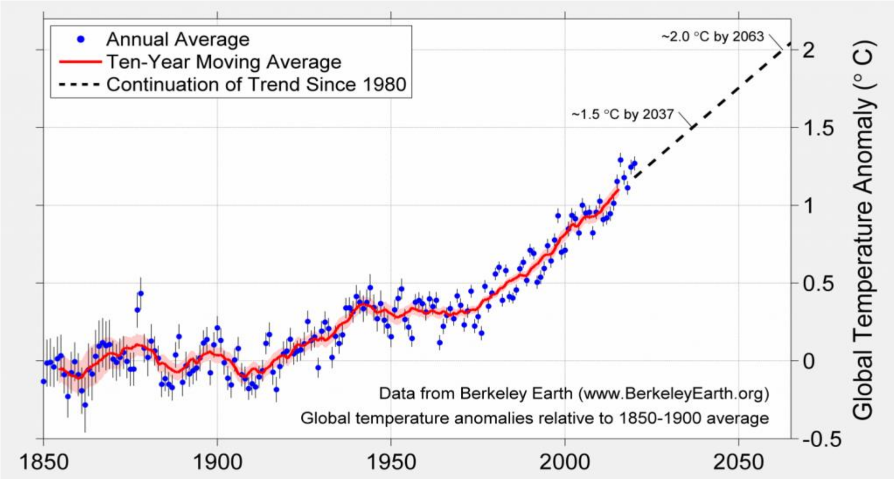


***Figure 1** Global average temperature and its projection (Berkeley, 2021)*

Scientific evidence currently concludes that climate change happens because of the increase of greenhouse gases (GHGs) in the global atmosphere. The key sources come from human actions which release large amounts of greenhouse gas including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases into the atmosphere. Most anthropogenic greenhouse gases emissions come from burning fossil fuels to produce energy and facilitate transportation. The US National Aeronautics and Space Administration's (NASA) study shows the increased concentration of carbon dioxide has been accompanied by an increase in global mean temperatures, shown in **Figure 2** (US NASA, 2010).

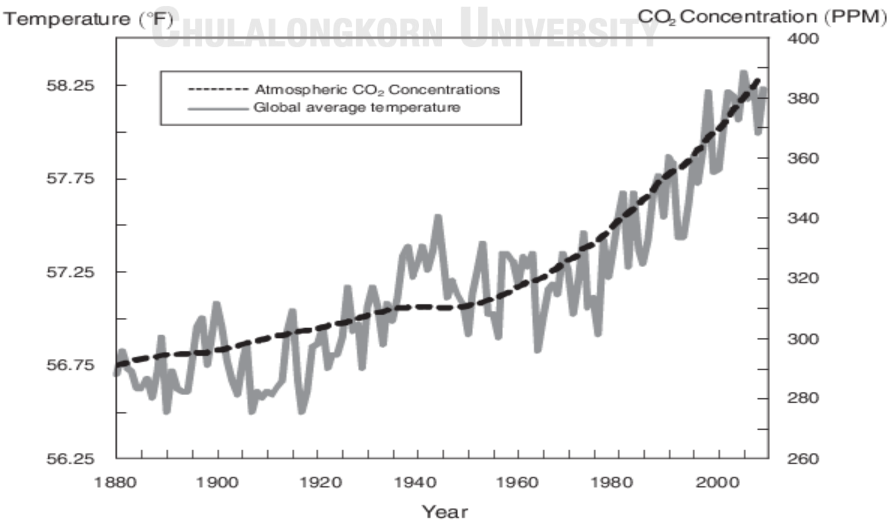


***Figure 2** Global Temperature and Carbon dioxide concentration, 1880-2010 (US NASA, 2010)*

1.2 Problem Statement

Scientific evidence continues to intensify those human activities have begun to change global climate. Besides this, the continuation of world population and urbanization growth presents serious challenges in combating climate problem. Cities are places where large numbers of people live and work; they are hubs of government, commerce, and transportation. It was projected 54.5 percent of the world's population lived in urban area (UN-Habitat, 2020). In the context of climate change, cities are major sources of greenhouse gas emissions as per their energy consumption, contamination of air and water and destruction of forests and ecosystem. However, it has a lot of opportunity to tackle climate change. This inspires the researcher to study on the title of "City-wide greenhouse gases mitigations to support global climate goals: case studies of Bangkok, Chiang Mai and Rayong, Thailand". In this research, there are divided into three dimensions. The first is technical perspective which provide the city greenhouse gas emission target aligns with national and global greenhouse gas emissions target. The second is social perspective. This is to understand the local interest and capacity on implementation of climate mitigation options supporting the National Determine Contribution (NDC). The third is economic perspective. This helped to identify the policy instruments relevant to cost effectiveness. On another word, local authorities exercise a degree of influence directly over on ability of national greenhouse gas emission to achieve internationally agreement target. In short, urban areas have many linkages with global climate change. They are sources of initiative policies, strategies and actions aimed at lowering carbon emissions. To tackle climate change, cities are now very important sector for driving greenhouse gas mitigation actions as means of securing global sustainable development. The 2015 Sustainable Development Goals (SDGs) are closely linked to a radical change toward a pro-urban policy consensus in sustainable development.

Over the same period, the Paris Agreement for Climate Action adopted in December 2015 at the 21st session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) global long-term goals for reducing greenhouse gas (GHG) emissions. The agreement is to strengthen the international response to the threat of climate change to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels. (UNFCCC, 2015). Thailand intends to reduce its GHG emissions by about 20% from the projected business-as-usual (BAU) level by 2030 (ONEP, 2015). As concerns the mitigation of greenhouse gas emissions are considered, there is a lack of reference data of greenhouse gas inventory and projection in sub-national level and how provincial strategies could potentially contribute to global climate goals. The author found there is no long-term climate mitigation strategy established in sub-national level to sustain global climate goals.

1.3 Research questions

RQ1: What are the current data and its trends of greenhouse gas emission for selected provinces?

RQ2: What are the potential options for lowering greenhouse gas emission in the selected provinces?

RQ3: How can selected provinces, as sub-national level representatives, support Thailand’s NDC to achieve the country's commitment to the Paris Agreement and 1.5oC limit pathway?

1.4 Research objectives

RO1: To explore the greenhouse gas emission and its trends of selected provinces.

RO2: To identify the feasibility of greenhouse gas mitigation options in selected provinces as representative of sub-national level.

RO3: To access perception of local authority toward climate change mitigation plan at city level.

1.5 Scope of study

This study focused on evaluating the greenhouse gas emissions in 2015, and projecting to 2050 in three provinces in Thailand, including Bangkok, Chiang Mai and Rayong. Bangkok city is also the economic center of Thailand, and the heart of the country's investment and development. In 2015, Bangkok had the second largest Gross Provincial Produce (GPP) per capita of the country next to Rayong province. The population of Bangkok was 8.6 million in 2015 and it was projected to be above 12 million by 2030 (UN-Habitat, 2020). Bangkok will be one of the world's megacities in 2030.

Rayong was also selected as a case study in the research because it generates the highest income per capita in Thailand. It can be representative of an industrial-base city. Rayong's economy mostly depends on three major sectors including mining and quarrying, industry, and retailing and wholesaling. Most of the country's petrochemical suppliers now carry out production in the Map Ta Phut Industrial Estate. Over the past 20 years, Rayong has experienced significant industrial development; however, most local residents are engaged in agriculture. Rayong is also known as a major source of tropical fruit in Thailand.

Chiang Mai was selected to represent the province of residential, agriculture and tourism-based economy. It is the largest province outside Bangkok. It is an economic, education and tourism center of Northern Thailand. Its GPP accounts for approximately 20% of the total GPP of the Northern region. Chiang Mai is currently a primary city in the North, where all economic activities are concentrated. The city has expanded rapidly with new development areas. The city is a Mekong regional hub for transportation, aviation, education, and medical services. The city is an important travel destination and hosts millions of tourists every year.

Figure 3 *Selected provinces in the research*

The greenhouse gas inventory and projection were introduced by adopting the Global Protocol for Community-Scale Greenhouse Gas Emissions (GPC) standard. The GPC is an international standard which allows selecting the city for more credible and meaningful reporting, and greater consistency in greenhouse gas accounting. It is also a clear framework that builds on existing methodologies for calculating and reporting city-wide greenhouse gas emissions.

According to GPC standard, city is suggested to firstly identify the boundary of inventory. This identified could be geographic area, time span, gases, and emission sources, covered by a greenhouse gas inventory. The emission sources were considered in this research including i) Stationary energy, ii) Transportation, iii) Waste, iv) Industrial processes and product use (IPPU), v) Agriculture, Forest, and other Land use (AFOLU). The study has grouped greenhouse gases into three categories based on where they occur: scope 1, scope 2 and scope 3 emissions, which are defined in **Table 1**. However, this study concentrated on scope 1 and scope 2 to simplify the effective mitigation actions for the local context. For the greenhouse gas accounting period in the study, 2015 was set up as the base year and the target year is considered to be 2050, aligned with the Paris Agreement 1.5^{o}C limit target year.

Table 1 *Scopes definitions for city inventories (GPC, 2017)*

Scope	**Definition**
Scope 1	GHG emissions from sources located within the city boundary.
Scope 2	GHG emissions happening as a consequence of the use of grid-supplied electricity.
Scope 3	All other GHG emissions that occur outside the city boundary

In the greenhouse gas emission projections these three provinces, the study provided the following three scenarios for evaluating greenhouse gas mitigation options: i) Business-as -usual (BAU) which assume the normal growth of the economy, ii) NDC scenario which apply the applicable mitigation measures in Thailand's existing NDC roadmap and iii) 1.5^{o}C pathway which aligns with global carbon budget in 2050. Social and economic perspectives for several mitigation options were considered to complete analysis of the applicability based on local interest. The outcome of this research was to provide long-term greenhouse gas emission target and the provincial climate mitigation strategy for actions.

1.6 Contribution to the sustainability discipline

The 17 United Nations Sustainable Development Goals (SDGs) aim to reach the needs of human living with no conceding the requirements for future generation. Some experts believe that climate change affects the ability to achieve SDGs, so "Climate Action" has become one of the global goals. The link between controlling global warming to 1.5^{o}C is established by the SDG for "Climate Action (SDG 13)". IPCC described that "limiting global warming to 1.5^{o}C above pre-industrial levels would make it markedly easier to achieve many aspects of sustainable development, with greater potential to eradicate poverty and reduce inequalities" (IPCC, 2020). The comparison of 1.5ºC and 2ºC shows in IPCC's study that 1.5ºC limit scenario would also make it easier to achieve the goals particularly those related to poverty, hunger, health, water and sanitation, cities, and ecosystem (SDG 1, 2, 8, 11, 14 and 15).

Figure 4 *SDGs related to "Climate Action – SDG13"*

CHAPTER II
LITERATURE REVIEWS

This chapter gives the better understanding of background and previous studies associated to the title of this research. Describing of the global climate change mitigation situation and its greenhouse gas emissions are provided as well as Thailand. In this chapter, it additionally provides the climate mitigation policies for Thailand according to their NDC target, proposed in Thailand's NDC roadmap. At the end of this chapter, the earlier studies in the area of climate change in cities are offered.

2.1 World's greenhouse gas emission

The Netherlands Environmental Assessment Agency in 2019 presented the recent trends in global greenhouse gas emissions up to 2018, for both carbon dioxide and non-carbon dioxide greenhouse gas emissions. This study found CO_2 made up 72% of total global greenhouse gas emissions while a respective 19% and 6% were from CH_4 and N_2O (Olivier, 2020). The main drivers of CO_2 emission were coal combustion, and oil and natural gas consumption which represented 89% of global CO_2 emission while calcination in cement clinker production accounted for 4%. The CO_2 emissions related fossil fuel can be considerably reduced by shifting to low carbon energy system such as hydropower, biomass, solar and wind. The carbon storage technology could provide a reducing of increasing CO_2 concentration in the atmosphere. In the global perspective, the report confirmed that agriculture, including livestock, and rice production, is the main global CH_4 source. The second largest source of CH_4 emission is from coal mining production, natural gas production and transmission as well as oil production. The third largest source is waste where produces methane. Agriculture activities are also the main source of N_2O emissions. The animal droppings on pastures, rangeland and paddocks are the largest global source of N_2O and the use of synthetic nitrogen fertilizer is the second largest source **(Table 2).** F-gas emissions accounted for around 3% of total global greenhouse gas emissions.

Table 2 *Global share of greenhouse gas emission (excluding land use and land-use change)*

Type of gas	Share gas in GHG	Main source drivers	Share in GHG gas total	Year of statistics
CO_2	72%	Coal combustion	39%	2019
		Oil combustion	31%	2019
		Natural gas combustion	18%	2019
		Cement clinker production	4%	2018
		Subtotal sources of CO_2	**92%**	
CH_4	19%	Cattle	21%	2018
		Rice production	10%	2018/19
		Natural gas production	14%	2019
		Oil production	9%	2019
		Coal mining	10%	2019
		Landfill:	10%	2018
		Wastewater	11%	2018
		Subtotal sources of CH_4	**85%**	
N_2O	6%	Cattle	23%	2018
		Synthetic fertilizers	13%	2017
		Animal manure	5%	2018
		Crops	11%	2017/18
		Fossil fuel combustion	11%	2019
		Manure management	4%	2018
		Indirect: atmospheric deposition & leaching and run-off (NH_3)	9%	2017/18
		Indirect: atmospheric deposition (NOx from fuel combustion)	7%	2017/18
		Subtotal sources of N2O	**83%**	
F-gases	3%	HFC use	61%	2018
		HFC-23 from HCFC-22 production	22%	2018
		SF_6 use	14%	2018
		PFC use and by-product	3%	2018
		Subtotal sources of F-gases	**100%**	

Source*: PBL Netherlands Environmental Assessment Agency, 2020*

As presented in **Figure 5**, the five largest emitters of greenhouse gases including China, the United States, the European Union, India, the Russian Federation, and Japan, together accounted for 62% of global greenhouse gas emission in 2019. The group of ~~(G20)~~ accounted for 77% of 2019 global greenhouse gas emissions.

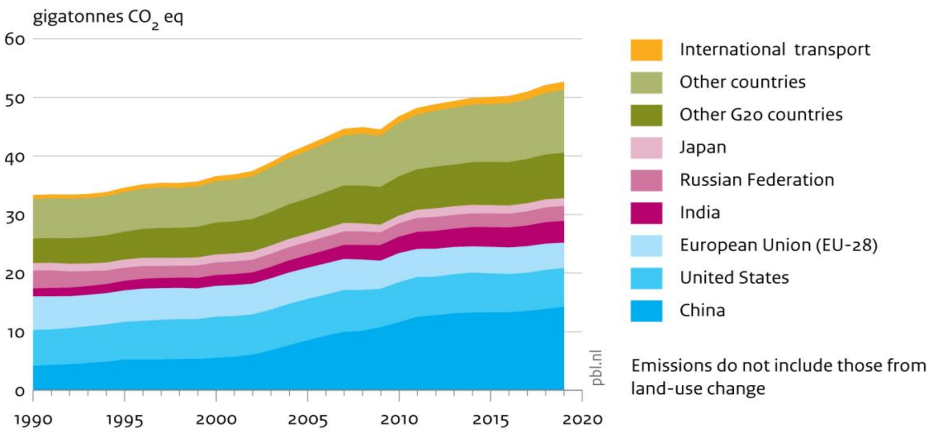


Figure 5 *Global greenhouse gas emissions, per country and region (EDGAR, 2019)*

In 2019, the growth in total global greenhouse gas emission, excluding those from land use and land-use change, continued at a rate of 1.1%, reaching 52.4 $GtCO_2eq$. China were an increase of 3% to around 420 $MtCO_2eq$, followed by Indonesia and Vietnam increasing a respective 5.5% and 12.8% as well as India at 1.4%. The global increase was partly offset by countries that decreased their greenhouse gas emission, in particular the EU which decreased by 3%, the United States by 1.7% and Japan and South Korea. Moreover, Figure 4 shows greenhouse gas emission per capita for the five main countries producing greenhouse gas and the European Union from 1990 to 2019 including the rest of the world. Since 2005, all five main emitters have per capita emission levels significantly higher than global average, except for India. China ranks fourth in per capita but it in the first place in absolute among of greenhouse gas emission in the same period.

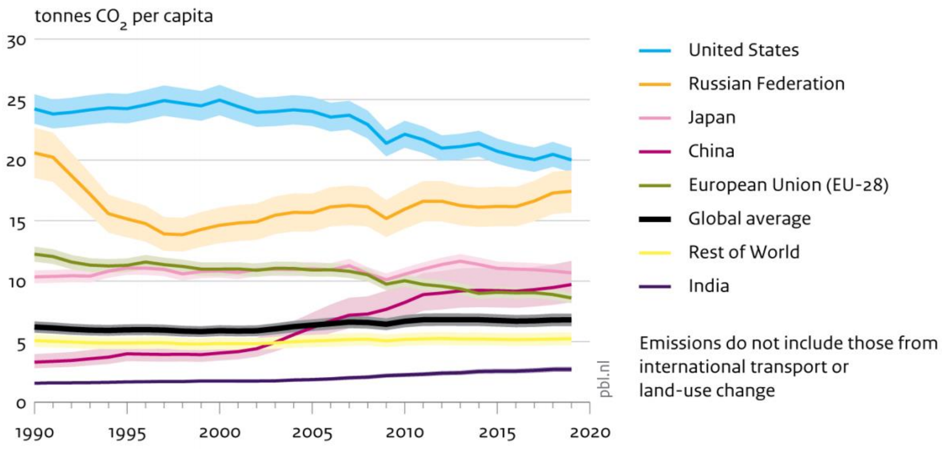


***Figure 6** Greenhouse gas emissions, per capita, per country and region (UNDP, 2019)*

April 2021, the US President Joe Biden invited 40 state leaders around the world to contribute to a climate change summit, expressing their commitment to addressing the climate crisis. One goal of the summit was to encourage attendees to commit to more ambitious cuts to greenhouse gas emissions in their NDCs, to bridge the gap between projected temperature rise under previous commitments and the Paris Agreement goal of limiting global temperature rise to 1.5°C. At the summit US announced new 2030 NDC targets of 50-52% below their 2005 greenhouse gas emission level. However, to meet Paris Agreement goal of 1.5°C, experts would like to see a target of 57-63% from the US. Japan also announced a new target, at 46% below their greenhouse gas emission level in 2013 but more than 60% is needed from Japan to be compatible with a 1.5°C pathway. Canada announced a new target range of 40-45% below their 2005 levels by 2030. Before the climate change summit, China had announced their goal of net-zero emission by 2060.

As presidency of 26th UN Conference of Parties (COP26) in 2021, the UK announced a new ambitious target of 68% reduction below their 1990 greenhouse gas emission level by 2030. This will also align with the UK's 2050 net zero greenhouse gas emission target. Meanwhile, a number of countries, including India, Indonesia, Mexico, Russia, Saudi Arabia and Turkey as well as Thailand have not announced ambitious NDCs. In the Climate Action Tracker report (Climate Action Tracker, 2021), fewer than 60% of the countries that have ratified the Paris Agreement have submitted a new target.

Table 3 *Countries which have submitted an update NDC and analysis against ambitious target (since April 2021)*

SUBMITTED A UPDATED NDCs				
ANDORRA	COLOMBIA	JAPAN	NORTH KOREA	SWITZERLAND
ARGENTINA	COSTA RICA	KENYA	NORTH MACEDONA	THAILAND
ARMENIA	CUBA	LAO	NORWAY	TONGA
AUSTRALIA	DOMINICAN REPUBLIC	LEBANON	PANAMA	UAE
BANGLADESH	ETHIOPIA	MALDIVES	PAPUA NEW GUINEA	UNITED KINGDOM
BRAZIL	EU	MARSHALL ISLANDS	PERU	UKRAINE
BOSNIA AND HERZEGOVINA	FIJI	MEXICO	RUSSIAN	USA
BRUNEI DARUSSALAM	GEORGIA	MOLDOVA	RWANDA	VANUATU
CABO VERDE	GRENADA	MONACO	SAINT LUCIA	VIETNAM
CAMBODIA	HONDURAS	MONGOLIA	SENEGAL	ZAMBIA
CANADA	ICELAND	NEPAL	SINGAPORE	
CHILE	INDONESIA	NEW ZEALAND	SOUTH AFRICA	
CHINA	JAMAICA	NICARAGUA	SOUTH KOREA	

SUBMITTED AN AMBITIOUS NDC TARGET		PROPOSED AN AMBITIOUS NDC TARGET		DID NOT INCRASE AMBTION*		DID NOT INCREASE AMBTION	
ARGENTINA	NEPAL	CANADA	SOUTH AFRICA	AUSTRALIA	SINGAPORE	INDONESIA	THAILAND
CHILE	NORWAY	CHINA	UKRAINE	BRAZIL	SOUTH KOREA		
COLOMBIA	PERU	JAPAN		MEXICO	SWITZERLAND		
COSTA RICA	UAE			NEW ZELAND	VIET NAM		
ETHIOPIA	UNITED KINGDOM			RUSSIAN			
EU	USA						

** Submitted the same numerical target; but, changes to their baseline assumptions.*
***Source**: Climate Action Tracker, 2020*

2.2 Thailand’s greenhouse gas emission

Geographically, Thailand is in a tropical area and subdivided into 76 provinces with a total area of approximately 513,120 km. Bangkok is the capital city and the center of the national economy. Local authorities consist of provincial administrative organization, district organization, sub-district organization and sub-district administrative organization. Due to rapid economic and population growth, the national greenhouse gas emissions have been increasing year by year according to world data. Thailand is ranked 27th for its share of global carbon dioxide emission in 2019 (CCPI, 2020). Its performance is mostly based on its energy consumption. **Figure 7** shows the historical data of Thailand’s carbon dioxide emission from 1931 to 2019. The carbon dioxide emission had been dramatically increasing from 1988 to 2012 but the emission slightly increased from 2012 to 2019 which would be a result of increasing renewable energy.

In the Thailand 3rd Biennial Update Report (UNFCCC, 2020), the report shows the largest share in 2016 was emission from the energy sector **(Figure 8**). Energy sector reported for 71% of total emissions, subsequently agriculture, industrial process and produce use (IPPU) and waste for 15%, 9%, and 5% respectively. The report found that in 2016 carbon dioxide emission made up around 79% of total country greenhouse gas emission while a respective 17% and 4% were contributed from methane and nitrous oxide. The main sources of carbon dioxide emissions in 2016 were contributed from energy sector while methane and nitrous oxide emissions were from agriculture sector.

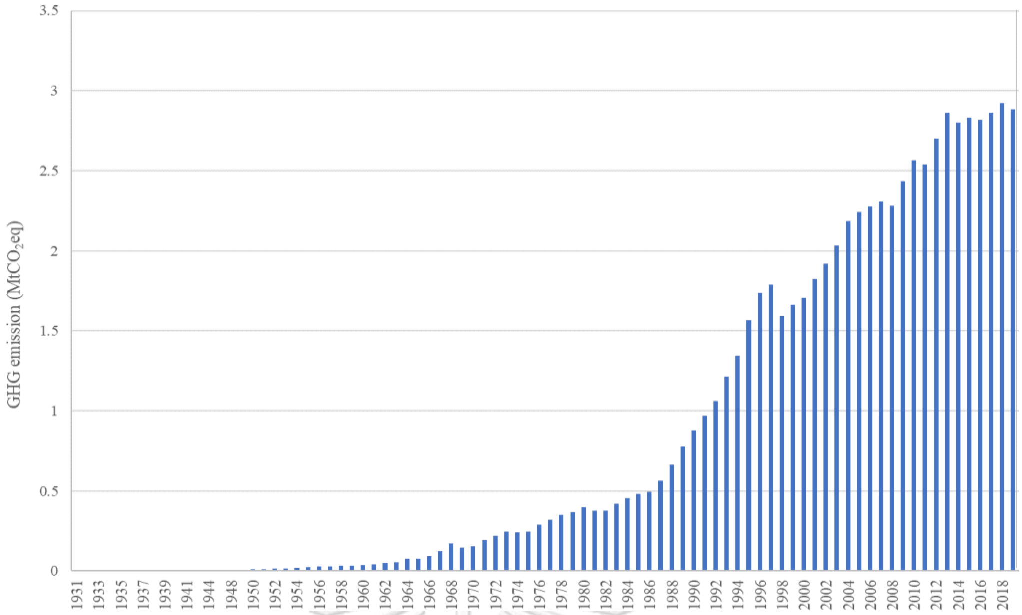


Figure 7 *Thailand's greenhouse gas emission historical data to 2019, (Our World Data,2020)*

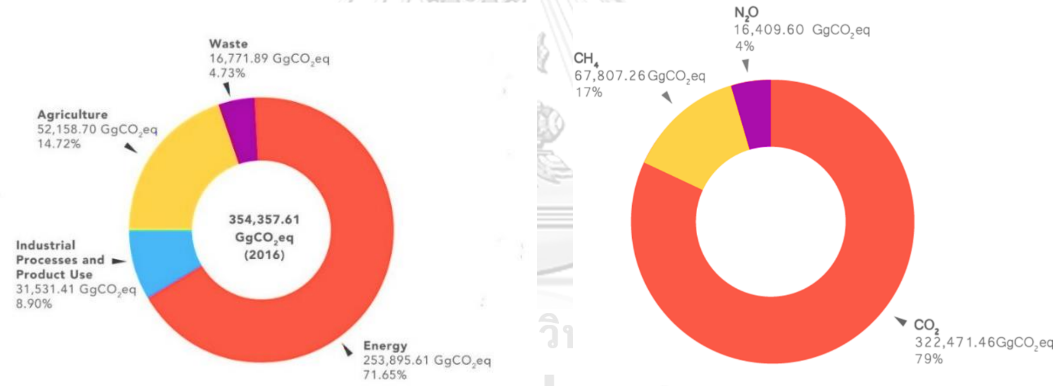


Figure 8 *Greenhouse gas emissions in 2016 by sector and gases ($GgCO_2e$), Thailand. (UNFCCC, 2020)*

2.2.1 Energy sector

In 2016 greenhouse gas emission came from the energy sector and was estimated to be 253,895.61 $GgCO_2eq$. The major source in this sector was the energy industries sub-sector which was calculated to have generated around 42.84% of total emissions in the energy sector in 2016, followed by the transport sub-sector at 27.21%. The energy consumption in the manufacturing industries and construction were ranked in the third share of total greenhouse gas emission in energy sector at 19.53% see in **Figure 9.**

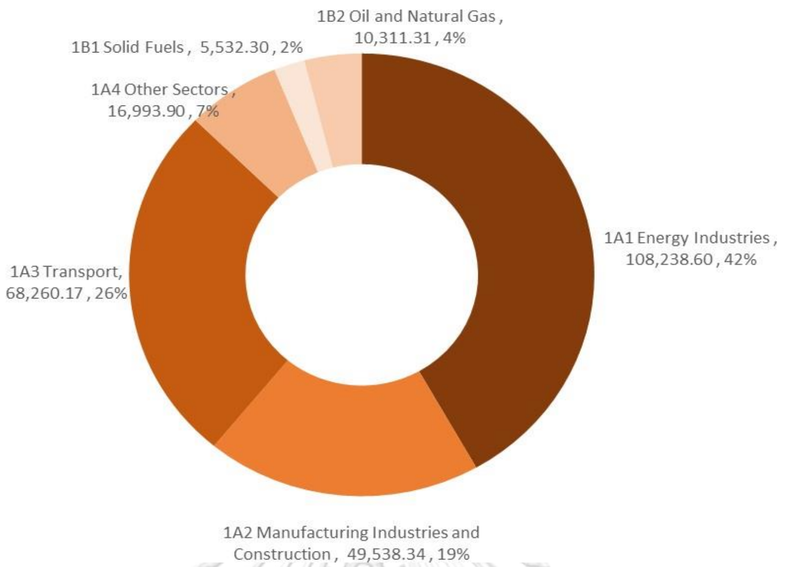


Figure 9 *Greenhouse gas emission in energy sector, 2016 (UNFCCC, 2020)*

2.2.2 Industrial processes and product use (IPPU) sector

In 2016, the total greenhouse gas emissions from the IPPU sector were estimated to be 31,531.41 GgCO_2eq. The most greenhouse gas emission in this sector came from the mineral industry sub-sector which accounted for around 60 % of total emission in IPPU. The second largest share was the chemical industry which shared at 38% of greenhouse gas emission in this sector, with the rest from non-energy products and metal production, as seen in **Figure 10.**

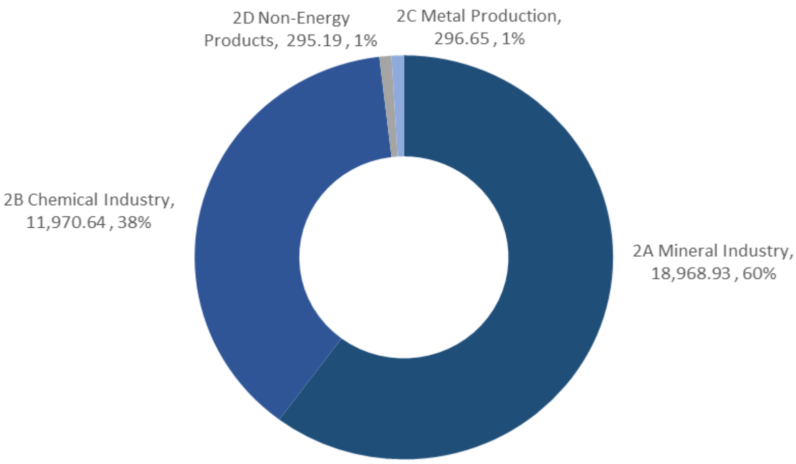


Figure 10 *Greenhouse gas emissions in IPPU sector, 2016 (UNFCCC, 2020)*

2.2.3 Agriculture sector

Total greenhouse gas emission in the agriculture sector in 2016 was estimated at around 52,158.70 GgCO_2eq. The rice cultivation sub- sector contributed the biggest share of greenhouse gas emission in 2016 at 53% of total greenhouse gas emission in this sector. Followed by the enteric fermentation and direct N_2O emission from managed soils at 17% each. The rest was from indirect N_2O emission from managed soils, manure management, field burning of agricultural residues and indirect N_2O emission from manure management at 6%, 4%, 2% and 1% respectively **(Figure 11).**

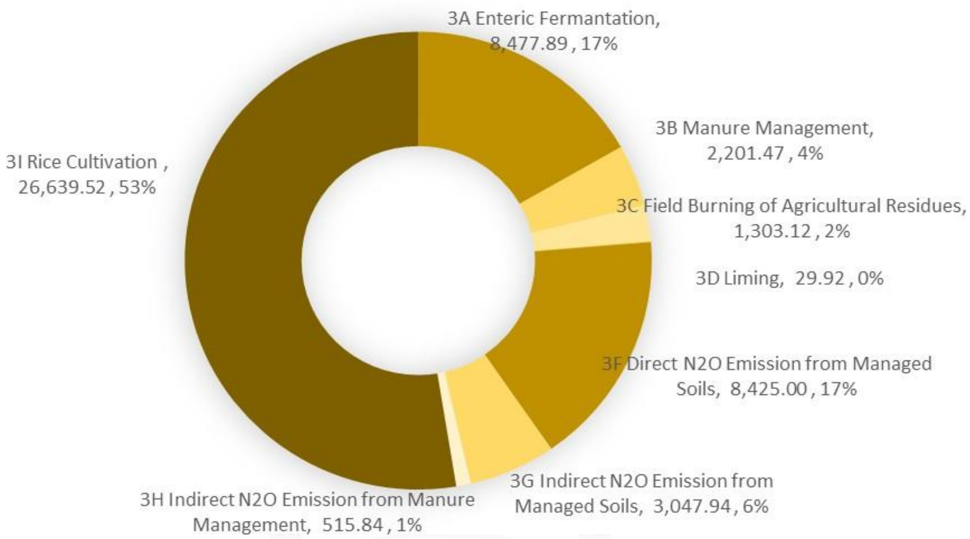


Figure 11 *Greenhouse gas emission in Agriculture sector, 2016, (UNFCCC, 2020)*

2.2.4 Waste sector

Total emissions in the waste sector in 2016 were estimated at 16,771.86 GgCO_2eq. The solid waste disposal and wastewater treatment and discharge were two main activities, representing 50% and 49% of total greenhouse gas emissions respectively. Waste incineration and open burning made up only 1% and the rest was shared by biological treatment of solid waste, as seen in **Figure 12**.

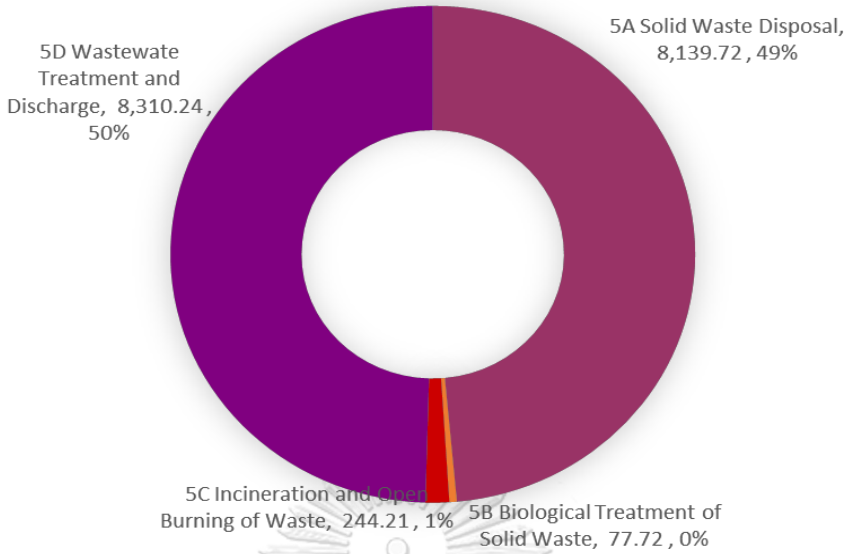


Figure 12 *Greenhouse gas emissions in Waste sector, 2016, (UNFCCC, 2020)*

2.3 Thailand's climate mitigation policies and measures

As per the Paris Agreement or 21st session of the Conference of the Parties (COP21) to UNFCCC, Thailand has updated and submitted the Nationally Determined Contributed (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in October 2020 with the target at 20% reduction from business-as-usual (BAU) by 2030. Some experts believe that Thailand could do better by proposing a more ambitious target. To achieve the target of 20%, Thailand plans to implement mitigation measures according to its NDC Roadmap on Mitigation 2021- 2030 and the NDC Action Plan. For a long-term strategy to net zero emission, Thailand is in the process of formulating. Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS) which will guide Thailand toward alignment with the global 1.5°C limit. Since 2007, Climate change topic has been integrated into the National Economic and Social Development Plan and currently addressed high priority policy to ensure continuity alongside other economic and social considerations. Thailand has also introduced the NDC Action Plan 2021-2030, summarized in **Table 4** to ensure that implementations and actions will be carried out continuously nationwide.

As the target setting in NDC, Thailand intents to reduce greenhouse gas emission by 20% below ~~(~~BAU~~)~~ level or by approximately 111 $MtCO_2eq$ by 2030. The Ministry of Natural Resources and Environment of Thailand estimated the greenhouse gas reduction potential to reduce around 115.6 $MtCO_2eq$ in 2030 **(see Figure 13),** which accounted for a 20.8% reduction by 2030 compared to the BAU. It is a bit higher than the target. The sectors targeted for emissions reductions are industry, power generation, transport, commercial buildings, households, solid waste, wastewater, and IPPU. The reduction potential in each sector is presented in **Figure 14.**

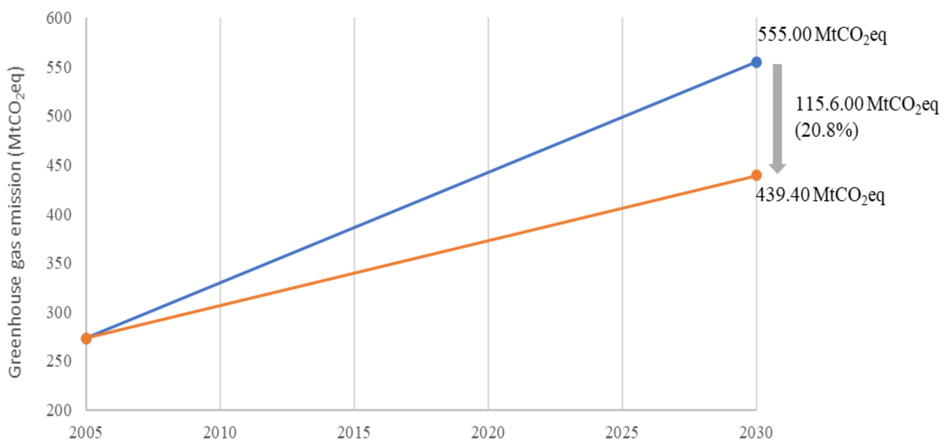


Figure 13 *Thailand's greenhouse gas reduction potential (ONEP, 2018).*

The sector with the highest greenhouse gas reduction potential is expected to be the industrial sector at 43 $MtCO_2eq$, followed by the transport sector at 41 $MtCO_2eq$ including modal shift, biofuel, and energy efficiency in transport **(see detail in Figure 14).** Other potential comes from power generation (24 $MtCO_2eq$), Commercial building (11 $MtCO_2e$), Household (4 $MtCO_2eq$), Municipal waste management (1.3 $MtCO_2eq$) and the rest 0.7 $MtCO_2eq$ and 0.6 $MtCO_2eq$ in Wastewater management and Industrial process and product use. Some experts still believe that Thailand still has significant opportunity for improvement particularly in mitigation measures in energy, transportation, and agriculture. Some specify that Thailand's target in renewable energy and low carbon transportation can be more ambitious.

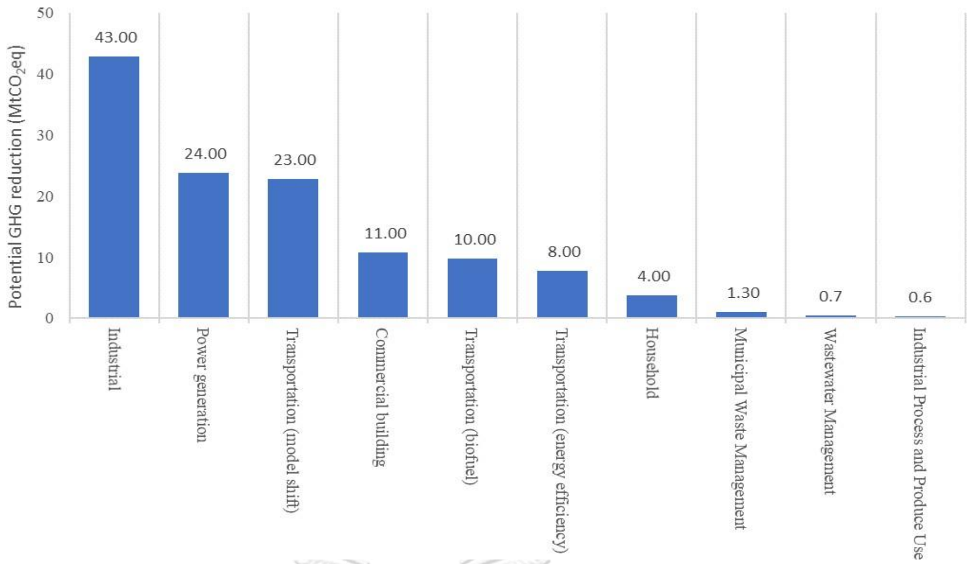


Figure 14 *The greenhouse gas reduction potential on target sectors (ONEP, 2020)*

From 2013 to 2018, Thailand made significant progress in implementing its mitigation action under the Nationally Appropriate Mitigation Action (NAMA) pledge. It effectively achieved its goal of cutting greenhouse gas emissions by 57.84 $MtCO_2eq$ in 2018, which was around 15.76% lower than its business-as-usual scenario.

***Table 4** Mitigation measures under Thailand's NDC Action Plan 2021-2030*

Sector	Mitigation measures
Energy	Energy generation Increase power generation efficiency. Renewable energy generation. Energy consumption in households Increase energy efficiency in households. Renewable energy in households. Energy consumption in commercial and public building Increase energy efficiency in households.
Transportation	Avoid/reduce traveling. Shift/maintain travel modes. Improve energy efficiency in transport
IPPU	Clinker substitution Refrigerant replacement/ modification Industrial wastewater management
Municipal waste management	Waste management Reducing the amount of waste Wastewater management Increasing biogas production from industrial wastewater through re-utilization of methane. Industrial wastewater management. Municipal wastewater management.

***Source:** ONEP, 2018*

2.4 Other policies related to climate change

Thailand is increasing its efforts to transition towards a zero-emission economy. Most recently, the country has committed to meet its NDC target of 20% reduction in greenhouse gas emission from the BAU level by 2020. While the NDC roadmap is the main policy to guide Thailand toward a low carbon economy, there are several national policies which relate to and support the NDC roadmap to achieve the target including the energy, transport, industrial and waste management policies. These are laid out in the following sections.

2.4.1 Energy efficiency plan 2018 (2018-2037)

The Energy Efficiency Plan 2018 (2018 – 2037) was prepared with a target of 30% energy intensity reduction by 2037 and to deliver energy savings of 54,371 ktoe. The plan prioritizes energy conservation, targeting the industrial, commercial building, residence, agriculture, and transport sectors. The industrial sector has the highest potential to save energy at around 21,137 ktoe including electricity and heat saving. The sector the next highest potential energy saving is the transport sector which is expected to account for 36% of total potential energy saving at the end of the plan. The commercial building sector is estimated to save energy of around 6,418 ktoe, followed by the household and agriculture sectors at 6.73% and 1.07% respectively **(Table 5)**

Table 5 *The energy efficiency target 2018-2037, (DEDE, 2018)*

Economic Sector	Electricity saving	Heat saving	Total (ktoe)
A. Industrial	6,777.00	14,360.00	21,137.00
B. Commercial building	5,532.00	886.00	6,418.00
C. Household	2,923.00	377.00	3,300.00
D. Agriculture	147.00	380.00	527.00
E. Transport	-	17,682.00	17,682.00

Source*: DEDE, 2018*

2.4.2 Alternative energy development plan 2018 (2018-2037)

The Alternative Energy Development Plan 2018 (AEDP2018**)** was approved by the cabinet in October 2018 and aims to increase the share of alternative energy in Thailand’s energy system both in heat and electricity production as well as promoting biofuel in the transport sector from 2018 to 2037. In the AEDP2018, the total target is estimated to be 18,696 MW reduced from electricity production and 30,985 ktoe from heat and biofuel. Solar is the focus source of electricity generation and is set at 64.26% of the total target of electricity generation, including floating solar technology which is a first for Thailand in this plan. Biomass is a main source in heat generation and Biodiesel is a core focus of biofuel **(Table 6).**

Table 6 *The alternative energy target 2018-2037 (EPPO, 2018)*

Electricity Generation	Target (MW)	Heat	Target (ktoe)	Biofuel	Target (ktoe)
Solar	9,290.00	Biomass	23,000.00	Ethanol	1,396.00
Floating solar	2,725.00	Biogas	1,283.00	Biodiesel	2,517.00
Biomass	3,380.00	Waste	495.00	C. Pyrolysis oil	171.00
Community power plant	120.00	D. Solar	100.00	-	-
Wind	1,485.00	Biomethane	2,023.00	-	-
Biogas	1,183.00	-	-	-	-
Municipal waste management	400.00	-	-	-	-
Industrial waste	44.00	-	-	-	-
Small hydro	69.00	-	-	-	-

Source*: EPPO, 2018*

2.4.3 Power development plan 2018 (2018-2037)

The Power Development Plan 2018 was formulated in line with the two plans above. It aims to emphasize the implementation of power generation and its systems. The plan also aims to reduce the dependency of high carbon intensity fuel and improve the share of renewable energy in electricity production. The plan has been established under the framework of i) Energy security which normally deals with meeting increasing electricity demand, ii) Economy of preserving an appropriate cost of electricity and iii) Ecology, which is reducing the impact of power generation on the environment, including greenhouse gas emissions. By the end of the plan, renewable energy is expected to be a major share of electricity generation. It is estimated to be

20,766 MW or 37% of the total power generation in the plan including floating solar technology.

The combined cycle is the second largest share in the power development plan at 23% which generally consumes natural gas as the fuel. Coal is still in the plan but very low compared to the other sources, particularly renewable energy with the share at 36.79% of total power generation by end of 2037.

Table 7 *The power generation plan and target 2018-2037. (EPPO, 2019)*

Power source	**Generation Target (MW)**
A. Renewable energy	20,766
B. Hydro power	500
C. Cogeneration	2,112
D. Combined cycle	13,156
E. Coal/ Lignite	1,740
F. Purchased from neighboring countries	5,857
G. IPP biding	8,300
H. Energy efficiency plan	4,000

Source*: EPPO, 2019*

2.4.4 Transport master plan

The National Transport Development Strategic 20-year Plan (2017-2036) (OTP, 2016) was formulated in the framework of green transport, inclusive transport, and transport efficiency. In the green transport perspective, it focused on using clean energy or alternative energy to encourage transportation systems to operate more environmentally, mainly to reduce greenhouse gas emissions. Increasing transport efficiency is another one of the measures which can reduce the greenhouse gas emission in the transport sector under the plan.

2.4.5 Eco industrial strategy

The Eco Industrial Strategy was developed under the Ministry of Industry. This strategy meets a green growth and developing more environmentally friendly industry. In the strategy, the Department of Industrial Works launched a project for setting up Eco Town Centers. Setting up Eco Town Centers is based on five dimensions such as physical, economic, environmental, social and management factors and it is used as a guideline for industrial zoning nationwide.

2.4.6 National master plan on waste management

The national waste management master plan as developed to encourage the population to reduce waste at the source by following the 3Rs concept of reduce, reuse, and recycle and to establish proper disposal methods for municipal solid waste and household hazardous waste by considering the centralization concept and supporting waste to energy policy. According to the last master plan (at the time of this research), there are six goals set as i) municipal solid waste will be disposed properly, targeted at 19.6 million tons by 2021, or 75% of total generated municipal solid waste, ii) all accumulated waste will be disposed of properly, targeted at 30.5 million tons or 100% of accumulated waste by 2019, iii) household hazardous waste is collected and disposed of properly, targeted at 0.17 million tons or more than 30% of total household hazardous waste by 2021, iv) all infectious waste is collected properly, targeted at 0.05 million tons or 100% of infectious waste by 2020, v) all hazardous industrial waste management is collected and disposed of properly, targeted at 2.06 million tons or 100% of it by 2020, and vi) local governments will install the waste separation system at source (households), targeted at 3,889 LGs by 2021. In April 2019, the cabinet acknowledged the Plastic Waste Management Roadmap for 2018-2030 which aims to stop the demand of plastic and promote environmentally friendly material. By 2027, the government targets 100% of plastic waste will be recovered. This will decrease the volume of plastic waste by 0.78 million tons a year and save 3.9 billion baht in waste management cost annually. The road map is estimated to reduce greenhouse gas emissions around 12 $MtCO_2eq$ at the end of the plan.

2.5 Literature reviews on previous research

This section provided a summary of some previous studies related to the research topic. The key concepts of urban or city greenhouse gas emission accounting method, climate change policy in the city, and climate mitigation actions in the city as well as the financial and social analysis tools on urban or city climate change policy are further emphasized.

2.5.1 Greenhouse gas emission: accounting and assessment

In terms of greenhouse gas emission, accounting and assessment, some studies focused their researched on how a city evaluated their GHG estimation and performed their emissions reductions, as follows:

P. J. Marcoyullio et al. (2012); the study aimed to explore greenhouse gas emissions from urban areas in Asia at the regional level, and to explore covariates of urban greenhouse gas emission. The Emission Database for Global Atmospheric Research was used to estimate carbon dioxide, methane, nitrous oxide, and sulfur hexafluoride from 14 activities and 3535 urban areas. The research used regression analysis to associate emissions with urban area and growth, economic, and biophysical characteristics. The study concluded that urban greenhouse gas inventories are limited by available data. The data collection and analysis method and consideration at three categories concerning to urban greenhouse gas emissions: what is the relevant unit of geography, what is measured as representing urban greenhouse gas emissions, and how the emissions can be measures. Due to these questions the study found that in the case of the city level, all urban greenhouse gas activities should be considered to answer what the relevant unit of geography is. All 6 Kyoto GHGs, GWP (Global Warming Potential) values 4th IPCC report and the Direct and Indirect emission definitions of sectors are different from the national inventory. The method used for measuring the national level uses a top-down approach, but the bottom-up approach is used for city level.

Jidong et al. (2014); the study provided an understanding of how a city performs its greenhouse gas emission, specifically Tianjin, China, from 2001 to 2009. The study used multi-sectoral decomposition analysis including in the agriculture, industrial, transportation, commercial and other sectors. In this study, greenhouse gas emissions were conveyed in carbon dioxide equivalents (CO_2eq) which converted form of carbon dioxide, methane, and nitrous oxide. These three greenhouse gases were converted by multiplying by the global warming potential (GWP), which are 1, 21, and 310, respectively. The total carbon dioxide emissions in Tianjin were estimated following the IPCC 2007 report based on the energy consumption, emission factors and fraction of oxidized carbon by fuel while methane and nitrous oxide emissions were estimated based on the same activity but using their respective emission factors. The interval-wise decomposition analysis was used in this study. This method allocates the period of study into two periods: from 2001 to 2005 and 2005 to 2009, which is consistent with China's five-year plan. The study found in 2009 the total greenhouse gas emissions in Tianjin increased from 56.02 Mt (million tons) in 2001 to 114.04 Mt, with a growth rate of 9.31% annually. Most of the greenhouse gas emissions were clearly from the industrial sector. The emissions from the other four sectors were smaller. In conclusion, the study proved that economic growth was the most important factor driving the increase of greenhouse gas emission in Tianjin and the energy efficiency measures were principally effective for the decrease in emissions mostly in the industrial sector. Controlling emissions from the industrial sector should be the priority of Tianjin local government on low-carbon economy transition. Energy efficiency measures are needed to strongly promote and support the industrial sector to cut emissions.

T. Wakiyama and T. Kuramochi (2017); this research conducted a comparative assessment of energy sector in Japan and greenhouse gas emission scenarios for 2030 in selected studies published between 2011 and 2015 to obtain insights into the ambition level of Japanese INDC. This study concentrated on bottom-up models and GHG mitigation potentials considered under varying policy effort levels. Moreover, this paper mainly examined journal articles and research commissioned by the government after the Fukushima nuclear disaster. Two analyses were presented in this paper. First, the relative assessment of mitigation scenarios for 2030 was performed for all sectors, with the exception of LULUCF sector. The analysis assessed the following five energy related indicators, of which three are for supply side and one for demand side. Second, the "Analysis B: projection of GHG emission for 2030 using a regression equation" showed that GHG emissions was determined by many factors motivated by the calculations of energy demand and supply. Analysis B intended to project the GHG emissions reduction level for 2030 with a limited number of illustrative variables making process by conducting a multiple regression analysis on the data of 48 scenarios compared in Analysis A. The regression equation was used to calculate the energy supply- and demand- related targets required to achieve GHG emission reduction of 20%, 30% and 40% by 2030. In the first analysis, GHG emissions levels ranged between 16% and 39% below 1990 levels. It was categorized to have the highest level of mitigation efforts including those consistent with the 2°C target, with the nuclear power share ranging at 0–29%. The second analysis suggested that regardless of the future nuclear share, GHG emissions reductions of more than 25% from 1990 levels may be considered a minimum effort required in the global efforts towards the 2°C target.

Q. Chena et al. (2017) reviewed the works on carbon emission at city level in China and examined the profile of GHG emission. A regression and inductive analysis of carbon emission data were conducted. Results presented that roughly 45% of prefecture level cities have different levels of emission. Energy-related carbon emissions change significantly across city typologies. Based on the available data source, methods used to calculate CO_2 emissions in Chinese cities. It can be classified into three types: 1) city emissions were classified into three scopes. Scope 1 included all direct emissions within the territorial boundary of the city. Scope 2 included indirect emissions outside the city boundary only from electricity consumption, district heating and cooling. Scope 3 included other indirect and embodied emissions that occur outside the city. 2) refers to part of the direct emission in Scope 1, cities' carbon emissions associated with direct energy use, which was caused by production or consumption. This study showed a data analysis using the data available in published literature. Data availability, methodologies, CO_2 emission data gaps, reporting delays, and emission estimates were counted in the analysis. The carbon emission data from energy sector values of 183 prefecture-level cities were analyzed. The main conclusions were CO_2 emissions data in prefecture-level cities was insufficient. More than half of city in China lack publicly available CO_2 emissions data, policymaking, and the practices of low-carbon cities. The standard methods of CO_2 emissions inventory development and comprehensive CO_2 emissions data management for cities in China should be considered based on the international or national guidelines.

T.V. Ramachandra et al., (2015) studied the reporting of the amount of three important greenhouse gases including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) and developed the carbon footprint of the major cities in India. This study involved (i) quantification of GHG emissions, (ii) calculation of carbon dioxide equivalent (CO_2eq) and (iii) representing a carbon footprint of a respective city. The study also aimed on eight metropolitan cities in India: Delhi, Greater Mumbai, Kolkata, Chennai, Greater Bangalore, Hyderabad and Ahmedabad. The major sources considered for inventory were (i)electricity consumption, (ii) household sector, (iii) transportation, (iv) industrial sector, (v) agriculture, (vi) livestock management and (vii) waste sector. Country specific emission factors were adopted from the national data, default emissions factors of IPCC have been used in absence of country specific emission factors. Greenhous gas emissions were estimated by multiplying fuel consumption with the corresponding emission factor. Total greenhouse gas emissions from all sources were summed as given in the equation. According to the results, the energy related emissions were emissions from electricity consumption. Consumption of fossil fuels and electricity in sectors like domestic and industrial were characterized independently under specific sectors respectively. The household sector was a major sector which contributed to an amount of emission at city level.

I. Sowka and Y. Bezyk (2017) investigated the process of greenhouse gas inventory most likely to enable cities to better manage and set realistic targets for emission reduction. The work included the determination of greenhouse gas emission calculating tools and approaches used to identify the key sources of these emissions at the local level. The actual task was the determination of major emitting sectors including the key characteristics of these emissions sources, setting targets for emissions reductions at Wroclaw urban area, Poland. Trends of sectoral greenhouse gas emissions in selected urban areas and comparison of national CO_2 emission data were presented. The IPCC method was applied to estimate greenhouse gas emission-at city scale. Activity data on different emission sources were gathered from official Polish public statistics. The study found that energy consumption was a major contributor, responsible for 63% of total emissions through the consumption of electricity and district and heating using coal and natural gas as energy sources. In order to determine the progress of city towards urban carbon neutrality, reducing 25% of greenhouse gas by 2020 and 80% by 2050.

Y. Li et al (2017) investigated potential sources of GHG emissions specified by the GPC. This study also considered the problem of missing data and low data quality. The authors provided that instead of seeking to compile a complete inventory, cities in China should firstly report their greenhouse gas emissions from these sources, while improving the data quality requesting the long run improvement. All greenhouse gas emission and removals were calculated in accordance with the IPCC suggested formula. Data available, and aggregating data format were a limitation of this study. The study could not separate the emissions from the consumption of fossil fuel on stationary energy and transportation. Therefore, the research assessed data in simple way based on data assessment. In fact, all the framework design, definitions, data quality, accounting years, emission factors, accounting approaches and management errors were found to the uncertainty of the inventory results. Missing data is urgently necessary to improve annual greenhouse gas inventories for multiple cities, so that comparisons can be made longitudinally for each city and among cities.

2.5.2 Greenhouse gas mitigation options and analysis tools

Beside this, previous studies also conducted climate change migration research by focusing on both climate policies and related analysis tools to better understand the potential of mitigation options in their own city's context.

Gouldson et al. (2016); Adopting of low emission development strategies (LEDS) in three cities in Asia as case study could be effective. However, the development of LEDS requests a coordination at multi-, cross- cutting governance. Kolkata, Palembang and Johor Bahru were selected as case study in this research. Findings in this study identified barriers for each city to adopting urban LEDS. There are common methodology adopted into the study, including i) assessing trends and projecting in energy consumption and greenhouse gas emissions from 2000 to 2013 to 2025, ii) using a bottom-up approach to analyze to analyze the economic effectiveness of low carbon electricity production technologies, and iii) using a bottom-up approach to other climate mitigation measures for analyzing the level of economic attractiveness of low carbon development Since lack of data in consideration of Scope 3 emissions, Greenhouse gas emission in Scope 1 and Scope 2 were considered in this study. The historical data on energy consumption from 2000 to 2013 were used to forecast greenhouse gas emissions to 2025 with the assumption of no additional climate and energy mitigation implementation in the period of study. The population, GDP per capita, energy use per capita, emissions per capita and energy bill were used to projection of greenhouse gas emissions. In economic view, the private cost and benefits of deployment, comprising lifetime capital, running and maintenance cost for implementing low carbon technologies were associated. Also in this study, 5% of interest rate and increase rate at 3% annually in energy price were assumed, while the prices for measures were held constant at 2014 level which made the conservativeness. The assessment of greenhouse gas emissions these three cities based on low carbon programs in each cities without any substituting actions in low carbon technologies such as replacement of renewable energy in electricity production. Finally, the study drew the results of economic and greenhouse gas emission reduction together to determine the potential impact of the cost-effectiveness in each measure. This would allow the researchers to understand of the needs in investment and greenhouse gas emissions reduction potential. In the comparative analysis, the study presented that greenhouse gas emissions were rising rapidly in all three selected cities due to the city economic changes-and energy consumption upward trend. The Indian government has set a target to reduce the GDP greenhouse gas emission intensity by 20-25% in comparison with 2005 level by 2020 Kolkata would reduce its emission intensity by 35.2% over this period under business-as-usual scenario. Correspondingly, the Malaysian government has committed to reduce their greenhouse gas emissions intensity of GDP by up to 40% based on 2005 level by 2020. The result of analysis found that Johor Bahru would reduce its emissions by 63.5% over the period of study. For Indonesia in study period, the government has not offered a specific target to reduce their greenhouse gas emission. Palembang is on track to reduce the greenhouse gas emission intensity by 30.9%. In this study, the economically attractive in low carbon electricity production would reduce emissions by 11% in West Bengal, 12% in Sumatra and 2% in Malaysia. Additionally, the study also indicated the economically attractive low carbon measures in the residential, commercial, transport and waste sectors, as outlined in **Table 8**.

Table 8 *The carbon-effective options in each city*

City	Measure	Carbon saving ($ktCO_2eq$)
Kolkata, India	Adopting green building standards in new commercial building for 100%	6,768
	Implementing the most energy efficient air conditioners currently available in the household sector	6,003
	Retrofitting fiberglass urethane roofs in existing households for 20%	4,989
	Implementing more energy efficient air conditions than BAU in the household sector	3,688
	Implementing the most energy efficient entertainment appliances in household sector	3,529
Palembang, Indonesia	Replacement of diesel with biodiesel in manufacturing	7,048
	Improving diesel boilers with solar water heating system	6,730
	Utilizing landfill gas	3,802
	Promoting waste to energy	3,414
	Promoting steam reforming technology-in the fertilizer production	3,166
Johor Bahru, Malaysia	Replacing diesel with biodiesel in manufacturing	43,798

Even though the cities have potential to cut their greenhouse gas emissions, the capacity of the city frequently dependents on support from national government, and non-state actors. Without this cooperation, cities were unlikely to meeting the greenhouse gas reduction target.

P. Misila et al. (2020); the study highlighted the achievement of renewable energy and energy efficiency policy in Thailand's long-term GHG emission reduction in 2050, beyond its NDC target. In the research, Thailand's "Alternative Energy Development Plan (AEDP)", "Energy Efficiency Plan (EEP)" and "Power Development Plan (PDP)" were introduced as well as their targets. The Long-range Energy Alternative Planning (LEAP) system was applied to assess the achievement of

Thailand's GHG mitigation target from 2015-2050. The framework of this model can estimate the GHG emissions related to energy consumption. The LEAP structure can be divided into two main modules which are transformation and demand. The transformation module includes the set of data on electricity supply and the demand module consists of the set of data in transportation, industry, building and household. Some other socio-economic data are included in the model, such as GDP, population, and number of households. Five economic sectors were considered in this study: power, transport, industry and buildings and household. The research was divided into three scenarios which can be descripted as a) business-as-usual (BAU) scenario, which is the greenhouse gas projection with no mitigation policy consideration, b) MT1 scenario, the projection under AEDP2015 plan and the EEP2015 from 2015 to 2036 and no additional policy related to greenhouse gas emission reduction during 2037 to 2050, and c) MT2 scenario, which is projection considering the same policy with MT1 from 2015 to 2036, but the advanced technologies are applied from 2037 to 2030. The greenhouse gas emissions were about 217,842.5 GgCO_2eq in 2010 as in BAU scenario and estimated to increase to 517,203.1 GgCO_2eq in 2036 and 817,631 GgCO_2eq in 2050, an average growth rate of around 6.7%. Under other two scenarios, the greenhouse gas emissions were expected to increase to 233,325.0 GgCO_2eq in 2036 and lower than BAU 54.6%. It came from the measures indicated in EEP2015 and AEDP2015. The result in MT2 from 2037 to 2050 included the application of new advanced technologies such as Carbon Capture Usage and Storage (CCUS) which provided more reduction in MT2 compared to other two scenarios. In conclusion, the study found that Thailand would meet its NDC target of 20% in 2030, if 50% of AEDP2015 targets and 75% of EEP2015 targets are achieved, or vice versa. For policy recommendation, this research points out the advanced technologies would be key to the success of GHG emissions reduction by 2050 for Thailand. Policy makers should consider the development of advanced technology such as renewable energy in electricity production which could result in lower energy intensity, and improved variation of energy sources.

2.5.3 Climate policies and actions in the cities

Previous studies also focused on the recommendations of potential mitigation actions to minimize GHG emissions and also support the low carbon society pathways in their city scale, as following:

Q. He et al. (2016) explored GHG emissions reductions in the residential sector in Chinese megacities including Beijing and Shanghai based on an integrated measure based assessment model. This proposed model consisted of 4 stages: a) scope and baseline (BAU) analysis by considering energy demand, future energy bills and CO_2 emissions from 2000 to 2030, b) identification and assessment of measures based on local stakeholder discussions, c) collection of potential and opportunities by grouping measures into scenarios from most to least 'cost-effective', and d) interactions and feedbacks. Results found the CO_2 emissions from 2015 to 2030 under the condition of BAU could be reduced by 10.2% in Beijing and 6.8% in Shanghai with the implementation of economically attractive low carbon measures. In addition, results in the case of low carbon investment in the residential sectors in megacities in China, a analysis requires the economical understanding of decarbonization in cities more generally.

S. Hatfield-Dodds et al. (2017) explored and analysis of scenarios which compares a baseline scenario within a resource efficiency and greenhouse abatement policy. The specific combination of future resources and future greenhouse gas emissions pathway were presented. To develop the projection of greenhouse gas emissions to 2050 under three policy scenarios. The finding showed that resource efficiency could offer pro-growth, pro-environment policies with total benefits of USD $2.4 trillion in 2050. In addition, it eases the politics of moving forward to sustainability. Under current developments, from 2015 to 2050 the resource extraction was projected to increase by 119% which estimated to increase from 84 to 184 billion tonnes annually. The greenhouse gas emissions increase by 41%, which driven by the global economic. The study found by 2050 resource efficiency reduces greenhouse gas emissions by 15-20%, with global emissions falling to 63% below 2015 levels when combined with a 2^oC emission pathway.

Y. Liu et al. (2017) analyzed two phenomena, urbanization and GHG emissions, by converting to per capita term, and increasing the effect rate of impact from the traditional urbanization. The result shows that population density has actually been the dominant demographic player in changing per capita emissions from the past two decades in China. The study provided a view of the relationship between greenhouse gas emission and urbanization. The result indicates that population density change should be taken into account to impact assessment of urbanization. The study also found that carbon emissions were affected by urbanization in two opposite directions. Firstly, urbanization aimed to increase per capita energy consumption because of increasing demand for goods and services, the transformation from traditional fuels to carbon intensive fossil fuels, and increased number of households with declining size. The other way around, when scale up effect during intensive development promotes the improvement of energy efficiency, urbanization may reduce per capita energy consumption. However, this impact was insignificant.

N. Zhou et al. (2015) used the low carbon and eco system tool for evaluating the performance of the cities and comparing them against benchmark performance goals in China. The 33 indicator was used for evaluation process. They were nominated to represent priority issues within eight primary categories and develop the package of these indicator in Excel tool. Explain indicator benchmarks, and calculation functions are transparency data recording institutions. This tool could be effective for defining the outline of low carbon and eco city. Also, it could be assessing the progress of cities. The selection of these indicator based on how it was suitable with the following criteria: (a) High-level relevance to sustainability, green cities, eco-cities, low-carbon, smart cities, and livability terminology; (b) Assessment of conduction at the national or sub-national level; (c) Indicator definitions; (d) Indicator selection criteria and methodology; and (e) High commonality in the reviewed literature.

A study conducted by **E. Croci et al. (2017)** was to encourage local government in designing strategies of climate change mitigation in coherence with the climate policy of European Union. This study aimed to investigate the CoM initiative by following goals including to analyze the adopted strategies to meet their carbon reduction target in each city, to assess the correspondence between emissions reduction target and baseline emissions by cities and to verify the emissions reduction driving force in each city.-In this study, cities were grouped according to 6 variables: Population size, Heating Degree Day (HDD), GDP per capita, Population density, Geographical area, and Electricity Emission Factor. The exemption of correlation between drivers and intended emission reductions from planned to actions were analyzed with a regression analysis. As per result of the study, the case study cities showed some difficulties in the disaggregation of the total carbon emissions and their intended emission reduction between sector and sub-sector. In case study baseline inventory, more than 75% of total emissions reported were disaggregated between the main sector As per results of the analysis, it is possible that urban policy makers could shape their climate change mitigation strategies according to some policy recommendation in this study. In the public sector, the study found the share of emission reductions was higher to compared with emissions in the base year; then the actions in the public sector would be a main consideration to meet the target of greenhouse gas emission in these cities. ~~Action in the public sector is of key importance.~~ Nevertheless, local government's climate change mitigation strategies need further enhancement with the aim to an effectiveness of designing and implementation involving private sector. For example, public agencies can encourage private actors in the sustainable energy investment through a range of supporting from public authorities including regulations, incentives and awareness raising. In this study, it was confirmed the building and transport sectors were important and most relevant for emissions reduction in the cities. Therefore, the mitigation strategies should be prioritized in these sectors. The combination of mitigation measures and intervention were most promising action in building sector particularly in energy efficiency measures and transportation mode shifting was the most promising mitigation action in transportation sector particularly to use of more public transportation. In view of levers, the energy management, raising awareness and improving infrastructure were the most important for emissions reduction in building and transportation sectors. However, there were restriction in this study according to data lacking.

2.5.4 Policy criteria decision tools

To address the third objective of this research, the following literatures were gathered to gain insight into how climate change related policies can be integrated with low carbon strategy development at the city level:

J. Lin et al. (2014) developed the indicator system of low carbon city by decomposition method. This method offered a better approach for evaluation of carbon reduction intensity performance in the city. In China, generally use the carbon intensity target to identify the low carbon performance in province- and city-level. The indicators could support local authorities to meet the greenhouse gas reduction target and understand their current performance. As mentioned, the emissions from energy consumption, industrial process, agriculture, forestry and waste were considered while the emissions from product use and other land used were not included in this study. The study presented a framework for estimating carbon intensity and compare its performance against a base year. The study suggested in the future more practical indicator should be developed. It should be included sector surveys, cost-benefit, and repeated carbon reduction target as well as a complete of city's greenhouse gas inventory report. In addition, the indicator could provide more accurate information and data in the creating of climate mitigation plan.

Kesicki and N. Strachan (2011) described the common too to indicate the emission abatement potential associated with abatement coast. Marginal Abatement Cost (MAC) curve are increasingly being applied to climate change policy. Moreover, this study found that in the past the partial methodology base on MAC curves was used for discussion in complex policy areas. This paper examined how there has been misleading and finds that the limits of the MAC curve. This could lead to biased decision making in the generation of MAC curves. However, policy makers were normally not considered only cost-effectives but also other aspects. In study found using MAC curves for a cost-effective on climate mitigation measures could provide more difficulty in reality, particularly where implied carbon prices of existing policy instrument. The awareness of pre-existing policies was suggested for policy makers to use MAC curve for climate mitigation policies. In current situation, the study showed that policy makers using MAC curves without attention to weakness of the MAC curve and principally inadequate methods to draw the MAC curve. However, the study still recommended that MAC curve was useful for illustrating and engagement various stakeholders in debate in climate mitigation actions.

Vogt-Schilb (2014) investigated how MAC curves can inform decision making. The researcher analyzed the misinterpreting of a MAC curve built for Brazil's climate mitigation options by 2030. The misinterpreting could lead into under-investment in low cost-effective measures, long implementation, and large potential options. On the other hand, it could lead the over-investment in high cost-effective measures but limiting of reduction potential options. The study proposed a new graphical representation to mitigate this issue. In the interpretation of the curve, the cheapest measure implementation should come first and preferring measures followed by the lower total saving potential but more cost-effective than those higher saving potentials. In the view of the cost saving potential, local capital turnover, slow in technology development, worker skills, availability of relevant specific capital, availability of funds and institutional constraints were a key parameter. Then developing the MAC curves should be presented together with wdge curves which could make the dynamic aspect of climate mitigation options. Presenting the new approach, the all negative cost-effective measures were introduce at full speed from 2010 which independent of greenhouse gas emission target. Also, the attractive measures could bring not only the cost even in the absence of carbon pricing. For the least cost-effective presented the positive cost measures, it can benefit from the change of discount rate.

Vogt-Schilb and S. Hallegatte (2011) explained why the abatement cost was commonly used for decision makers in development of climate mitigation plan, even there were weaknesses using a traditional MAC curve. The new way of using MAC curve were suggested. To classify of existing MAC curve would be the first step of this study. The researcher would explore a simplification of mode including the optimal timing of greenhouse gas emissions reduction together with optimal dispatch in three dimension including cost, abating potential of reduction and speed of implementation. In the research, it was suggested the abatement strategies may implement expensive option before the whole cheaper measures potential, use expensive options when the inexpensive measures insufficient to meeting the target, and start to implement the expensive one before inexpensive measures. Currently this approach was received significant attention from policy makers which it could answer the options that could decrease large amounts of greenhouse gas emissions in the future and time for implementation.

S. Taylor (2012) support that MAC curves were a common tool used for assessing the economics view for climate mitigation options. However, the researcher mentioned about the calculation for negative costs on behavior measures. The MAC curve normally was constructed according to a number of merit and total emissions reduction potential of each measure. Some measures gave a negative cost during the period of interest. Developing the MAC curve, it was convenient to compile the normalizing present value and refer to the relevant specific cost and emissions saving. However, in conclusion part of this study, it suggested to rank emissions reduction measures by using cost-effectiveness measured in $/t$CO_2$. In the mathematical analysis session presented if sufficient requirements were imposed, there were no existing function could be used as a merit for ranking the profit on emission reduction. Inapplicability of standard metric could be likely to make ranking errors in MAC curve. Finally, this study was confirmed that conventional MAC curve was not an appropriate way for ranking the measures for climate mitigation measures. Pareto ranking suggested as an alternative options for ranking profit-making measures.

Siksnelyte-Butkiene et al. (2013) developed a technique for prioritizing the climate mitigation policies based on sustainable energy implementation. Multi-criteria decision making (MDCM) was proposed in this study to provide a rational sustainable energy policy. MULTIMOORA method was applied in the study which confident in facilitating multi objective comparison and identify the most interesting policy. Study finding show the fixed electricity price from the RES could be reduce the greenhouse gas emissions at 0.002 Mt in 2012 but the emission trading scheme could allow to reduce greenhouse gas emissions by 0.45 Mt by 2012 and 1.9 Mt to 2020. It could confirm that the emissions trading scheme could be more efficient than fixed price approach to reduce the greenhouse gas emissions. In the study, the EU emissions trading scheme and green certificate in energy sector were used as example which could be a crucial climate policy package to reach EU emissions reduction target by 2050.

S. Grafakos et al. (2010) the study presented a combined weighting methodology incorporating with weighting preferences to evaluate the ex-ante between climate and energy policy interactions. The combination of pairwise comparisons and weighting ratio method were elaborated as a multi-criteria analysis (MCA). In addition, a ranking consistency test was provided for the users to see the degree of their preferences. Also, in this study, a decision support tool was developed to compare stand along policy instrument against the selected evaluation criteria. The describing biases and difficulties of the tool were mainly focused rather than development of criteria means as in previous studies. The weighing design overwhelms the main difficulties in criteria weights induction stage, namely, sensitivity, consistency, hierarchical bias, and the verbal expression association to the AHP nine-point scale. Rank order information may be a solution for time consuming; thus, the application and use of ranking technique was regarded appropriate. Moreover, this methodology could decrease and minimize the burden of respondents and encourage users to re-consider their initial preferences, thinking harder on their given score. For the future research, it suggested to concern the enhancement and further application of proposed methodology in this study including weighting methodology testing into other policy problems at the design stage, to recognize the merit on methodology application on various kind of climate change and energy evaluation problem with the impact of different measurement scales.

CHAPTER III
RESEARCH METHODOLOGY

In this chapter, the research framework and method are described. Research design begins with conceptual framework, developing the greenhouse gas inventory and its projection, and introducing the scenario analysis and climate mitigation cost effectiveness. Then, expert interviews applied in this study as well as SWOT analysis.

3.1 Research framework

3.1.1 Conceptual framework

Climate change mitigation policy lacks consideration at the sub-national level around the world, including city, provincial and municipality levels. As found in the literature review in Chapter 2, this is because of the complexity of the methodologies and lack of knowledgeable staff in the local authority. Therefore, the researcher is interested to contribute recommendations for development of climate change policy and actions in selected provinces in Thailand. The aim of the framework is to maximize economic, social, and environmental wellbeing in the context of sub-national or provincial level to align with current national and international policy.

A comprehensive international recognition on climate change drives nations around the world in reducing greenhouse gas emissions and developing climate mitigation policy and implementation. Therefore, every nation party to the UNFCCC must make reduction efforts under its commitment. This “top-down” approach was introduced at the beginning of the UNFCCC to guide all parties in development of their policy. However, in COP20 at Lima, Peru, the “mixed track” was introduced which allows for flexibility within negotiation [ADP, COP decision1/CP.17]. It means that specific nations would be able to take up different pledges according to their capacity and capability.

In line with findings of the literature review, the mixed concept between top-down and bottom-up approaches are adjusted in this research. The policy recommendations from the study will be proposed as an alternative option to improve provincial climate change mitigation policy. The conceptual framework of this study has been modified to align with the local context and is illustrated in **Figure 15**. The conceptual framework of this study shows the framework of the relationship among international and country climate change mitigation policies, and the country's national development goals and local climate policy and action. This modified framework is to explore whether sub-national level climate change mitigation policy is appropriate for local perspective and developing their own mitigation measures, and how their greenhouse gas emission targets link to national level.

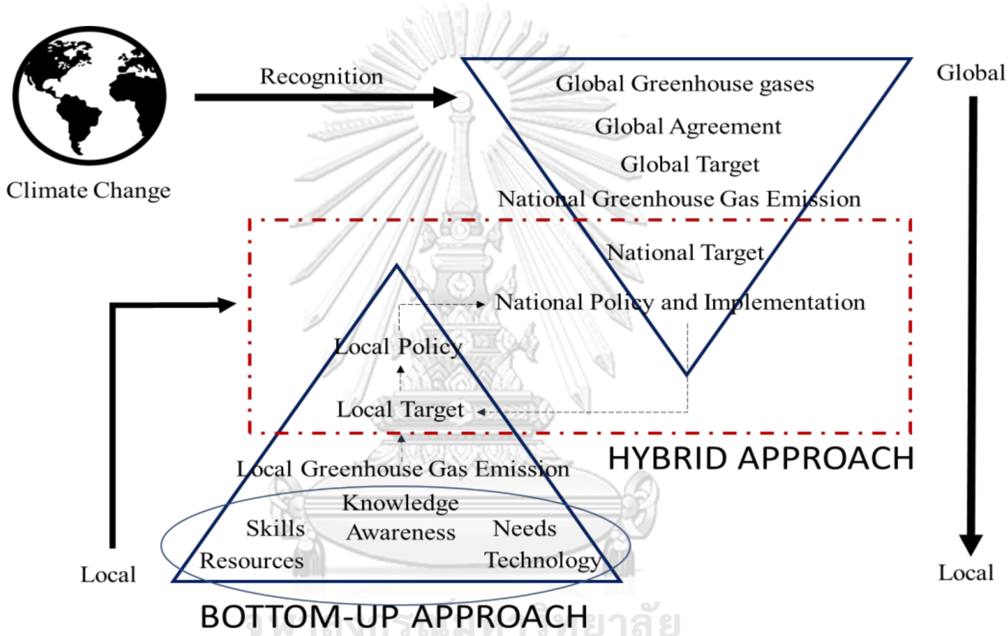


Figure 15 *Conceptual Framework of the study*

3.1.2 Research methodology framework

The diagrammatic methodology of this research is given in **Figure 16**. The certain local greenhouse gas inventory was firstly investigated by collecting the related data such as electricity consumption, fuel consumption, wastewater and emission factor and converting them using the standard unit, according to Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) guideline. The projections to the target year in different scenarios were developed according to assumption including a) Business as usual scenario, b) NDC scenario and c) 1.5°C scenario. National climate mitigation policy and implementations were considered as a part of the national influence; moreover, the international and several low carbon city studies were included. To take into consideration the economic perspective for local actions, the cost-effective analysis was also accounted for in this study. Moreover, the research applied some social indicators and parameters to evaluate the effects of different instruments on proposed climate change mitigation, making the local policy portfolio clearer, and allowing recommendations to be more applicable to local perspectives.

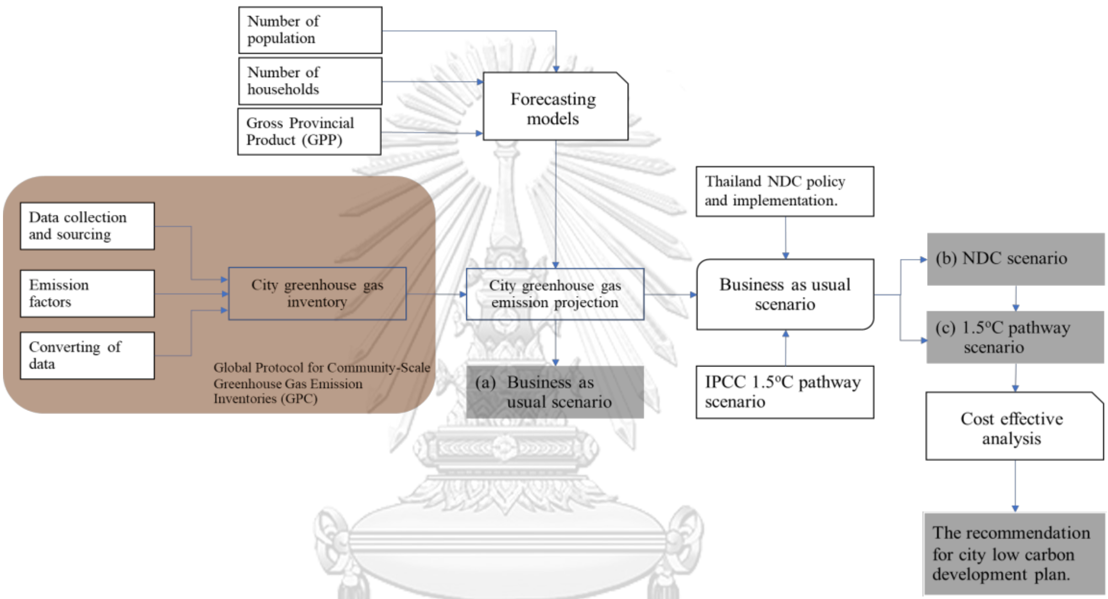


Figure 16 *Research methodology diagram*

3.2 Research design

3.2.1 Data collection

Regarding the varieties of climate change policy research, some of them use quantitative data while others involve qualitative data. In this research, the data collection for greenhouse gas inventory and its projection followed the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). As data collection is a key part of greenhouse gas inventory development, it should be composed of reliable statistical organizations. Starting the inventory development for the first time, it needs to identify key categories which are estimated. Sometimes expert judgment could be used initially to identify likely key categories or find out relatively easily, such as major agriculture activities, major fossil fuel consumption, type of land used and major industries.

Figure 17 presents the step of data collection starting from the identification and evaluation of data sources. There are varieties sources of data used to develop the greenhouse gas inventory. The kind of data is documented in the key categories for example the electricity in kWh is an activity data to use for calculating the greenhouse gas generated from electricity consumption, while liters of petrol oil is an activity data to use for calculating the greenhouse gas produced from transportation. Next, the study uses existing statistical data from international, national, and sub-national sources and other official data collections where this is available for use in the emission inventory and then focuses on the collection of data needed. Sometimes existing data may not directly be used for greenhouse gas inventory. The researcher needs to cooperate with data suppliers and modify existing data sets to meet the inventory requirements; for example, converting to calendar year and re-classifying sources to meet the inventory obligations.

In this study, national data sources were prioritized, such as National Statistics Office, Ministry of Energy, Ministry of Transport, Ministry of Natural Resources and Environment, Ministry of Agriculture and Cooperative, Office of the National Economic and Social Development Council, Provincial Electricity Authority, Metropolitan Electricity Authority and Thailand Greenhouse Gas Management Organization. Moreover, sub-national or provincial statistical agencies were also used for some data such as the wastewater, land use change, and livestock.

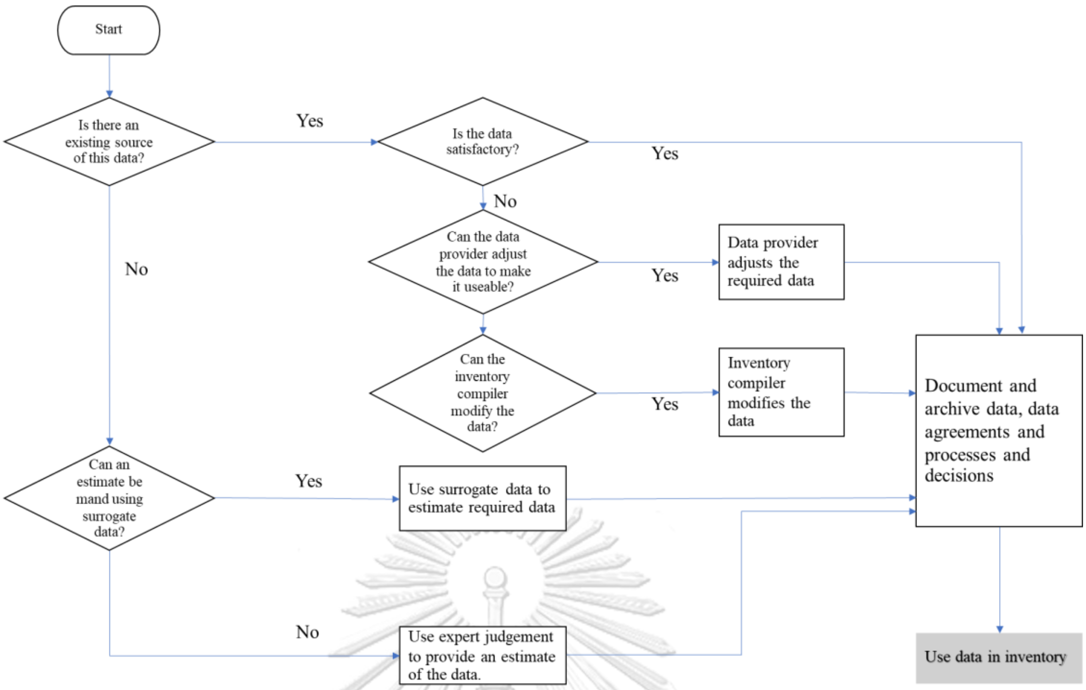


Figure 17 *Outline of data collection steps and decisions (modified IPCC, 2010)*

3.2.2 Greenhouse gas inventory development processes

A city-wide greenhouse gas inventory is a list of emission sources and the associated emissions quantified according to existing standardized methods. Although there are existing standards to apply for national and sub-national organizations and produce a greenhouse gas inventory or footprint, in this research, the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories (GPC) is employed. According to the GPC, an inventory boundary of the cities should be identified first including geographic area, time span, gases, and related emissions sources.

The inventory boundary can provide a city with a comprehensive recognition of where emissions are coming from as well as an indication of where it can act or influence change. In this study, all seven of the greenhouse gases under Kyoto Protocol are accounted the same as the development of national greenhouse gas inventory: iCO_2, iCH_4, iN_2O, HFCs, PFCs, iSF_6, and iNF_3. As shown in **Figure 18**, greenhouse gas inventory development in this study was performed based mainly on the following steps:

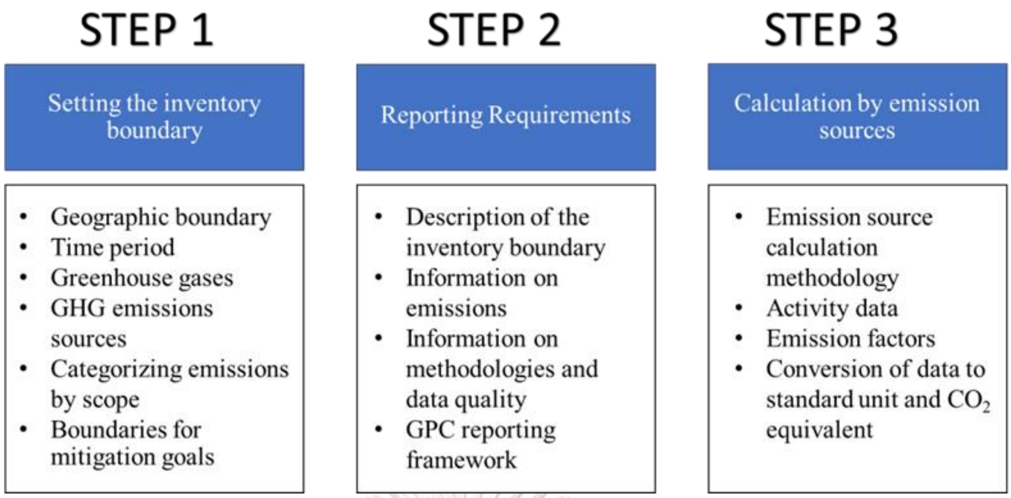


Figure 18 *Steps of greenhouse gas inventory development process*

STEP 1: Setting the Inventory Boundary

Establishing a geographic boundary depends on objective of the inventory; the alliance of the administrative boundary of the specific local authority could be an option or a combination of administrative and metropolitan area or other recognizable entity. In this research, geographical area of of Bangkok, Chiang Mai and Rayong were established as the greenhouse gas inventory boundary. According to the literature review and previous studies, the common period used for city greenhouse gas inventory was a calendar year of 12 months continuing period. Moreover, calculation methodologies in the GPC generally quantify emissions released during the reporting year. As suggested in the GPC, six main sectors below were classified as the greenhouse gas emission sources in the city;

- Stationary energy#
- Transportation#
- Waste#
- Industrial processes and product use (IPPU)#
- Agriculture, forestry, and other land use (AFOLU)#
- Any other emission occurring outside the geographic boundary because of city activities#

The definition of those emission source sectors is shown in Table 9. However, each sector is be divided into different sub-sectors# according to the reporting requirement of the GPC. The sub-sectors can be a method of waste management, the treatment of wastewater, the transport mode and others presented in **Table 9**.

Table 9 *Definition and explanation of emission source sectors (GPC, 2014)*

Source	**Definition and explanation**
STATIONARY ENERGY#	Stationary energy sources are a major source contributing greenhouse gas emission in the city. The emissions normally come from the combustion of fossil fuel in residential, commercial building as well as in power plants located in the city. This includes emissions from fugitive occur during coal and oil extraction, transformation, and transportation.
TRANSPORTATION#	Transportation activity covers all road journeys, rail, water, and air, including inter-city and international travel. Greenhouse gas emissions in this sector are generated from direct combustion of fossil fuel or the electricity consumption from the grid supply.
WASTE#	Greenhouse gas emission in waste sector is produced mostly from aerobic and anaerobic decomposition or incineration process. The emissions from solid waste can be estimated by the treatment technologies.
INDUSTRIAL# PROCESSES AND PRODUCT USE (IPPU)	Greenhouse gas emissions are produced from non-energy related industrial activities. The main emission sources are released from industrial processes that chemically or physically transform materials. During these processes many different greenhouse gases can be produced. In addition, certain products used by industry and end-consumers, such as refrigerants, foams or aerosol cans, also contain greenhouse gases which can be released during use and disposal.
AGRICULTURE, FOREST, AND OTHER LAND USE (AFOLU)	Emissions from the Agriculture, Forestry and Other Land Use (AFOLU) sector are produced through a variety of pathways, including livestock (enteric fermentation and manure management), land use and land use change, and aggregate sources and non-CO_2 emission sources on land. Given the highly variable nature of land-use and agricultural activities across geographies, greenhouse gas emissions from AFOLU are amongst the most complex categories for greenhouse gas accounting.

***Table 10** #Sectors and sub-sectors of city GHG emissions (GPC, 2014)*

GPC ref.	GHG Emission Source
I. Stationary Energy	
I.1	Residential buildings
I.2	Commercial and institutional buildings and facilities
I.3	Manufacturing industries and construction
I.4	Energy industries
I.5	Agriculture, forestry and fishing activities
I.6	Non-specified sources
I.7	Fugitive emissions from mining, processing, storage, and transportation of coal
I.8	Fugitive emissions from oil and natural gas systems
II. Transportation	
II.1	On-road transportation
II.2	Railways
II.3	Waterborne navigation
II.4	Aviation
II.5	Off-road transportation
III. Waste	
III.1.1/2	Solid waste disposal
III.2.1/2	Biological treatment of waste
III.3.1/2	Incineration and open burning
III.4.1/2	Wastewater treatment and discharge
III.1.3	Waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary
III.2.3	Waste generated outside the city boundary but treated biologically within the city boundary
III.3.3	Waste generated outside the city boundary but treated within the city boundary
III.4.3	Wastewater generated outside the city boundary but treated within the city boundary
IV. Industrial Processes and Product Uses (IPPU)	
IV.1	Industrial processes occurring within the city boundary
IV.2	Product use occurring within the city boundary
V. Agriculture, Forestry and Other Land Use (AFOLU)	
V.1	Livestock within the city boundary
V.2	Land within the city boundary
V.3	Aggregate sources and non-CO_2 emission sources on land within the city boundary

According to the inventory reporting standard and in the previous study, greenhouse gas emissions in the city can occur inside and outside the city boundary. To differentiate between these, greenhouse gas emissions reporting as scope 1, scope 2 and scope 3 emissions are categories in the GPC. Definitions of these three scopes are explained in **Table 11**.

The sources and scopes are illustrated in **Figure 19** which shows emission sources occur within, outside, and across the geographic boundary established for the inventory. Setting mitigation goals, existing climate action plans and targets in cities can be different to the inventory boundary.

Table 11 *#Scopes definitions for city inventories (GPC, 2014)*

Scope	Definition
Scope 1i	GHG emissions from sources located within the city boundary
Scope 2i	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam, and/or cooling within the city boundary
Scope 3i#	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary

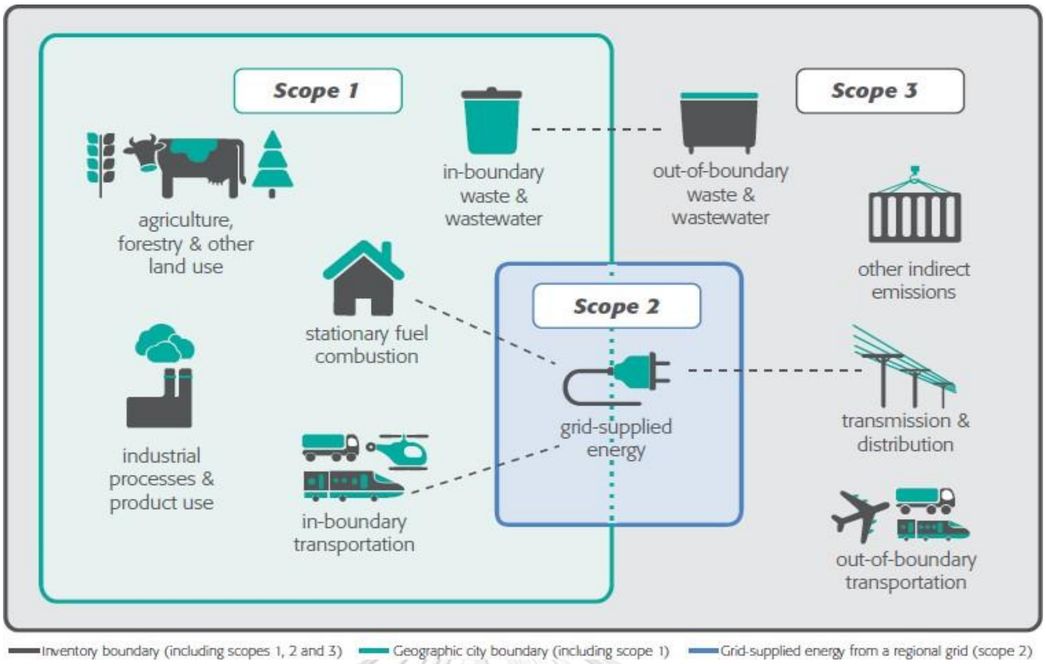


Figure 19 *Sources and scopes covered by the GPC (GPC, 2014)*

STEP 2: Reporting Requirements

BASIC and BASIC+. The emissions occur in geographic boundary of the city is reported in the BASIC level. The BASIC+ level covers more range of greenhouse gas emission sources including emissions from IPPU, iAFOLU, transboundary transportation, and energy transmission and distribution losses. In this study, the researcher decided to report the inventory under the scope framework because of data available in selected provinces. As activity data obtained from a variety of sources and formats, mentioned in the above section, it needs to be modified for the principles of the inventory reporting system.

STEP 3: Calculating by Emission Sources

The calculation methodologies of greenhouse gas emission have defined the calculation formulas between emissions factors and activity data establishing the total emissions from individual emission sources. The city-wide greenhouse gas emissions were estimated by activity data multiplied by an emission factor associated with the activity being quantified as shown in **Eq. (1).**

GHG emissions = Activity data x Emission Factor **(1)**

Where:

GHG emissions = Greenhouse gas emissions from specific activity

Activity data = Amount of activity which result of greenhouse gas emissions

Emission factor = An amount of mass of greenhouse gas associated with-a unit of activity

The activity data represent a quantitative amount of activity which result of greenhouse gas emissions occurring in an interesting period; for example, volume of fossil fuel consumed in the residential sector, driving kilometers, and tonnes of solid waste transporting to landfill, etc. An emission factor is the mass of greenhouse gas associated with a unit of activity, such as estimating CO_2 emissions from gasoline consumption multiplying the emission factor (kgCO_2/liter) for gasoline.

Table 12 *Greenhouse gas emission sources and scope reporting framework*

Sector and sub-sectors	Scope 1	Scope 2	Scope 3
STATIONARY ENERGY			
Residential buildings	✓	✓	✓
Commercial and institutional building 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 system	✓		
TRANSPORTATION			
On-road	✓	✓	✓
Railways	✓	✓	✓
Waterborne navigation	✓	✓	✓
Aviation	✓	✓	✓
Off-road	✓	✓	
WASTE			
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 degenerated in the city	✓		✓
Wastewater generated outside the city	✓		
INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU)			
Industrial processes	✓		
Product use	✓		
AGRICULTURE, FORESTRY AND OTHER LAND USE (AFOLU)			
Livestock	✓		
Land	✓		
Aggregate sources and non-CO_2 emissions sources on land	✓		
OTHER SCOPE 3			
Other Scope 3			

Source: *GPC, 2014*

In some cases, the existing data may not support the geographical boundary or time assessment. The using a scaling factor is used to modify a data. The formula for scaling data is presented in **Eq (2).**

$$Inventory\ data = \frac{Factor_{inventory\ data}}{Factor_{available\ data}} \times Available\ data \qquad \textbf{(2)}$$

Where:

Available data	= Activity or emissions data available which needs to be scaled to align with the inventory boundary.
Inventory data	= Activity or emissions data total for the city.
Factor inventory data	= Scaling factor data point for the inventory
Factor available data	= Scaling factor data point for the original data

3.2.3 Emission calculation

In this section, the emission calculation methodologies and formulas are described in each source.

3.2.3.1 Stationary energy

The emissions in the stationary energy source were mostly from energy consumption including fossil fuel and electricity (see Table 13). For the previous study, this sector contributes a significant amount to greenhouse gas in the city. Emissions from this sector were estimated by multiplying fuel consumption as activity data by the corresponding emission factor for each individual fuel, by gas as shown in **Eq (1).** The following details are sources of stationary energy sector emission by scope:

Scope 1: Emissions from fossil fuel combustion and fugitive emissions in the city boundary.

Scope 2: Emissions from the electricity consumption in the city from the grid supply.

Scope 3: Distribution losses from grid-supplied electricity in the city

Table 13 *Definitions of stationary energy source sub-sectors, (GPC, 2014)*

Sub-sectors	**Definition**
Emissions from stationary energy production and use	Emissions from the intentional oxidation of materials within a stationary apparatus that is designed to raise heat and provide it either as heat or mechanical work to a process, or from use away from the apparatus.
I.1 Residential buildings	All emissions from energy use in households
I.2 Commercial, institutional building, and facilities	All emissions from energy use in commercial buildings and in public buildings such as schools, hospitals, government offices, highway streetlights, and other public facilities.
I.3 Manufacturing industries and construction	All emissions from energy use in industrial facilities and construction activities, except those included in the energy industries sub-sector. This also includes combustion for the generation of electricity and heat for own use in these industries.
I.4 Energy industries	All emissions from energy production and energy use in energy industries
I.4.4 Energy generation supplied to the grid	All emissions from the generation of energy for grid-distributed electricity, steam, heat, and cooling
I.5 Agriculture, forestry, and fishing activities	All emissions energy use in agriculture, forestry, and fishing activities
I.6 Non-specific source	All remaining emissions from facilities producing or consuming energy not specified elsewhere
Fugitive emissions from fuel	Includes all intentional and unintentional emissions from the extraction, processing, storage, and transport of fuel to the point of final use. *Note: some product use may also give rise to emissions termed as "fugitive" such as the release of refrigerants and fire suppressants. This shall be reported in IPPU.*
I.7 Mining, processing, storage, and transportation of coal	Includes all intentional and unintentional emissions from the extraction, processing, storage, and transport of fuel in the city.
I.8 Oil and natural gas system	Fugitive emissions from all oil and natural gas activities occurring in the city. The primary sources of these emissions may include fugitive equipment leaks, evaporation losses, venting, flaring and accidental releases.

3.2.3.2 Transportation

In estimating emissions from transportation, there are typically four types of transboundary trips:

1) Trips that originate in the city and terminate outside the city.
2) Trips that originate outside the city and terminate in the city.
3) Regional transit with an intermediate stop within the city.
4) Trips that pass through the city, with both origin and destination outside the city.

A transportation greenhouse gas emissions inventory development depends on the available data and objectives of the inventory. Then, different methods can be used. The GPC does not require a specific calculation method for each transport mode. However, in the reporting system, it is still in the scope framework.

Scope 1:	Emissions from transportation occurring in the city
Scope 2:	Emissions from grid-supplied electricity used for transportation in the city
Scope 3:	Emissions from the portion of transboundary journeys occurring outside the city

In this sector, the GPC has categorized the transit mode into five sub-sectors for greenhouse gas inventory in the transportation sector **(Table 14).**

Table 14 *Definition of transportation source sub-sectors, (GPC, 2014)*

Sub-sectors	Definition
II.1 On-road transportation	All emissions from electric and fuel powered cars, taxi, buses, etc.
II.2 Railway	All emissions from trans, urban railway subway system, reginal commuter rail transport, national rail system, and international rail systems, etc.
II.3 Waterborne transportation	All emissions from sightseeing ferries, domestic inter- city vehicles, or international water-borne vehicles
II.4 Aviation	All emissions from helicopters, domestic inter-city flights, and international flights etc.
II.5 Off-road transportation	All emissions from airport ground support equipment, agricultural tractors, chain saws, forklifts, snowmobiles, etc.

As mentioned above, the calculation methods for estimating transport emissions can be roughly classified as top-down and bottom-up approaches. Top-down approaches use the data of fuel consumption as a proxy for travel behavior. The emissions were reported as the result of fuel sold multiplied by an emission factor for each fuel. While in the bottom-up approach, the details of activity data called an ASIF framework to determine the total emissions.

To simplify and suit the data for available sources in this research, the top-down or fuel sales method was used for calculating the emissions from the transportation sector, particularly on-road transportation. In theory, this approach considers fuel sold as a proxy for transportation activity. The activity data was based on the volume of fuel sold and consumed within the city boundary. Calculating fuel sales emissions requires multiplying activity data by the GHG-content of the fuel-by-fuel type (CO_2, CH_4, N_2O). The vehicle registration by vehicle class can be an apportioning factor to allocate total sales by on-road vehicle. As noted, for reporting under scope framework all emissions from fuel sales within the city should be accounted for in scope 1, even though fuel purchases may be for transboundary trips.

The combination of the top-down (fuel consumption) approach and induced activity system boundary is considered in this study. To estimate the emissions from the railway sub-sector in scope 1, it includes the emissions from direct combustion of fossil fuels and electricity consumption incurred during the length of railway transit within the city boundary. The activity data, fuel, and electricity consumption, from the railway operator by application. The distance covered within the city boundary were reported in scope 1 and the lines' extension outside the city will be reported in scope 3. Where the activity data are not available, rail company queries or surveys, scale up of incomplete transportation activity data, or scale down of regional transit system fuel consumption are considered.

For scope 2 emissions from the railway sub-sector, it is assumed the emissions from grid-supplied electricity are used to power rail-based transportation systems. Moreover, emissions from direct fuel combustion and on-grid electricity consumption outside the city boundary can be allocated to report in scope 3. For example, extended lines outside the city boundary for urban transit systems. Waterborne navigation emission calculation includes ships, ferries, and other boats operating within the city boundary, as well as marine-vessels whose journeys originate or end at ports located in the city boundary. However, the emissions from international waterborne navigation and air travel can be excluded according to IPCC Guidelines. The emissions from direct combustion of fossil fuel for trips that originate and terminate within the city boundary is reported in scope 1. The top-down approach is used in this study. The emissions from any grid-supplied electricity consumed by electric ferries or other boats operating within the city boundary is reported in scope 2. In this case, scope 3 covers emissions from departing transboundary trips. Aviation emission calculation includes emission from airborne trips occurring within the geographic boundary and emissions from flights departing airports located in the city. The GPC suggested that a significant number of emissions associated with air travel occur outside the city boundary. To simplify in this study, emissions from the aviation sub-sector were reported in the scope 3 as per GPC's recommendation.

3.2.3.3 Waste

Waste can be treated at facilities inside the city and sometimes it is transported to other cities for treatment. Waste disposal and treatment generally creates greenhouse gas through aerobic and anaerobic decomposition, or incineration. In the reporting framework, the emissions generated from waste are divided into:

Scope 1: Emissions from waste treated inside the city
Scope 2: Not applicable
Scope 3: Emissions from waste generated by the city but treated outside the city

Accounting guidance to estimate greenhouse gas emission in the waste sector is provided in the GPC guideline which following waste management activities:

- Solid waste disposal in landfills or dump sites including disposal in an unmanaged site, disposal in a managed dump or disposal in sanitary landfill.
- Biological treatment of solid waste.
- Incineration and open burning of waste.
- Wastewater treatment and discharge.

The first order of decay (FOD) **(see Eq 4.)** model was used for accounting methane emissions from solid waste disposal. After waste disposal, for about a year it contributes to greenhouse gas in that year and in following years. However, the composition of solid waste from the city needs to be determined. In the absence of a waste composition study, the IPCC Guideline provides sample regional and country-specific data to determine waste composition and carbon factors. The degradable organic carbon can be estimated from **Eq 3**.

$$DOC = (0.15 \times A) + (0.2 \times B) + (0.4 \times C) + (0.43 \times D) + (0.24 \times E) + (0.15 \times F)$$

(3)

Where:

A = Faction of solid waste that is food

B = Faction of solid waste that is garden waste and other plant debris

C = Faction of solid waste that is paper

D = Faction of solid waste that is wood

E = Faction of solid waste that is textiles

F = Faction of solid waste that is industrial waste

The FOD model assumes that the DOC in waste decays slowly over a few decades, and releases CH_4 and CO_2 to the atmosphere. The highest rate of CH_4 generation is in the first year and gradually declines as the degradable carbon left in the waste decomposes. This model is recommended from IPCC Guidelines since it provides a more accurate estimate of annual emissions. However, this model requires historical waste disposal data and other information related to the formulation. The FOD model requests additional information including site opening and closing year, total capacity (in m^3), and density conversion (mg/m^3).

$$CH_4\, emissions = \left[\sum_x \langle MSW_x \times L_0(x) \times \left((1 - e^{-x}) \times e^{-k(t-x)}\right)\rangle - R(t)\right] \times (1 - OX)$$

(4)

Where:

CH4 emissions	= Total CH4 emissions in tonnes
x	= Landfill opening year or earliest year of historical data
t	= Inventory year
MSWx	= Total municipal solid waste disposed at SWDS in year x
R	= Methane collected and removed (ton) in inventory year
L0	= Methane generation potential **(see Eq.5)**
k	= Methane generation rate constant, which is related to the time taken for the DOC in waste to decay to half is initial mass
OX	= Oxidation factor

$$L_0 = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \qquad \textbf{(5)}$$

Where:

L_0 = Methane generation potential

MCF = Methane correction factor based on type of landfill site for the year of deposition factors. (Managed = 1, Unmanaged (≥ 5 m deep) = 0.8, Unmanaged (≤ 5 m deep) = 0.4, Uncategorized = 0.6)

DOC = Degradable organic carbon in year of deposition factor **Eq.3.**

DOCF = Fraction of DOC that is ultimately degraded; assumed 0.6

F = Fraction of methane in landfill gas; default taken 0.5

16/12 = Stoichiometric ratio between methane and carbon

Calculating emissions from biological treatment of solid waste requires recognizing that in some cities, the solid waste is managed by biological treatment. Biological treatment can reduce overall waste volume for the final disposal in landfill. The data of solid waste for biological treatment is suggested to be collected separately, in order to use different sets of emission factors as well as for reporting. The direct emissions from biologically treated solid waste is in **Eq 6** and **Eq 7**.

$$CH_4\, emissions = \sum_i \left(m_i \times EF_{CH_4}\right) \times 10^{-3} - R \qquad \textbf{(6)}$$

$$N_2O emissions = \sum_i \left(m_i \times EF_{N2O}\right) \times 10^{-3} \qquad \textbf{(7)}$$

Where:

CH_4 emissions = Total CH4 emissions in tonnes

N_2O emissions = Total N2O emissions in tonnes

M = Mass of organic waste treated by biological treatment type, kg

EF_{CH4} = CH4 emissions factor base upon treatment type, Table 15

EF_{N2O} = N2O emissions factor base upon treatment type, Table 15

i = Treatment type composing or anaerobic digestion

R = Total tonnes of CH4 recovered in the inventory year if gas recovery **system is in place**

Table 15 *Biological treatment emission factor (IPCC, 2006)*

Treatment type	CH_4 Emissions Factors (gCH_4/ kg waste)		N_2O Emissions Factor (gN_2O/ kg waste)	
	Dry waste	Wet waste	Dry waste	Wet waste
Composting	10	4	0.6	0.3
Anaerobic digestion at biogas facilities	2	1	NA	NA

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 4: Biological Treatment of Solid Waste

CO_2 emissions link to incineration facilities which can be estimated based on the mass and carbon content of waste incinerated at the facility as well as the carbon faction in the solid waste. However, non-CO_2 emissions, including CH_4 and N_2O are more dependent on technology and incinerating conditions. Therefore, to calculate the emissions from waste incineration, it requests the following data: quantity of total solid waste incinerated in the city boundary and the portion of waste generated by other communities and incinerated in the inventory year, type of technology and conditions used in the incineration process, and energy transformation efficiency. The equation for CO_2 emission from incineration processes is shown in **Eq (8).** Also, the CH_4 and N_2O emissions can be calculated in **Eq (9).** Default data for CO_2 emissions factors for incineration and open burning was given in **Appendix A.**

$$CO_2 emissions = m \times \sum_i (WF_i \times dm \times CF_i \times FCF_i \times OX_i) \times \frac{44}{12} \quad \textbf{(8)}$$

Where:

CO_2 emissions = Total CO2 emissions from incineration of solid waste

m = Mass of waste incinerated in tonnes

WF_i = Fraction of waste consisting of type i matter

dm_i = Dry matter content in type i matter

CF_i = Fraction of carbon in the dry matter type i matter

FCF_i = Fraction of fossil carbon in total carbon component of type i matter

OF_i = Oxidation faction or factor

i = Matter type of solid waste incinerated such as paper, textile, food

$$CH_4\ emissions = \sum (IW_i \times EF_i) \times 10^{-6} \quad \textbf{(9)}$$

Where:

CH_4 emission = CH4 emissions in inventory year, tonnes

IWi = Amount of solid waste of type i incinerated or open- burned, tonnes

EFi = Aggregate CH4 emissions factor, gCH4/ton of waste

10^{-6} = Converting factor for gCH4 to tCH4

i = Category or type of waste incinerated or open-burned, specified as follows:

MSW: municipal solid waste

ISW: industrial solid waste

HW: hazardous waste

CW: clinical waste

SS: sewage sludge

As noted, CH_4 emission factors for incineration of MSW were given in **Appendix B.** Beside this, N_2O emissions from solid waste management were computed by using **Eq. 10** and default N_2O emission factors for different types of waste and management practices were provided in **Appendix C**.

$$N_2O\ emissions = \sum (IW_i \times EF_i) \times 10^{-6} \quad \textbf{(10)}$$

Where:

N_2O emission = N2O emissions in inventory year, tonnes

IW_i = Amount of solid waste of type i incinerated or open- burned, tonnes

EF_i = Aggregate N2O emissions factor, gN2O/ton of waste

10^{-6} = Converting factor for gN2O to tN2O

i = Category or type of waste incinerated or open-burned, specified as follows:

MSW: municipal solid waste

ISW: industrial solid waste

HW: hazardous waste

CW: clinical waste

SS: sewage sludge

Calculating emissions from wastewater treatment and municipal wastewater can be conducted by using **Eqs. 11-14**, as follows:

$$CH_4\ emissions = \sum_i \left[(TOW_i - S_i)EF_i - R_i\right] \times 10^{-3} \quad \textbf{(11)}$$

Where:

CH_4 emissions = Total CH4 emissions in tonnes

TOW_i = Organic content in the wastewater, kg BOD/yr

EF_i = Emission factor kgCH4/kg BOD

S_i = Organic component removed as inventory year, kgBOD/yr

R_i = Amount of CH4 recovered in inventory year, kgCH4/yr

i = Type of wastewater

$$TOW_i = P \times BOD \times I \times 365 \quad \textbf{(12)}$$

$$EF_i = B_0 \times MCF_j \times U_i \times T_{i,j} \quad \textbf{(13)}$$

Where:

TOWi = For domestic wastewater: total organic in wastewater in inventory year, kgBOD/yr

P = City's population in inventory year (person)

BOD = City-specific per capita BOD in inventory year, g/person/day

I = Correction factor for additional industrial BOD discharged into sewers

EF_i = Emission factor for each treatment and handling system

B_0 = Maximum CH4 producing capacity

MCF_j = Methane correction factor (fraction)

U_i = Fraction of population in income group i in inventory year

$T_{i,j}$ = Degree of utilization (ratio) of treatment/discharge pathway or system, j, for each income group fraction I in inventory year

$$N_2O\ emissions = [(P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM}) - N_{SLUDGE}] \times EF_{EFFLUENT} \times \frac{44}{28} \times 10^{-3}$$

(14)

Where:

N_2O emissions= Total N2O emissions in tonnes

P = Total population served by the water treatment plant

Protein = Annual per capita protein consumption, kg/person/yr

$F_{NON-CON}$ = Factor to adjust for non-consumed protein Counties with no garbage disposals = 1.1 Countries with garbage disposals = 1.4

F_{NPR} = Fraction of nitrogen in protein; 0.16 kgN/kg protein

$F_{IND-COM}$ = Factor for industrial and commercial co-discharged protein into the sewer system; 1.25

N_{SLUDGE} = Nitrogen removed with sludge, kgN/year; 0

$EF_{EFFLUENT}$ = Emission factor for N2O emissions from discharged to Wastewater in kg N2O-N per kg N2O; 0.005

44/28 = The conversion of kg N2O-N into kg N2O

3.2.3.4 Industrial processes and product use (IPPU)

The greenhouse gas emission sources in the Industrial Processes and Product Use (IPPU) sector can be divided into two categories including industrial process and product use. In this sector, the emissions from the energy consumption in the industrial processes were not included in this calculation. Only the emissions from chemically or physically transformed materials were accounted for. In the GPC, three industrial processes are highlighted and suggested to be considered in the mineral industry: cement production, lime production and glass production. For these processes, CO_2 is released from calcination of carbonate compounds. All emission sources and default emission factors in the mineral industry are provided in **Table 16** and **Eqs 15-17.**

Table 16 *Calculating mineral industry emissions*

Emission sources	**GHG emissions**	**Simplest approach for qualifying emissions**	**Source of active data**	**Link to default emission factor calculation**
Cement production		Emission factor multiplied with weight (mass) of clinker produced	• Contact the operators or owners of the industrial facilities at which the processes occur and obtain relevant activity data. • Contact the national inventory compiler to ask for specific production data within the city boundary.	2.2.1.2 of Page 2.11 from Chapter 2 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Lime production	CO_2	Emission factor multiplied with weight (mass) of each type of lime produce		Table 2.4 of Page 2.22 from Chapter 2 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Glass production		Emission factor multiplied with weight (mass) for each year of glass produced		Table 2.6 of Page 2.30 from Chapter 2 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Source*: GPC, 2017*

$$CO_2 emissions = M_{cl} \times EF_{cl} \quad \textbf{(15)}$$

$$CO_2 emissions = \sum \quad (EF_{lime,i} \times M_{lime,i}) \quad \textbf{(16)}$$

$$CO_2 emissions = M_g \times EF_g \times (1 - CR) \quad \textbf{(17)}$$

Where:

CO_2emissions = CO2 emissions in tonnes

M_{cl} = Weight (mass) of clinker production in metric tonne

EF_{cl} = CO2 per mass unit of clinker production

M_{lime} = Weight (mass) of lime production of lime type i

EF_{lime} = CO2 per mass unit of lime production of lime type i

M_g = Weight (mass) of glass production

EF_g = Emission factor for manufacturing of glass

CR = Cullet ratio for manufacturing of glass

For chemical industry emissions under GPC, the emissions sources are considered the emissions from the production of various inorganic and organic chemicals including Ammonia, Nitric acid, Adipic acid, Caprolactam, Carbide, Titanium dioxide and Soda ash. **Appendix D and E** provide information on emission sources and sources of active data and emission factors used to quantify GHG chemical and metal industry emissions.

To estimate changes in carbon stock depends on data and model availability. Some of them are complicated; however, this research adopted a simplified approach as recommended by GPC, the Gain-Loss Method shown in **Eqs .18 – 28.**

$$\Delta C = \Delta C_B + \Delta C_{DOM} + \Delta C_{soils} \quad \textbf{(18)}$$

Where:

ΔC = Carbon stock changes for a stratum of a land-use category

ΔC_B = Annual change in carbon stocks in biomass for each land sub-category, considering the total area, tonnes C/year

ΔC_{DOM} = Annual change in carbon stocks in dead organic matter, tonnes C/year

ΔC_{soils} = Annual change in carbon stocks in soils, tonnes C/year

$$\Delta G_B = \Delta C_G - \Delta C_L \quad \textbf{(19)}$$

Where:

ΔC_G = Annual increase in biomass carbon stocks due to biomass growth in land remaining in the same land-use category, tonnes C/year

A = Area of land remaining in the same land-use category, ha

G_{TOTAL} = Mean annual biomass growth, tonnes d. m. ha-1 yr-1

CF = Carbon fraction of dry matter, tonne C (tonne d. m-1)

$$\Delta G_{TOTAL} = \sum \{G_W \times (1 + R)\} \quad \textbf{(20)}$$

Where:

G_{TOTAL} = Mean annual biomass growth, tonnes d. m. ha-1 yr-1

G_w = Average annual above-ground biomass growth for a specific woody vegetation type, tonnes d. m. ha-1 yr-1

R = Ratio of below-ground biomass to above-ground biomass for specific vegetation type, tonne d. m. R must be set to zero if assuming no changes of below-ground biomass allocation patterns.

$$\Delta C_L = L_{wood-removals} + L_{fuelwood} + L_{disturbance} \quad \textbf{(21)}$$

Where:

Δ_{CL} = Annual decrease in carbon stocks due to biomass loss in land remaining in the same land-use category, tonnes C/year

$L_{wood\text{-}removals}$ = Annual carbon loss due to wood removals, tonne C/year

$L_{fuelwood}$ = Annual carbon loss due to fuelwood removals, tonnes C/year

$L_{disturbance}$ = Annual carbon loss due to disturbances, tonnes C/year

$$L_{wood-removals} = \{H \times BCEF_R \times (1 - R) \times CF\} \quad \textbf{(22)}$$

Where:

$L_{wood\text{-}removals}$ = Annual carbon loss due to wood removals, tonnes C/year

H = Annual wood removals, roundwood, m3/year

R = Ratio of below-ground biomass to above-ground biomass for specific vegetation type, tonne d. m. R must be set to zero if assuming no changes of below-ground biomass allocation patterns

CF = Carbon fraction of dry matter, tonne C (tonne d. m.)-1

$BCEF_R$ = Biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals, tonnes biomass removal (m3 of removals)-1

$$L_{fuelwood} = \left[\{FG_{trees} \times BCEF_R \times (1 + R)\} + FG_{part} \times D\right] \times CF \quad \textbf{(23)}$$

Where:

$L_{fuelwood}$ = Annual carbon loss due to fuelwood removals, tonnes C/year

FG_{trees} = Annual volume of fuelwood removal of whole trees, m3/year

FG_{part} = Annual volume of fuelwood removal as tree parts, m3/year

R = Ratio of below-ground biomass to above-ground biomass for specific vegetation type, tonne d. m. R must be set to zero if assuming no changes of below-ground biomass allocation patterns.

CF = Carbon fraction of dry matter, tonne C (tonne d. m.)-1

D = Basic wood density, tonnes d. m. m-3

$BCEF_R$ = Biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals, tonnes biomass removal (m3 of removals)-1

$$L_{disturbance} = \{A_{disturbance} \times B_W \times (1 + R) \times CF \times fd\} \quad \textbf{(24)}$$

Where:

$L_{disturbance}$ = Annual carbon loss due to disturbances, tonnes C/year

$A_{disturbance}$ = Area affected by disturbances, ha/year

B_w= Average above-ground biomass of land areas affected by disturbances, tonnes d. m. ha-1

R = Ratio of below-ground biomass to above-ground biomass for specific vegetation type, tonne d. m. R must be set to zero if assuming no changes of below-ground biomass allocation patterns.

CF= Carbon fraction of dry matter, tonne C (tonne d. m.)-1

fd = Fraction of biomass lost in disturbance, default fd=1

$$\Delta C_{DOM} = \frac{(C_n - C_0) \times A_{on}}{T_{on}} \quad \textbf{(25)}$$

Where:

ΔC_{DOM} = Annual change in carbon stock in dead wood, tonne C/year

C_o = Dead wood stock, under the old land-use category, tonnes C/ha

C_n = Dead wood stock, under the new land-use category, tonnes C/ha

A_{on} = Area undergoing conversion from old to new land-use, ha

T_{on} = Time period of the transition from old to new land-use, year default is 20 years for carbon stock increase and 1 year for carbon losses.

$$\Delta C_{soils} = \Delta C_{mineral} - L_{organic} + \Delta C_{Inorganic} \quad \textbf{(26)}$$

Where:

ΔC_{soils} = Annual change in carbon stocks in soils, tonnes C/year

$\Delta C_{mineral}$ = Annual change in organic carbon stocks in mineral soils, tonnes C/year

$L_{organic}$ = Annual loss of carbon from drained organic soils, tonnes C/year

$\Delta C_{inorganic}$ = Annual change in inorganic carbon stocks from soils, tonne C/year assumed to be 0

$$\Delta C_{mineral} = \frac{(SOC_o - SOC_{(o-T)})}{D} \quad \textbf{(27)}$$

$$SOC = \sum_{c,s,i} \left(SOC_{REF_{c,s,i}} \times F_{LU_{c,s,i}} \times F_{MG_{c,s,i}} \times F_{I_{c,s,i}} \times A_{c,s,i} \right) \quad \textbf{(28)}$$

Where:

$\Delta C_{mineral}$ = Annual change in organic carbon stocks in mineral soils, tonne C/year

SOC_0 = Soil organic carbon stock in the last year of an inventory year, tonne C

$SOC_{(0-T)}$ = Soil organic carbon stock in the beginning of an inventory year, tonne C

T = Number of years over a single inventory year, year

D = Time dependence of stock change factors which is the default time for transition between equilibrium SOC value, year (D-20)

SOC_{REF} = The reference carbon stock, tonnes C/ha; SCOREF = 34

F_{LU} = Stock change factor for land-use systems for particular land-use; dimensionless

F_{MG} = Stock change factor for management regime, dimensionless

F_{I} = Stock change factor for input of organic matter, dimensionless

A = Land area of stratum being estimated, ha

Calculating emissions from aggregate sources and non-CO_2 emissions sources on land, the emissions from rice cultivation, fertilizer use, liming and urea application is included as well as the emissions from biomass burning. The emission from biomass burning was estimated from **Eq (29).**

$$GHG = A \times M_B \times CF \times EF \times 10^{-3} \quad \textbf{(29)}$$

Where:

GHG = GHG emissions in tonnes of CO2 equivalent

A = Area of burnt land in ha

M_B = Mass of fuel available for combustion, tonnes/ha

CF = Combustion factor

EF = Emission factor

The emissions from rice cultivation are a significant consideration for cities in Thailand according to the national greenhouse gas inventory. Anaerobic decomposition of organic material in flooded rice fields produces CH_4. This is a function of the number and duration of the crop grown, water regimes before and during cultivation period, and organic and inorganic soil amendments. Estimating of CH_4 emission was conducted by using **Eq 30.**

$$CH_4\ emissions = \sum_{i,j,k} \left(EF_{i,j,k} \times t_{i,j,k} \times A_{i,j,k} \times 10^{-6}\right) \quad \textbf{(30)}$$

Where:

CH_4 emissions = Methane emissions from rice cultivation, Gg

$EF_{i,j,k}$ = Daily emissions factor for i,j,k condition, kg CH4/ha. year

$t_{i,j,k}$ = Cultivation period of rice for i,j,k condition, days

$A_{i,j,k}$ = Harvested area of rice for i,j,k condition, ha/year

i,j,k = Represent different ecosystem, water regimes, type and amount of organic amendments (e.g., irrigated, rain-fed and upland)

3.3 Modeled emission scenarios and greenhouse gas emission target

This section provided details of the methodology employed to model and project greenhouse gas emissions of cities and estimated the potential of emissions reduction targets. The model explored a way to consolidate reduction targets in the cities, and aggregates commitments to give a sense of how the city target may relate to emissions reductions embedded in NDCs. Generally, modeling the city's emission scenarios requires the base year of greenhouse gas inventories, population, and economic data. Additional input data include economic and population growth rate, as well as per capita emissions projection and committed target. The output data of the model presented the annual emissions and trend estimates for the cities according to scenario assumption.

For the proposed model in this study, Baseline scenarios or Business-as-usual (BAU) illustrate cities' projected greenhouse gas emissions absent of achievement or without any city greenhouse gas policy. BAU describes how the current situation would evolve without additional GHG emission reduction activities. In other words, there is basically neither a future GHG reduction policy nor significant relevant technological advancement in the absence of public intervention. The key macroeconomic assumptions are listed to model the BAU scenario which may include population size, urbanization rate, gross provincial product (GPP) and economic structure (Jianyi, 2017). NDC target scenarios were projected in the assumption of achieving Thailand's NDC target and its commitments in the context of the baseline scenario. It can demonstrate cities' future GHG following the national climate change policy and target and without any additional and ambitious target. To meet the objective of this study, as shown in **Figure 20**, more aggressive policies and implementation on climate mitigation options need to be modeled. The ambitious scenario was developed under the assumption of a 1.5^{o}C pathway. This scenario includes the challenging or reinforcing of emission reduction policies introduced in the NDC emission control scenario. Producing the results from these scenario modelling involves three key steps: estimating baseline scenario emissions levels, estimating target scenario emissions levels, and calculating avoided emissions.

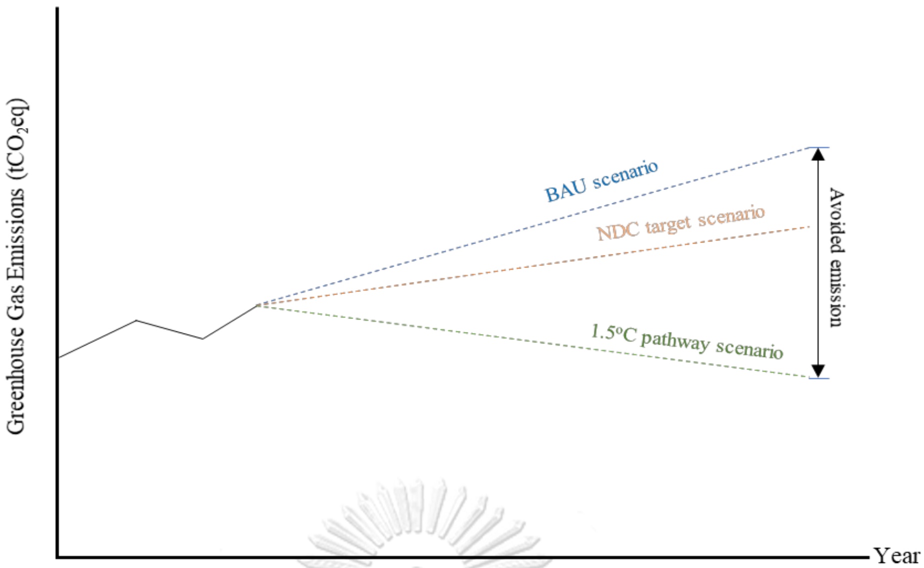


***Figure 20** Modeled scenarios and avoided emissions*

The annual avoided emissions of a given year were estimated based on the difference of baseline scenario emissions in year i and target scenario emissions in the same year. The cumulative avoided emissions over a given number of years were estimated by the sum of the difference of baseline scenario emissions in year i and target scenario emissions in the same year from the base year to target year.

3.3.1 Input data

The choice of input data is important for the quality of analysis results since the model provides methodologies for estimating a cities' emission target which is dependent on the input data used and user assumption specification. In this study, the cities have not provided their target and the model estimates the emissions reduction by assuming adoption of the national target. The following considerations of choosing input data are:

- Providing greenhouse gas inventory data creates the foundation of the model. If a city has committed to setting a target but has not yet reported information about their target the input should include their commitment of target. The model will yield more certain forecasting results.
- To develop scenarios, the compiler must select an appropriate data set

and options appropriate in each scenario e.g., population growth rate, fuel consumption growth rate and GPP growth rate to account for different policy and technology assumptions. Model developers should consider the policy characteristic and sector coverage of adjustment to ensure the selected options suit the city's needs.

- The model can include only scope 1 or scope 1 and 2 depending on the city's policy. In this study, the mitigation options in scope 1 and 2 are considered in the modelling. However, in including scope 1 and 2 there is a possibility of double counting between cities depending on the electricity grid system and whether any city hosts fossil fuel power plants.

3.3.2 Business-as-usual scenario

The first step in producing the model was conducted by estimating the baseline scenario emissions levels for selected cities. Ideally, a baseline scenario analysis would simply use the baseline scenario data from each city's action plan. Some cities have publicly accessible action plans with detailed scenario projections, but most do not, and those that are available are not all comparable. For this model, baseline scenarios were based on each city's historical greenhouse gas emissions level and projected population growth without any climate mitigation actions. The Polynomial regression shown in **Eq (31)** was used in the forecasting data activity model. The independent variable could be displayed in the following from **Eq (32)** and **Eq (33)** were used for linear regression analysis to project the change in populations, households or GPP growth rate for the selected cities.

$$Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \varepsilon \quad \textbf{(31)}$$

$$Economy\ Growth\ Rate\ (\%) = \left[\left(\frac{GPP_{pv}}{GPP_{init}}\right)^{\frac{1}{n}} - 1\right] \times 100 \quad \textbf{(32)}$$

$$Poppulation\ Growth\ Rate\ (\%) = \left[\left(\frac{Population_{pv}}{Population_{init}}\right)^{\frac{1}{n}} - 1\right] \times 100 \quad \textbf{(33)}$$

Where

pv is present value at the end of the historical periods, *init* is the initial value of projected parameter, and *n* is the number of consideration years.

3.3.2 Target emission scenarios

Target scenarios are the projection of greenhouse gas emissions to limit or reduce their emissions under the specific assumption. In this study, two target emission scenarios were developed, an NDC target scenario and a 1.5^{o}C pathway scenario by creating under different assumptions. The NDC target scenario was created under Thailand's NDC target, while the 1.5^{o}C pathway is created under the world target for 2050.

As classified in the GPC, target year emissions can be considered as four categories as seen in **Table 17.** To align with Thailand's NDC target approach, the baseline scenario target base was used. The calculation of greenhouse gas emissions level for baseline scenario target is in **Eq 34**.

$$Target\ year\ emissions = BE_{projected,\ yr} \times (1 - ER_{yr}) \quad \textbf{(34)}$$

Where

$BE_{projected,\ yr}$ is the projection baseline emissions in the target year and

ER_{yr} is a percent reductio at the target year.

Table 17 *Target Categories according to the GPC standard*

Base Year Target	Reduce, or control the increase of emissions by a specific quantity relative to a base year, such as a 25% reduction from 2010 by 2050
Fixed-Level Target	Reduce, or control the increase of, emissions to an absolute emissions level in a target year. One type of fixed-level goal is a carbon neutrality goal, which is designed to reach net zero emissions by a certain date.
Base Year Intensity Target	Reduce emissions intensity (emissions per unit of other variable, typically gross domestic product) by a specified quantity relative to a base year, such as a 40% reduction in emissions intensity from the base year 2000 by 2050
Baseline Scenario Target	Reduce emissions by a specified quantity relative to a projected emissions baseline scenario. A baseline scenario represents future conditions most likely to occur in the absence of activities taken to meet the target such as a 30% reduction from 2050 baseline scenario emissions.

Source: *The Global Covenant of Mayors for Climate and Energy Model, 2020*

The model of target emission scenarios was constructed to provide an estimation of the baseline and potential target emissions of the cities. It requires proxy data to estimate potential emissions and targets. This could be achieved by presuming greenhouse gas emissions per capita and target for cities. A set of socioeconomic and emission calculation parameters are matched, and proxy targets generated for the scenarios.

3.4 Development of criteria decision analysis

This section describes a tool used in this study for identification of criteria on mitigation options proposed in each target emission scenario. The first element for developing an analysis tool is defining a criteria decision framework **(see Figure 21).** The framework was developed under the concept of the modified research framework in Figure 14 which is a mix of top-down and bottom-up approaches. The country's low carbon development policy and implementation are reviewed by experts. The city's long list of climate mitigation will be bottom-up, with provinces identifying potential mitigation opportunities in context of their development plans. Additionally, local benefits are considered to make the policy more sustainable, including social interest, local authority responsibility, local environment, and local economy. The city's potential mitigation measures are then analyzed for cost effectiveness by using the Marginal Abatement Cost Curve (MAC).

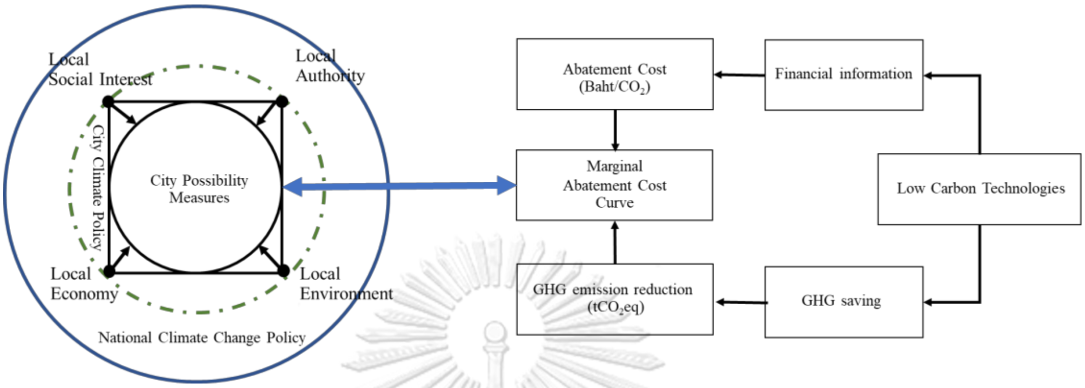
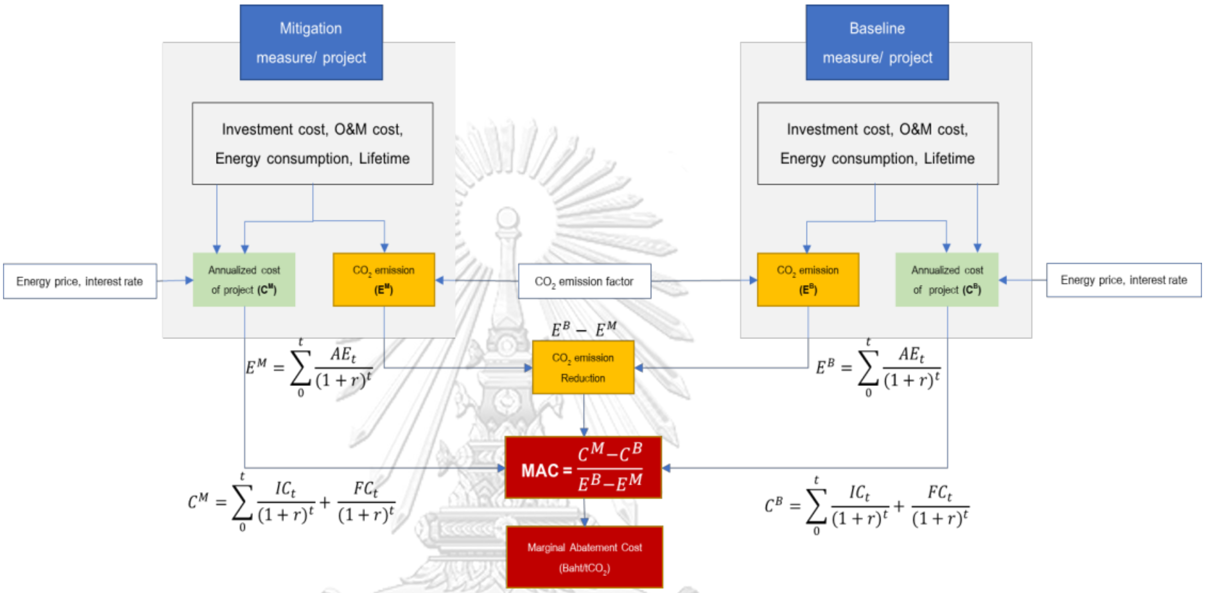


Figure 21 *Criteria decision framework*

According to the literature review in Chapter II, MAC curves are a common tool to identify cost effectiveness for a set of mitigation measures. The cost curve illustrates the range of emissions reduction and technological cost to compare each potential technology. It could be a visual representation of a set of climate mitigation measures listed from the most cost effective per tonne of carbon dioxide equivalent abated to the least cost effective. To generate a MAC, it is necessary to determine financial data of the specific measures and the expected volume of greenhouse gas saving over the project lifetime. Sourcing this information is limited and challenging. The simplification of the calculation is needed on some points. However, the basic financial data needed for MAC development are project lifetime, total cost of the project, any expected savings to be delivered by the project, and volume of greenhouse gas emissions saved over the project lifetime. The project lifetime is the number of years for which a project is expected to be implemented during the policy period. In the analysis, the climate mitigation options can be an infrastructure or asset component which normally use the asset lifetime as the project lifetime. The project cost refers to the total implementation cost and any ongoing operational costs required for the life of the project. It could be upfront capital cost, cost of finance, operational expenses, and discount rate. In this study, to simplify this as data available, the capital and operational cost are considered. And the 3% discount rate (Alex, 2020) was set to reflect a low risk that the future value of money was diminished. To determine the emission reduction saving from an abatement project, it can be changed in consumption by multiplying by an emission factor. The step of marginal abatement cost is illustrated in **Figure 22**.



Note: the concept diagram has applied from Japan Scenarios and Actions towards Low-Carbon Societies (LCSs)

***Figure 22** Marginal abatement cost calculation chart*

The marginal abatement cost of each mitigation technology was calculated by **Eqs. 35 – 38** as follows:

$$MAC = \frac{C^M - C^B}{E^B - E^M} \qquad \textbf{(35)}$$

Where

C is a discounted total costs and E refers to total emissions, in particular greenhouse gas emissions technology, while superscripts M and B refer to the case of greenhouse mitigation and baseline.

$$C = \sum_0^t \quad \frac{IC_t}{(1+r)^t} + \frac{FC_t}{(1+r)^t} \tag{36}$$

$$E = \sum_0^t \quad \frac{AE_t}{(1+r)^t} \tag{37}$$

Where

IC refers to annualized investment cost, *FC* refers to annual operational expenses, *AE* is an annual greenhouse gas emissions which t refers to period of consideration time and r is discount rate.

$$IC = INV \times r \times \frac{(1+r)^n}{(1+r)^n - 1} \tag{38}$$

Where

INV is an upfront investment cost of a mitigation option and n is economic lifetime, which is not a same as t in **Eq 38**, of the measures.

The basis of a MAC curve is illustrated in **Figure 23.** It presents a simple marginal abatement cost curve. The curve was divided into discrete blocks. Each block represents an individual greenhouse gas reduction measure. As an example, in combining various measures, the width indicates the amount of potential carbon emission abatement (tCO_2eq) while the height estimates the marginal cost of the carbon emission abatement ($\$/tCO_2eq$). The blocks are ordered such that the lowest cost options, which may represent negative cost, are shown first on the left with subsequent higher cost options proceeding to the right. However, the MAC does not inform which measures should be implemented or not be implemented. It provides input information to a decision-making process. The city can decide to implement some of the measures in order of least cost abatement; however, it can depend on the national or local policy and budget.

To complete the objectives this research, SWOT analysis was adopted to identify strengths, weaknesses, opportunities, and threats of having city greenhouse gas emission reduction target and climate mitigation strategy. This is designed to facilitate a realistic, fact-based, data-driven look at the strengths and weaknesses in local perspective. Interviews have been carried out with key actors in the city and climate mitigation experts.

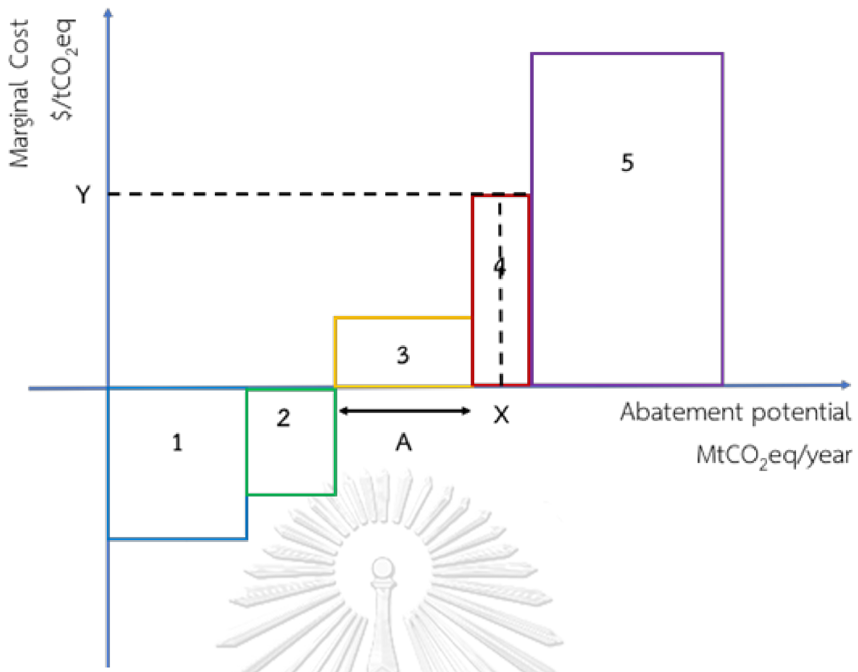


Figure 23 *Basic marginal abatement cost curve*

CHAPTER IV
RESULTS AND DISCUSSIONS

This chapter provided the overall results of greenhouse gas inventory at the base year, projection in baseline scenario and target emissions scenarios in each selected provinces including Bangkok, Chiang Mai and Rayong. The overall of greenhouse gas emissions in five key sources in base year (2015) according to GPC guidance are presented and forecast the trend of greenhouse gas emissions in three scenarios to target year (2050). The five key sectors are included: stationary energy, transportation, waste, industrial process, and product use (IPPU), agriculture forestry and other land use (AFOLU), as following:

4.1 Greenhouse gas inventory and projections

4.1.1 Bangkok's greenhouse gas inventory in base year

Bangkok is the capital city of Thailand and the most populated city in the countries. According to the report East Asia's Changing Urban Landscape (World Bank, 2015), Bangkok was the fifth largest in East Asia in terms of area and ninth largest in terms of its population approximately 9.40 million in 2015 (BMA, 2016) including registered and non-registered population. Bangkok population has been projected, by United Nations – World Population Prospects, having around 12.48 million in 2050 (Daniel H, 2014). The GHG inventory was scoped in the geographically area of Bangkok city. It is including the greenhouse gas sources happening in the Bangkok city area as well as greenhouse gas emissions that appear outside the city boundary as a result of activities taking place within the city border. The period used for Bangkok greenhouse gas inventory in this research was a continuous of 12 months, aligning to a calendar year. Additionally, calculation methodologies in the GPC generally quantify emission released during the reporting year. The study boundary is illustrated in **Figure 24.**

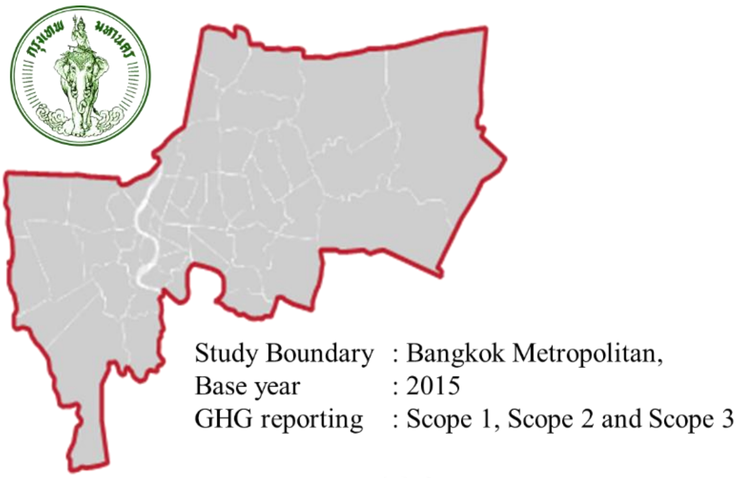


Figure 24 *Bangkok's greenhouse gas Inventory Boundary*

In 2015, the overall greenhouse gas emissions were estimated all sectors according to the framework mentioned in Chapter III. The Bangkok emissions were around 41.25 MtCO_2eq reporting in the basis of BASIC+ while the emissions were generated around 36.32 MtCO_2eq in reporting of BASIC concept. This is accounted as 4.64 tCO_2eq per capita for the BASIC+ and 4.08 tCO_2eq per capita for the BASIC. **Figure 25** showed that 36.65% of total emissions in 2015 was accounted in Scope1, while the greatest greenhouse gas emissions were presented 51.62% of total emissions was accounted in Scope2 which related to the electricity consumption in stationary energy and transportation sectors. The emissions in Scope3 were reported at 11.73% of total Bangkok greenhouse gas emissions in 2015.

Considering in sector level, in 2015, the greatest greenhouse gas emissions were accounted in stationary energy sector of 24.50 MtCO_2eq or 59.38% of total emission reported in BASIC+. It is followed by transportation sector which approximated at 12.42 MtCO_2eq which is 30.09% of total emissions. Emissions from waste sector was intimately generated at 4.24 MtCO_2eq or 10.27% and the rest from AFOLU which estimated around 0.26% or 0.10 MtCO_2eq. The summary of Bangkok greenhouse gas inventory in base year is presented in **Table 18.**

***Table 18** Bangkok's greenhouse gas emission inventory in base year (2015)*

GHG Emission Source		Total GHG Emission (Metic tonnes CO_2e)				
		Scope 1	Scope 2	Scope 3	BASIC	BASIC+
I. Stationary Energy	Total fuel combustion	3,349,437	21,150,608	IE	24,500,045	24,500,045
	Energy generation supplied to the grid	84,805				
II. Transportation	Total	10,787,686	147,270	1,481,100	10,934,957	12,416,057
III. Waste	Waste generated within the city boundary	883,091		3,355,030	883,091	4,238,121
	Waste generated outside the city boundary	NO				
IV. Industrial Processes and Product Uses (IPPU)	Total	NE				0
V. Agriculture, Forestry and Other Land Use (AFOLU)	Total	101,904				101,904
VI. Other Scope 3	Total					0
Total		15,122,117	21,297,879	4,836,130	36,318,092	41,256,126

Sources required for BASIC reporting

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

\+ Sources required for BASIC+ reporting

Non-applicable emissions

Sources included in Other Scope 3

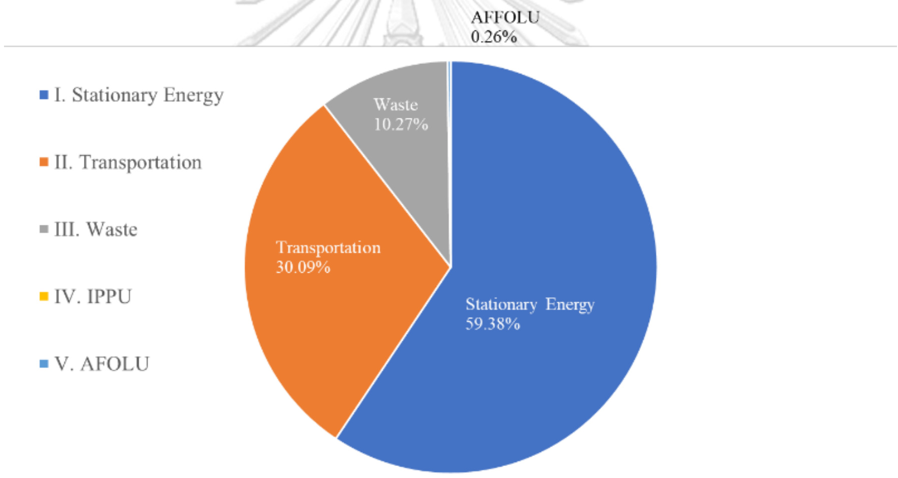


***Figure 25** Bangkok's greenhouse gas inventory in the base year (2015)*

4.1.1.1 Stationary energy

According to the GPC guideline, the emission sources are divided into eight sub-sectors showed in the **Table 19** including (I.1) Residential building, (I.2) Commercial and instructional building and facilities, (I.3) Manufacturing industries and construction, (I.4) Energy industries, (I.5) Agriculture, forestry and fishing activities, (I.6) Non-specified sources, (I.7) Fugitive emissions from mining, processing, storage, and transportation of coal, and (I.8) Fugitive emissions from oil and natural gas system.

***Table 19** Bangkok's greenhouse gas emissions in stationary energy sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
I. Stationary Energy					
I.1	Residential buildings	317,793	5,698,457	IE	6,016,251
I.2	Commercial and institutional buildings and facilities	58,231	9,720,931	IE	9,779,161
I.3	Manufacturing industries and construction	1,431,296	4,518,621	IE	5,949,917
I.4.1/2/3	Energy industries	NO	NO	IE	0
I.4.4	Energy generation supplied to the grid	84,805			
I.5	Agriculture, forestry and fishing activities	IE	IE	IE	0
I.6	Non-specified sources	1,542,116	1,212,600	IE	2,754,716
I.7	Fugitive emissions from mining, processing, storage, and transportation of coal	NO			0
I.8	Fugitive emissions from oil and natural gas systems	NO			0
Total		**3,349,437**	**21,150,608**	**0**	**24,500,045**

Sources required for BASIC reporting

\+ Sources required for BASIC+ reporting

Sources included in Other Scope 3

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

Non-applicable emissions

As the result in **Table 19**, the overall emissions in stationary energy sector were estimated at 24.50 $MtCO_2eq$. The residential building sub-sector was accounted at 6.01 $MtCO_2eq$ or 24.56% of total emission in this sector. These emissions largely contributed from the energy consumption in household including LPG and electricity. The emissions in commercial building were estimated around 9.77 $MtCO_2eq$ which shared at 39.91% of total emissions in this sector. The main source of emissions in commercial building was electricity consumption in sub-sector. The emissions in manufacturing industries presented in the third rank of total greenhouse gas emissions in stationary energy sector. It was estimated around 5.94 $MtCO_2eq$ or 24.28% of total emissions in this sector, following by the emissions in non-specific source at 2.75 $MtCO_2eq$ or 11.25% of total emission in the stationary energy sector.

As per reporting system, the emissions were reported in the Scope 1 around 3.34 $MtCO_2eq$ or 13.67% of the total emission in this sector. The emissions were reported in the Scope 2 estimated at 21.15 $MtCO_2eq$ or 86.33% of total emission in this sector. This can be converted that main source of greenhouse gas emissions in stationary energy sector was the electricity consumption activity. Moreover, 0.84 $MtCO_2eq$ of were estimated as the contribution of power plant located in Bangkok which supplied electricity to the national grid which required the city to report, but not including in the BASIC and BASIC+ reporting. According to the study boundary, the data dose not available for energy consumption in agriculture, forestry, and fishing activities in Bangkok: however, it is considered to be included elsewhere. Also, the fugitive emissions from coal, oil and natural gas system are not occurring in the study boundary.

4.1.1.2 Transportation

In transportation sector, the emissions were divided into five categories including (II.l) On-road transportation, (II.2) Railway, (II.3) Waterborne navigation, (II.4) Aviation and (II.5) Off-road transportation. The fuel sales approach is used to estimate the greenhouse gas emission in this sector. The total emission from the transportation sector was estimated around 12.42 $MtCO_2eq$ which sharing at 30.09% of total emission in the base year. Emissions from on-road transportation was estimated around 10.76 $MtCO_2e$ or 86.70% of total emissions in transportation sector **(Table 20).**

Table 20 *Bangkok's greenhouse gas emissions in transportation sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2eq)			
		Scope 1	Scope 2	Scope 3	Total
II. Transportation					
II.1	On-road transportation	10,764,901	NO	NO	10,764,901
II.2	Railways	6,370	147,270	88,229	241,869
II.3	Waterborne navigation	16,415	NO	748,449	764,864
II.4	Aviation	NO	NO	644,422	644,422
II.5	Off-road transportation	IE	NO		0
Total		10,787,686	147,270	1,481,100	12,416,057

Sources required for BASIC reporting
Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)
+ Sources required for BASIC+ reporting
Non-applicable emissions
Sources included in Other Scope 3

The emissions from on-road transportation sub-sector were mostly from the motor fossil fuel consumption including diesel oil, gasoline, natural gas, and liquefied petroleum gas. The second largest of greenhouse gas emissions in this sector in 2015 was the emissions from waterborne navigation. It was estimated around 0.76 $MtCO_2eq$, following by the emissions from aviation at 0.64 $MtCO_2eq$ and railway at 0.24 $MtCO_2eq$, respectively. However, the emissions from aviation sub-sector were reported in Scope 3 as suggested by the GPC as well as the waterborne navigation which is transboundary journey.

4.1.1.3 Waste

In the study boundary, there is a strong correlation between municipal solid waste generated in the city and level of greenhouse gas emission. GPC divided emission sources into four key sub-sector including solid waste and wastewater. The emissions from this sector also depend on the treated technology as mentioned in Chapter III. The four key sub-sectors are (III.1) Solid waste disposal, (III.2) Biological treatment of waste, (III.3) Incineration and open burning, and (III.4) Wastewater treatment and discharge. The greenhouse gas emissions from the sector are presented in **Table 21**

***Table 21** Bangkok's greenhouse gas emissions in waste sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2eq)			
		Scope 1	Scope 2	Scope 3	Total
III. Waste					
III.1.1/2	Solid waste disposal	NO		3,355,030	3,355,030
III.2.1/2	Biological treatment of waste	41,421		NO	41,421
III.3.1/2	Incineration and open burning	9,952		NO	9,952
III.4.1/2	Wastewater treatment and discharge	831,717		NO	831,717
III.1.3	Waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary	NO			
III.2.3	Waste generated outside the city boundary but treated biologically within the city boundary	NO			
III.3.3	Waste generated outside the city boundary but treated within the city boundary	NO			
III.4.3	Wastewater generated outside the city boundary but treated within the city boundary	NO			
Total		883,091	0	3,355,030	4,238,121

Sources required for BASIC reporting

\+ Sources required for BASIC+ reporting

Sources included in Other Scope 3

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

Non-applicable emissions

The most of greenhouse gas emissions in waste sector in Bangkok was solid waste disposal sub-sector, followed by emissions from wastewater treatment and discharge. The emissions from solid waste disposal were estimated at 3.35 $MtCO_2e$, accounting at 79.16% of total emission in this sector in the base year. The 0.83 $MtCO_2eq$ was generated from wastewater treatment sub-sector. The rest formed biological treatment of waste and incineration and open burning sub-sector.

4.1.1.4 Industrial processes and product uses (IPPU)

The following two sub-sectors used to estimate IPPU emissions in this research: (IV.1) Industrial processes occurring within the city boundary and (IV.2) Product use occurring within the city boundary. According to definition provided in the GPC, there were no activities related to IPPU emissions in the study boundary of Bangkok.

***Table 22** Bangkok's greenhouse gas emissions in IPPU sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2eq)			
		Scope 1	Scope 2	Scope 3	Total
IV. Industrial Processes and Product Uses (IPPU)					
IV.1	Industrial processes occurring within the city boundary	NO			0
IV.2	Product use occurring within the city boundary	NE			0
Total		0	0	0	0

Sources required for BASIC reporting

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

\+ Sources required for BASIC+ reporting

Non-applicable emissions

Sources included in Other Scope 3

4.1.1.5 Agriculture, forest and other land use (AFOLU)

According to the GPC, the three main sources of AFOLU emissions are (V.1) Livestock within the city boundary, (V.2) Land within the city boundary and (V.3) Aggregate sources and non-CO_2 emissions sources on land within the city boundary. In 2015, total greenhouse gas emissions were estimated around 0.10 MtCO_2eq (0.24% of total emission) in 2015 in Bangkok. The largest emissions were generated by aggregate sources and non-CO_2 emission sources on land within the city boundary (93.07% of total emission) in this sector, following by emissions from livestock (7,059 tCO_2eq). The AFOLU emissions in Bangkok in 2015 were reported in the **Table 23.**

***Table 23** Bangkok's greenhouse gas emissions in AFOLU sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2eq)			
		Scope 1	Scope 2	Scope 3	Total
V. Agriculture, Forestry and Other Land Use (AFOLU)					
V.1	Livestock within the city boundary	7,059			7,059
V.2	Land within the city boundary	0			0
V.3	Aggregate sources and non-CO_2 emission sources on land within the city boundary	94,844			94,844
Total		101,904	0	0	101,904

Sources required for BASIC reporting

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

\+ Sources required for BASIC+ reporting

Non-applicable emissions

Sources included in Other Scope 3

4.1.2 Bangkok's greenhouse gas projections

According to the projection methodology stated in Chapter III, the projections of the greenhouse gas emissions in this research are considered in three scenarios involving baseline scenario or business-as-usual (BAU), NDC target scenario and 1.5°C pathway scenario.

4.1.2.1 Business-as-usual (BAU) scenario

The key macroeconomic assumptions were used to model the scenario including the following data: population size and gross provincial produce (GPP). These data are based on the city's historical data and the forecasting data activity model mentioned in the Chapter III. For this research, the greenhouse gas emission was forecasted to 2050 according to research timeframe. The result of BAU scenarios, the greenhouse gas emissions was projected to 57.74 $MtCO_2eq$ in 2030 from 41.25 $MtCO_2eq$ in the base year 2015 and expected to reach 112.53 $MtCO_2eq$ in the target year 2050 (**Figure 26**).

Table 24 *Projection of greenhouse gas emissions in Bangkok in2050*

Year	2015	2030	2050
GHGs ($MtCO_2eq$)	41.25	57.74	112.53

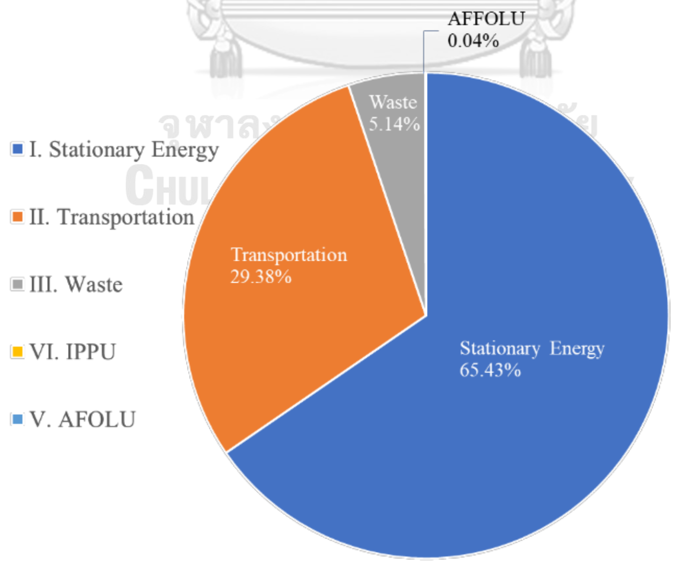


Figure 26 *Bangkok's greenhouse gas inventory in the target year (BAU scenario 2050)*

In 2050, the stationary energy is expected to be a largest contribution source in Bangkok in particular greenhouse gas emissions from electricity consumption in residential and commercial buildings estimated at 65.43% of total expected greenhouse gas emissions in 2050. Following by transportation sector, this sector is projected to generate greenhouse gas around 29.38% of total expected greenhouse gas emissions in 2050. Waste sector was a source where possibly generate emissions around 5.14% of total emissions in the target year.

Considering to sub-sector greenhouse emission prediction, **Figure 27** shows the trend of greenhouse gas emission for key sub-sectors in BAU scenario. On-road transportation was the largest contributor to greenhouse gas emissions in the target year accounted for 31.13 $MtCO_2eq$, while the emissions from commercial building were expected to contribute around 28.31 $MtCO_2eq$. The residential building and solid waste disposal sub-sector were expected to contribute around 13.10 $MtCO_2eq$ and 7.71 $MtCO_2eq$ of GHGs emissions in 2050, respectively.

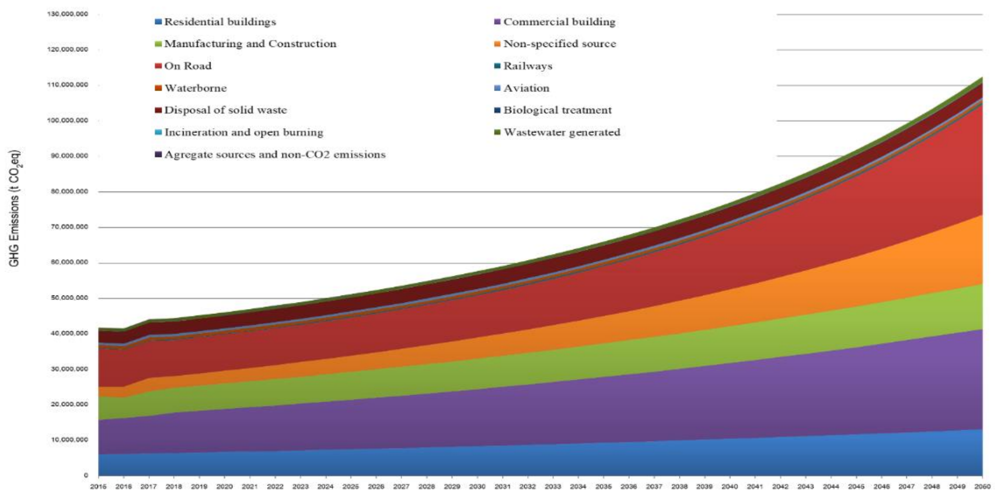


Figure 27 *Bangkok's greenhouse gas emission projections under business-as-usual scenario (2015-2050)*

Table 25 *Assumption used in business-as-usual scenario (Bangkok)*

Sector	Activity Data	Assumption
Stationary Energy	LPG	Residential sector = -0.5% growth rate Commercial sector = -0.5% growth rate Manufacturing sector = 1.7% growth rate
	Electricity	Residential sector = 2.3% growth rate Commercial sector = 2.9% growth rate Manufacturing sector = 1.6% growth rate
	Diesel	Manufacturing sector = 1.44% growth rate
	Fuel oil	Manufacturing sector = 6.4% growth rate
Transportation	LPG	On-road = -14.4% growth rate
	Electricity	Railway = 2.3% growth rate
	Diesel	On-road = -1.55% growth rate
	Benzene	On-road = -0.31% growth rate
	Gasohol E85	On-road = -2.47% growth rate
	Gasohol E20	On-road = 10.40% growth rate
	Gasohol 91/95	On-road = 2.74% growth rate
Waste	Solid waste	Population = 2.8% growth rate
	Wastewater	Population = 2.8% growth rate
AFOLU	Livestock	GHG emissions = 2.43% growth rate
	Non-CO_2	GHG emissions = -2.97% growth rate

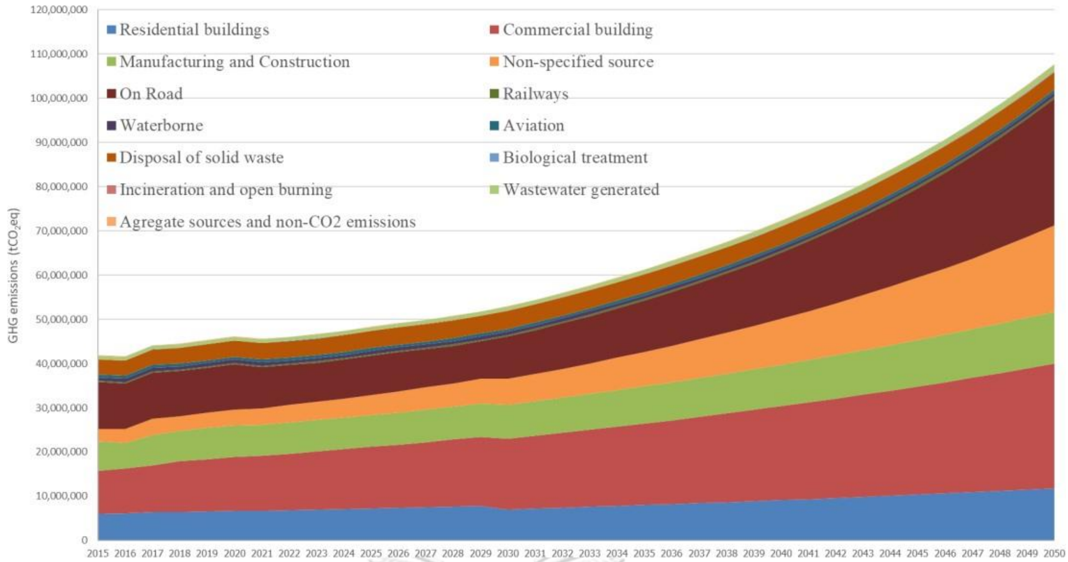
4.1.2.2 NDC target scenario

This scenario provided the overview projection under the application of national emission reduction target committed in the NDC. According to the NDC implementation plan, some measures could not be feasible to implement in the sub-national level. Then, only the expert's adjustment measures were considered and focused to represent the possibility to implement the NDC target scenario.

As expert's comments, the energy efficiency measures in residential and commercial building were recommended. In the transportation sector, increasing the energy consumption in transportation sector, promoting of biofuel, and shifting the transportation type were also suggested. Source waste prevention and reduction and waste management were the key recommendation in the waste sector. The trend of greenhouse gas emission in NDC target scenario is illustrated in the **Figure 28**. As the result of NDC scenario model, results shown that greenhouse gas emissions are projected to 52.80 $MtCO_2eq$ in 2030 from 41.25 $MtCO_2eq$ in the base year 2015 and it is expected to 107.59 MtCO2eq in the target year 2050 (**Table 26**).

Table 26 *Projections of greenhouse gas emissions in Bangkok in 2050*

Year	2015	2030	2050
GHGs ($MtCO_2eq$)	41.25	52.80	107.59



Note: Considered the mitigation option in National Determined Contribution Roadmap on Mitigation 2021–2030

***Figure 28** NDC target Scenario*

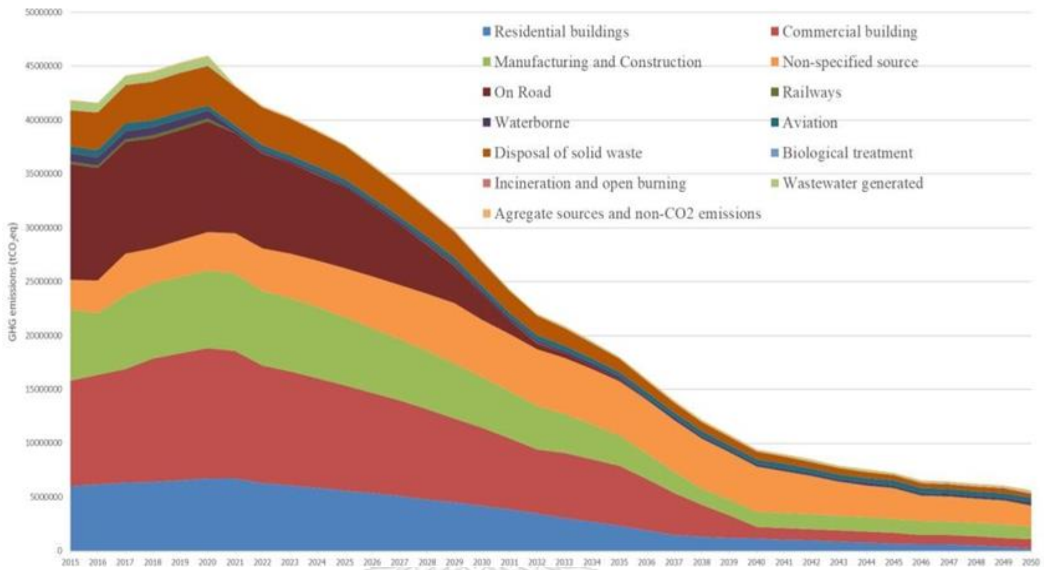
Considering to sub-sector greenhouse emission prediction, **Figure 28** shows the trend of greenhouse gas emission for key sub-sectors in NDC target scenario. On-road transportation was the largest greenhouse gas emissions source in Bangkok in the target year (2050) accounted around 28.75 $MtCO_2eq$, while the emissions from commercial building are expected to contribute around 28.22 $MtCO_2eq$. The residential building and solid waste disposal sub-sector are expected to generate around 11.75 $MtCO_2eq$ and 6.87 $MtCO_2eq$ in 2050, respectively.

4.1.2.3 1.5°C pathway scenario

This scenario provided the overall greenhouse gas emission aligned with the 1.5°C pathway suggested in IPCC special report. The scenario was developed under the assumptions suggested in the C40 report (C40, 2019). Under 1.5°C pathways, electricity supply by renewables should be reached 85% by 2050. In the transportation sector, roughly 30% emission reduction in final energy consumption by 2050 are consistent with limiting 1.5°C scenario. Moreover, residential, and commercial building sector was expected to contribute to 90% GHG reduction potential (**Figure 29**). According to C40's study, a share of Southeast Asia cities' emission allocation could be at least 0.7 tCO_2eq per capita in 2050 (C40, 2019). As the result of 1.5°C pathway scenario model, it shows that the greenhouse gas emissions were projected to 27.01 $MtCO_2eq$ in 2030 from 41.25 $MtCO_2eq$ in the base year 2015 and expected to 5.64 $MtCO_2eq$ in the target year 2050 (**Table 27**)

Table 27 *Projection of greenhouse gas emissions in Bangkok in 2050*

Year	2015	2030	2050
GHGs ($MtCO_2eq$)	41.25	27.01	5.64



Note: Assumption based on global 1.5°C pathway target (0.7 tCO2eq/capita), C40

Figure 29 *The 1.5°C Pathway Scenario for Bangkok*

Under the assumption of 1.5°C pathway, the commercial building and on-road transportation activities were considered the largest potential for emission reduction in Bangkok. In 2050, the commercial building could be allowed to generate around 0.85 $MtCO_2eq$ and zero emissions for on-road transportation. Residential building could allow to create only 0.26 $MtCO_2eq$ in 2050. **Figure 29** shows the greenhouse gas emission profile under the assumption in 1.5°C pathway scenario.

4.1.3 Chiang Mai's greenhouse gas inventory in base year

Chiang Mai is the biggest province in the north of Thailand, and it is a reginal economic hub in the northern Thailand. The population of Chiang Mai were 1.72 million. The density of population is about 77 people per square kilometers. The total household was 742.489 in 2015 respectively (ONESDC, 2019). In 2015, ChiangMai's gross provincial produce (GPP) was 206,857 million baht, sharing by agriculture 22.2%, manufacturing 9.5%, trade and services 12.5%, hotel and restaurant 6.9%, and other 48.9%. In 2015, the number of tourists visit Chiang Mai totally were 8.66 million people including local Thai around 70.28% and foreigner 29.72%. Socio-economic progress of Chiang Mai in the base year of 2015 is given in **Table 28.**

Table 28 *Chiang Mai's socio-economic in the base year (2015)*

Socio-Economic Parameter	Unit	Chiang Mai	Thailand	Contribution
Population	million	1.72	65.73	2.61%
GPP	million baht	206,857	9,512,400	2.17%
GPP-Agriculture	million baht	45,922	615,000	7.46%
GPP-non-agriculture	million baht	160,935	8,972,600	1.79%
Area of province	square kilometers	22,135	513,115	4.31%

The scope of base year inventory was identified as the geographically occupied all area in Chiang Mai. Then the inventory included the greenhouse gas sources occurring in Chiang Mai's area as well as greenhouse gas emission that occur outside the city boundary as a result of activities taking place within the city area. The period used for Chiang Mai greenhouse gas inventory in this research was a continuous of 12 months, aligning to a calendar year. Additionally, calculation methodologies in the GPC generally quantify emission released during the reporting year. The study boundary is illustrated in **Figure 30.**

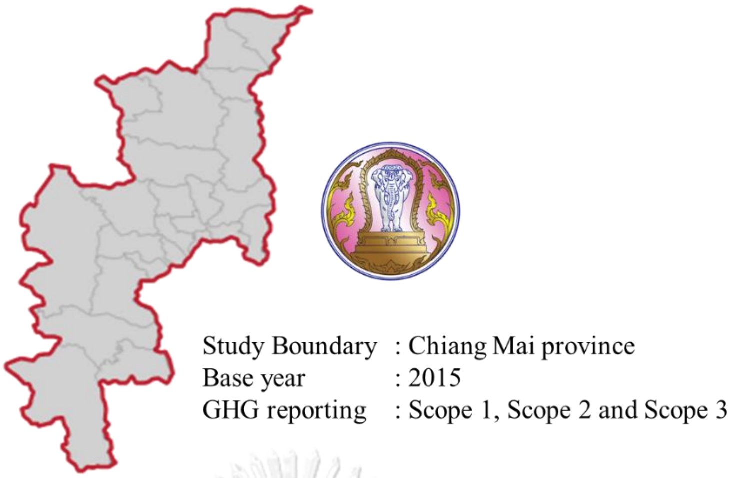


Figure 30 Greenhouse Gas Inventory Boundary in Chiang Mai, Thailand

In 2015, the total greenhouse gas emissions were estimated from all sectors according to the framework mentioned in Chapter III. The total emissions in Chiang Mai were around 6.82 $MtCO_2eq$ reporting in the basis of BASIC+, while the emissions were about 4.75 $MtCO_2eq$ in reporting of BASIC concept. This was accounted as 6.40 tCO_2eq per capita for the BASIC+ and 4.45 tCO_2eq per capita for the BASIC. **Table 28** showed that 67.59% of total emissions in 2015 accounted in Scope1, while Scope2 related to the electricity consumption in stationary energy and transportation sectors were the greatest emissions (28.45%). Only 4.21% of total greenhouse gas emissions came from Scope 3 of greenhouse gas emissions in 2015. By sector, in 2015, the greatest greenhouse gas emission was stationary energy sector (2.27 $MtCO_2eq$ or 33.32% of total emission) reported in BASIC+, followed by transportation sector (2.18 $MtCO_2eq$ or 32.06% of total emissions). Emissions from waste sector was intimately generated at 576,574 tCO_2eq or 8.44%, while the AFOLU emissions were about 26.18% or 1.78 $MtCO_2eq$ **(Figure 31).** The summary of Chiang Mai greenhouse gas inventory in base year is presented in **Table 29.**

***Table 29** Chiang Mai's greenhouse gas emission inventory at base year (2015)*

GHG Emission Source		Total GHG Emission (Metic tonnes CO_2e)				
		Scope 1	Scope 2	Scope 3	BASIC	BASIC+
I. Stationary Energy	Total fuel combustion	332,582	1,942,888	NO	2,275,470	2,275,470
	Energy generation supplied to the grid	NO				
II. Transportation	Total	1,901,783	47	287,544	1,901,829	2,189,373
III. Waste	Waste generated within the city boundary	576,574		0	576,574	576,574
	Waste generated outside the city boundary	17,409				
IV. Industrial Processes and Product Uses (IPPU)	Total	NE				0
V. Agriculture, Forestry and Other Land Use (AFOLU)	Total	1,787,546				1,787,546
VI. Other Scope 3	Total					0
Total		4,615,895	1,942,935	287,544	4,753,874	6,828,964

Sources required for BASIC reporting

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

\+ Sources required for BASIC+ reporting

Non-applicable emissions

Sources included in Other Scope 3

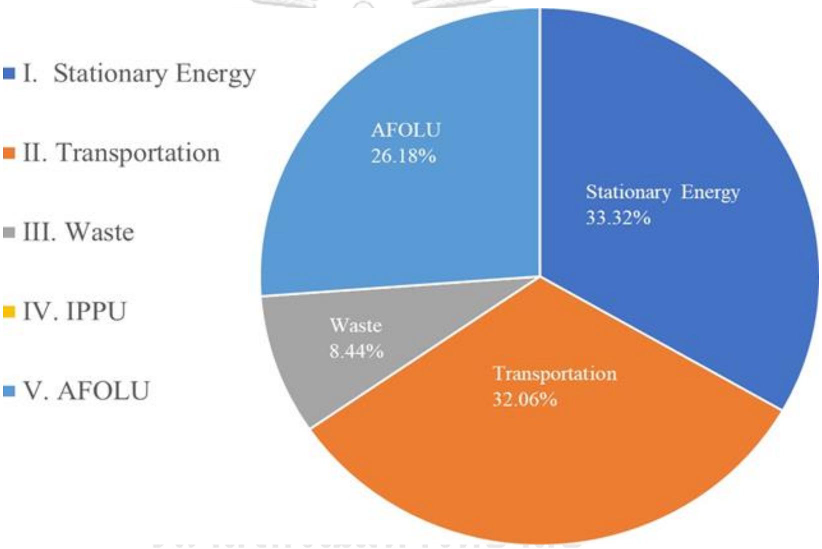


***Figure 31** Chiang Mai's greenhouse gas inventory in base year (2015)*

4.1.3.1 Stationary energy

According to the GPC guideline, **Table 30** presented the key sources of stationary energy emissions including (I.1) Residential building, (I.2) Commercial and instructional building and facilities, (I.3) Manufacturing industries and construction, (I.4) Energy industries, (I.5) Agriculture, forestry and fishing activities, (I.6) Non-specified sources, (I.7) Fugitive emissions from mining, processing, storage, and transportation of coal, and (I.8) Fugitive emissions from oil and natural gas system.

***Table 30** Chiang Mai's greenhouse gas emissions in stationary energy in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
I. Stationary Energy					
I.1	Residential buildings	37,887	689,285	NO	727,172
I.2	Commercial and institutional buildings and facilities	49,063	491,299	NO	540,362
I.3	Manufacturing industries and construction	43,276	683,792	NO	727,068
I.4.1/2/3	Energy industries	NO	NO	NO	0
I.4.4	Energy generation supplied to the grid	NO			
I.5	Agriculture, forestry and fishing activities	17,391	7,662.2	NO	25,054
I.6	Non-specified sources	184,965	70,849	NO	255,814
I.7	Fugitive emissions from mining, processing, storage, and transportation of coal	NO			0
I.8	Fugitive emissions from oil and natural gas systems	NO			0
Total		332,582	1,942,888	0	2,275,470

Sources required for BASIC reporting

\+ Sources required for BASIC+ reporting

Sources included in Other Scope 3

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

Non-applicable emissions

As the result in **Table 30**, the total emissions were 2.27 $MtCO_2eq$. The residential building sub-sector was accounted at 0.72 $MtCO_2eq$ or 31.96% of total emission in stationary energy sector. These emissions mostly contributed from the energy consumption in household, including LPG and electricity. The emissions in the base year from electricity consumption was 0.68 $MtCO_2eq$ or 94.78% of total emissions in residential building sub-sector. The rest came from the consumption of LPG and other energy types indicated in Scope 1. At base year in stationary energy sector, the largest emissions came from residential building and manufacturing industries sub-sectors accounted around 727,172 tCO_2eq or 31.96% and 727,068 tCO^2eq or 31.95% of total emission in stationary energy sector, respectively. Residential building and manufacturing industries sub-sectors, most of emissions were generated from electricity consumption as reported in Scope 2. The commercial and institutional building and facilities were expected to generate greenhouse gas emissions 540,362 tCO_2eq in 2015 (23.75% of total emissions in stationary energy sector), followed by non-specified source category. The rest in the emissions came from agriculture, forestry, and fishing activities sub-sector (25,054 tCO_2eq in the base year).

4.1.3.2 Transportation

In transportation sector, the total emission from transportation sector was 2.18 $MtCO_2eq$ (32.06 % of total emission) in the base year. Emissions from on-road transportation was 1.94 $MtCO_2e$ accounted for 88.98% of total emissions in transportation sector. The emissions in each sub-sector in transportation sector are illustrated in **Table 31.**

Table 31 *Chiang Mai's greenhouse gas emissions in transportation in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
II. Transportation					
II.1	On-road transportation	1,901,332	47	46,790	1,948,169
II.2	Railways	451	NO	23,526	23,977
II.3	Waterborne navigation	NO	NO	NO	0
II.4	Aviation	NO	NO	217,228	217,228
II.5	Off-road transportation	IE	NO		0
	Total	1,901,783	47	287,544	2,189,373

Sources required for BASIC reporting

\+ Sources required for BASIC+ reporting

Sources included in Other Scope 3

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

Non-applicable emissions

The emissions from on-road transportation sub-sector were mostly from the motor fossil fuel consumption, including diesel oil, gasoline, natural gas, and liquefied petroleum gas. The second largest of greenhouse gas emissions in this sector in 2015 was aviation sub-sector (217,228 tCO_2eq), followed by railways sub-sector (23,977 tCO_2eq). The emission from waterborne navigation was excluded since there were no related activities in the boundary.

4.1.3.3 Waste

In the study boundary, greenhouse gas emissions from the waste sector in Chiang Mai are presented in **Table 32.**

***Table 32** Chiang Mai's greenhouse gas emissions in waste sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
III. Waste					
III.1.1/2	Solid waste disposal	371,595		NO	371,595
III.2.1/2	Biological treatment of waste	NO		NO	0
III.3.1/2	Incineration and open burning	NO		NO	0
III.4.1/2	Wastewater treatment and discharge	204,979		NO	204,979
III.1.3	Waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary	15,353			
III.2.3	Waste generated outside the city boundary but treated biologically within the city boundary	NO			
III.3.3	Waste generated outside the city boundary but treated within the city boundary	2,056			
III.4.3	Wastewater generated outside the city boundary but treated within the city boundary	NO			
	Total	576,574	0	0	576,574

Sources required for BASIC reporting

\+ Sources required for BASIC+ reporting

Sources included in Other Scope 3

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

Non-applicable emissions

The most of greenhouse gas emissions in waste sector came mainly from solid waste disposal sub-sector, followed wastewater treatment and discharge. The emissions from solid waste disposal were estimated at 371,595 tCO_2e, accounting at 64.45% of total emission in the base year. Wastewater treatment sub-sector contributed 204,979 tCO_2eq or 35.55% of total emission in waste sector. Beside this, there were no activities of biological treatment and incineration and open burning happening in city boundary.

4.1.3.4 Industrial processes and product uses (IPPU)

There were no activities related to IPPU GHG emissions in the Chiang Mai's city boundary.

***Table 33** Chiang Mai's greenhouse gas emissions in waste sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
IV. Industrial Processes and Product Uses (IPPU)					
IV.1	Industrial processes occurring within the city boundary	NO			0
IV.2	Product use occurring within the city boundary	NE			0
	Total	0	0	0	0

Sources required for BASIC reporting

\+ Sources required for BASIC+ reporting

Sources included in Other Scope 3

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

Non-applicable emissions

4.1.3.5 Agriculture, forest and other land use (AFOLU)

In 2015, total greenhouse gas emissions from AFOLU in Chiang Mai were 1.78 $MtCO_2eq$ (26.18% of total emission) in 2015. The largest emissions came mainly from land within the city boundary (1.18 $MtCO_2eq$; 66.22% of total emission in this sector), followed by emissions from livestock (338,697 tCO_2eq; 18.95%,) and aggregate sources and non-CO_2 emission sources on land within the city boundary (265,067 tCO_2eq; 14.83%), respectively. Emissions are reported in the **Table 34.**

Table 34 *Chiang Mai's greenhouse gas emissions in AFOLU sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
V. Agriculture, Forestry and Other Land Use (AFOLU)					
V.1	Livestock within the city boundary	338,697			338,697
V.2	Land within the city boundary	1,183,783			1,183,783
V.3	Aggregate sources and non-CO_2 emission sources on land within the city boundary	265,067			265,067
Total		1,787,546	0	0	1,787,546

Sources required for BASIC reporting

\+ Sources required for BASIC+ reporting

Sources included in Other Scope 3

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

Non-applicable emissions

4.1.4 Chiang Mai's greenhouse gas projections

According to the projection methodology stated in Chapter III, the projections of the greenhouse gas emissions in this research are considered in three scenarios involving baseline scenario or business-as-usual (BAU), NDC target scenario and 1.5°C pathway scenario.

4.1.4.1 Business-as-usual (BAU) scenario

In the BAU scenario, the total greenhouse gas emissions have continuously increased and reached 7.83 $MtCO_2eq$ in 2030 and 13.47 $MtCO_2eq$ in study target year in 2050, respectively. The main source of greenhouse gas emissions in 2050 was stationary energy sector (7.82 $MtCO_2e$; 58.02% of total expected greenhouse gas emissions in target year), followed by transportation (3.18 $MtCO_2eq$; 23.64%). The AFOLU GHGs emissions were 1.33 $MtCO_2eq$ or 9.91% of total greenhouse gas emissions in 2050, followed by waste sector (1.13 $MtCO_2eq$ or 8.43%) in target year **(Table 35** and **Figure 32).**

Table 35 *Projections of greenhouse gas emissions in Chiang Mai in 2050*

Year	*2015*	*2030*	*2050*
GHGs ($MtCO_2eq$)	6.83	7.83	13.47

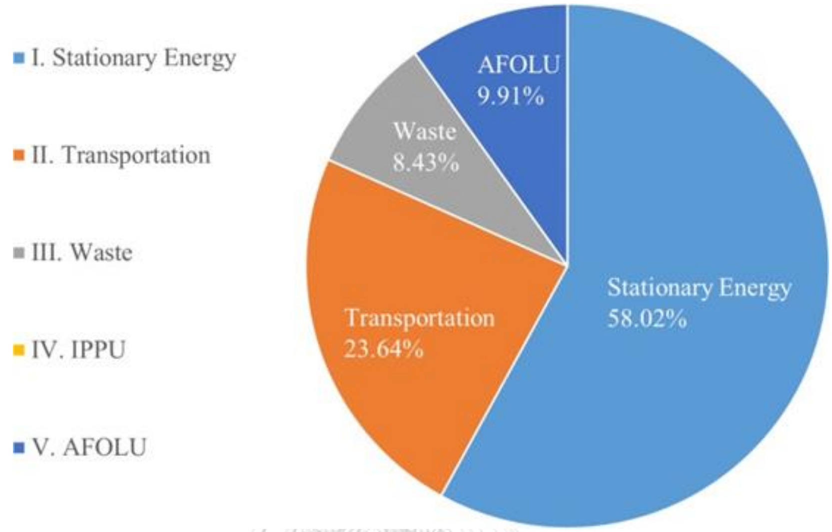


Figure 32 *Chiang Mai's greenhouse gas inventory in 2050 (BAU scenario 2050)*

Figure 33 shows the trend of greenhouse gas emissions in each sub-sector under BAU scenario. The manufacturing and construction sub-sector were the largest contributor in the target year (3.33 $MtCO_2eq$), followed by residential building, commercial building, and on-road around 2.97 $MtCO_2eq$, 1.23 $MtCO_2eq$ and 1.96 $MtCO_2eq$, respectively.

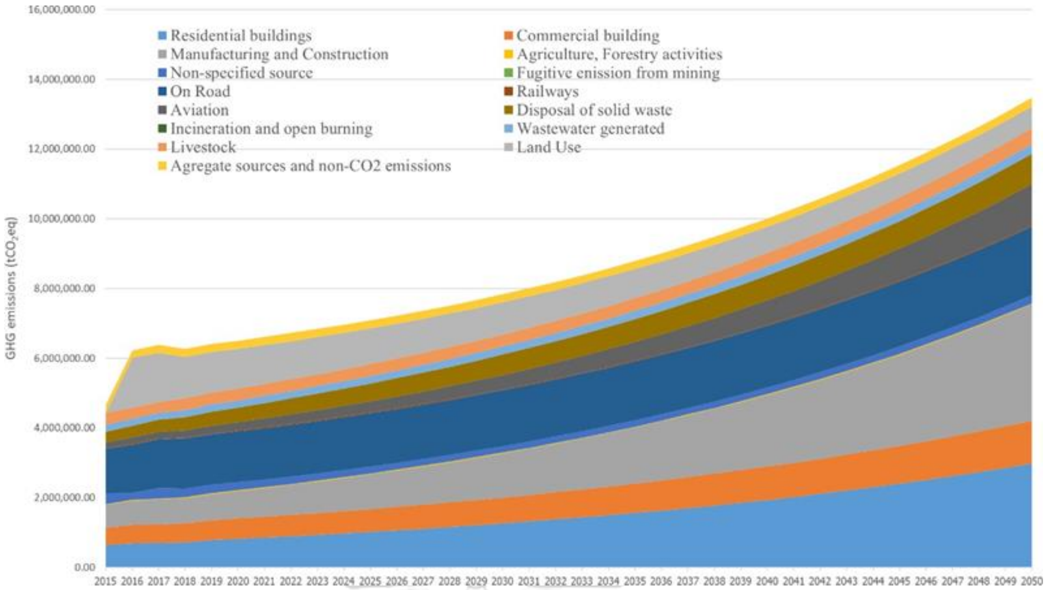


Figure 33 Chiang Mai's greenhouse gas emission projection under Business-as-Usual Scenario

Table 36 Assumption used in business-as-usual scenario (Chiang Mai)

Sector	Activity Data	Assumption
Stationary Energy	LPG	Residential sector = 2.0% growth rate Commercial sector = 2.0% growth rate Manufacturing sector = 3.0% growth rate
	Electricity	Residential sector = 4.0% growth rate Commercial sector = 3.0% growth rate Manufacturing sector = 5.0% growth rate Agriculture sector = 3.0% growth rate
	Diesel	Manufacturing sector = 6.0% growth rate
	Fuel oil	Manufacturing sector = -1.0% growth rate
Transportation	LPG	On-road = -9.0% growth rate
	Diesel	On-road = 3.0% growth rate
	Benzene	On-road = -3.0 growth rate
	Gasohol E85	On-road = 8.0growth rate
	Gasohol E20	On-road = 9.0% growth rate
	Gasohol 91/95	On-road = 3.5% growth rate
Waste	Solid waste	Population = 1.0% growth rate
	Wastewater	Population = 1.0% growth rate
AFOLU	Livestock	GHG emissions = 1.0% growth rate
	Land use	Land use change = -2.0% growth rate
	Non-CO_2	GHG emissions = -2.0% growth rate

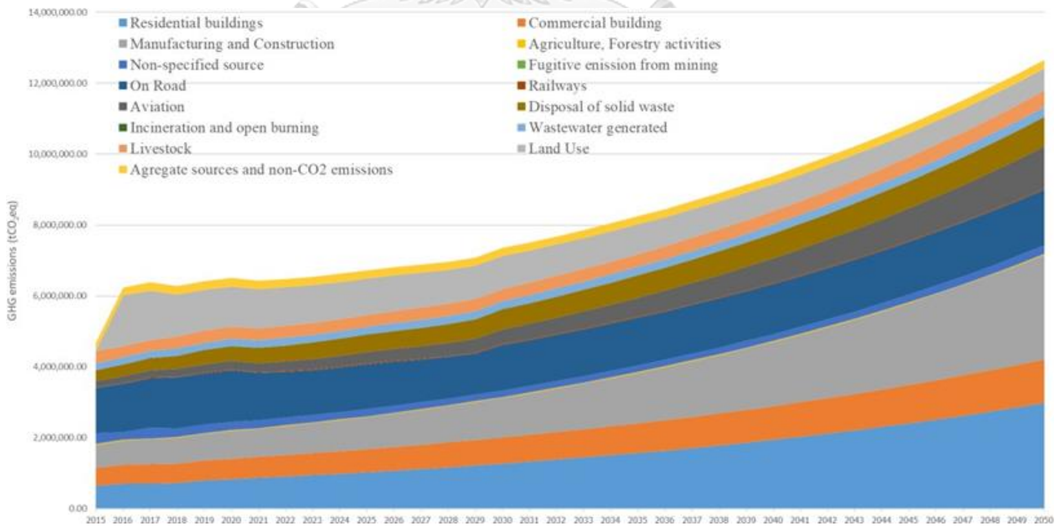
4.1.4.2 NDC scenario

As the result of NDC scenario model, the results showed that emissions are projected to reach 7.35 $MtCO_2eq$ in 2030 from 6.82 $MtCO_2eq$ in the base year 2015 and expected to increase to 12.66 $MtCO_2eq$ in the target year 2050 **(Table 37).**

Table 37 *Projection of greenhouse gas emissions in Chiang Mai in 2050, NDC target scenario*

Year	2015	2030	2050
GHGs ($MtCO_2eq$)	6.83	7.35	12.66

As expert's comments, energy efficiency measures in residential and commercial building are recommended as potential mitigation option. In the transportation sector, improving energy efficiency in transportation sector, promoting of biofuel, and shifting the transportation types to green mode are also suggested. Waste management related practices are recommended in the waste sector. The trend of greenhouse gas emission in NDC target scenario is illustrated in the **Figure 34**.



Note: Considered the mitigation option in National Determined Contribution Roadmap on Mitigation 2021–2030

Figure 34 *Chiang Mai's Greenhouse Gas Emission Projection under NDC scenario*

Figure 34 shows the trend of greenhouse gas emission in each sub-sector under NDC target scenario. The residential sub-sector was the largest emissions sources in the target year (2.98 $MtCO_2eq$), followed by manufacturing and construction, commercial building, and on-road sub-sector with 2.95 $MtCO_2eq$, 1.23 $MtCO_2eq$ and 1.57 $MtCO_2eq$ of emissions, respectively.

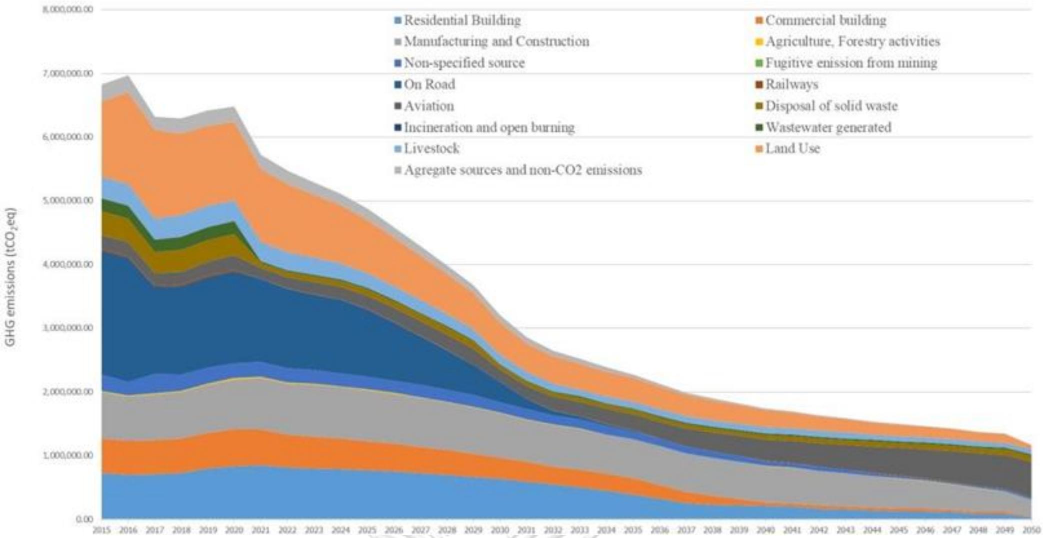
4.1.4.3 1.5^{o}C pathway scenario

Under 1.5^{o}C pathways, electricity supply by renewables should be reached 85% by 2050. In the transportation sector, roughly 30% emission reduction in final energy use by 2050 are consistent with limiting 1.5^{o}C scenario. Moreover, 90% reduction are suggested in residential and commercial building sector. According to C40's study, a share of Southeast Asia cities' emission allocation could be at least 0.7 tCO_2eq per capita in 2050 (C40, 2019).

Table 38 *Projection of greenhouse gas emissions in Bangkok in 2050*

Year	2015	2030	2050
GHGs ($MtCO_2eq$)	6.83	3.20	1.16

As the result of 1.5^{o}C pathway scenario model, the results of scenario analysis revealed that the greenhouse gas emissions are projected to increase to 3.20 $MtCO_2eq$ in 2030 from 6.82 $MtCO_2eq$ in the base year 2015 and expected to 1.16 $MtCO_2eq$ in the target year 2050 **(Table 38).**



Note: Assumption based on global 1.5°C pathway target (0.7 tCO2eq/capita), C40

Figure 35 *Chiang Mai's greenhouse gas emission projections under the 1.5°C pathway scenario*

Under the assumption of 1.5°C pathway, the residential building, manufacturing and construction, and on-road transportation sub-sectors were the largest potential of emission reduction in Chiang Mai. In 2050, the manufacturing and construction sub- sector could be allowed to contribute 0.26 $MtCO_2eq$ of emissions and zero emissions in on-road transportation were expected. Residential building could allow to create only 0.03 $MtCO_2eq$ in 2050. **Figure 35** shows the greenhouse gas emission profile under the assumption in 1.5°C pathway scenario.

4.1.5 Rayong's greenhouse gas inventory in base year

Rayong was selected to represent the industrial base province that generating highest GPP contribution to the country. Rayong's economy depends mainly on industry sector, but the expansion of manufacturing production is a slower pace than before. Most of the country's petrochemical industry are located in the Map Ta Phut Industrial Estate. The population of Rayong was estimated at 1.06 million in 2015 and it is expected to meet 1.62 million by 2050. In 2015, Rayong contributed at 9.06% of total national income which was in the first rank of the country. It is one of the three provinces included in Thailand's Eastern Economic Corridor (EEC) which expected to be a leading ASEAN economic zone. Socio-economic progress of Rayong in the base year of 2015 is given in **Table 39.**

Table 39 *Rayong's socio-economic in the base year (2015)*

Socio-Economic Parameter	Unit	Rayong	Thailand	Contribution
Population	million	1.62	65.73	2.46%
GPP	million baht	862,613	9,512,400	9.06%
GPP-agriculture	million baht	20,803	615,000	3.38%
GPP-non-agriculture	million baht	841,810	8,972,600	9.38%
Area of province	square kilometers	16.95	513,115	0.003%

The inventory is scoped in the geographically area of Rayong. It is including the greenhouse gas sources happening in the Rayong province area as well as greenhouse gas emissions that appear outside the city boundary as a result of activities taking place within the city border. The period used for Rayong greenhouse gas inventory in this research was a continuous of 12 months, aligning to a calendar year. The study boundary is illustrated in **Figure 36.**

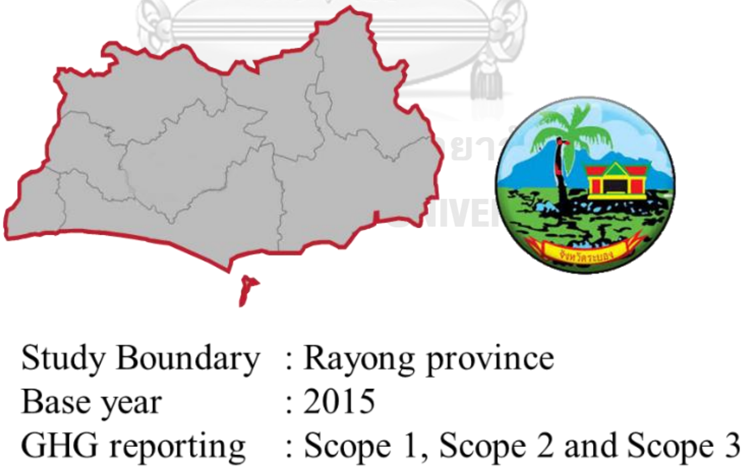


Figure 36 Rayong's greenhouse gas inventory boundary in Rayong, Thailand

In 2015, the total greenhouse gas emissions were 21.25 $MtCO_2eq$ reporting in the basis of BASIC+, 15.90 $MtCO_2eq$ were reported in BASIC concept. Within this, emissions per capita in Rayong were 43.25 tCO_2eq per capita for the BASIC+ and 32.30 tCO_2eq per capita for the BASIC, respectively**. Table 40** showed that 70.97% of total emissions in 2015 was accounted in Scope 1, while 26.17% of total emissions in base year were accounted in Scope 2 associated with the electricity consumption in stationary energy and transportation sectors. Only 2.56% of total emissions in 2015 were reported in Scope 3.

***Table 40** Rayong's greenhouse gas emission inventory in the base year (2015)*

GHG Emission Source		Total GHG Emission (Metic tonnes CO_2e)				
		Scope 1	Scope 2	Scope 3	BASIC	BASIC+
I. Stationary Energy	Total fuel combustion	8,580,571	5,563,708	IE	14,144,279	14,144,279
	Energy generation supplied to the grid	18,249,384				
II. Transportation	Total	1,431,344	NO	607,235	1,431,344	2,038,579
III. Waste	Waste generated within the city boundary	328,506		0	328,506	328,506
	Waste generated outside the city boundary	61,927				
IV. Industrial Processes and Product Uses (IPPU)	Total	4,675,920				4,675,920
V. Agriculture, Forestry and Other Land Use (AFOLU)	Total	68,773				68,773
VI. Other Scope 3	Total					0
Total		**15,085,113**	**5,563,708**	**607,235**	**15,904,128**	**21,256,055**

Sources required for BASIC reporting

\+ Sources required for BASIC+ reporting

Sources included in Other Scope 3

Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

Non-applicable emissions

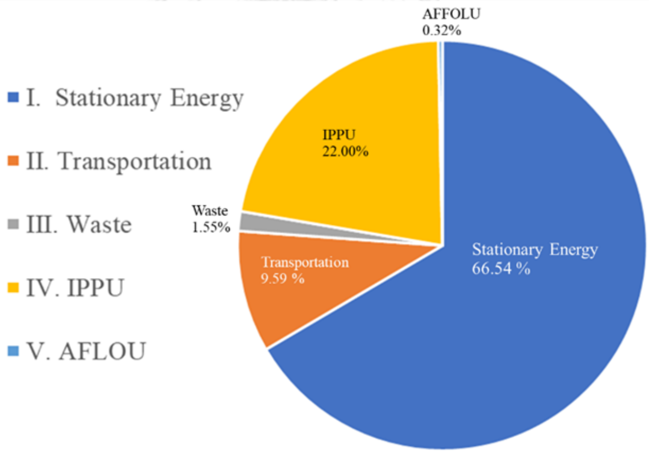


***Figure 37** Rayong's greenhouse gas inventory in the base year (2015)*

The greatest greenhouse gas emissions in 2015 were stationary energy sector with 14.14 $MtCO_2eq$ or 66.54% of total emission reported in BASIC+, followed by IPPU) (4.67 $MtCO_2eq$; 22.00% of total emissions). Transportation emitted approximately 2.03 $MtCO_2eq$ (9.59%), and the rest came from waste sector (1.55%; 0.32 $MtCO_2eq$). AFLOU contributed only 0.32% (68,773 tCO_2eq) of total emissions. The summary of Rayong greenhouse gas inventory in 2015 as a base year is presented in **Table 40**.

4.1.5.1 Stationary energy

As the result in **Table 41**, the total emissions of stationary energy were approximately 14.14 $MtCO_2eq$. The energy industries sub-sector emitted 7.77 $MtCO_2eq$ (54.95%) of GHG emissions. These emissions mostly came from consumption of natural gas and diesel oil for off-grid energy generation. Manufacturing industries and construction sub-sector was the second largest sub-sector emitted at 5.16 $MtCO_2eq$ or 36.53% of total emission in stationary energy sector. The emissions from the residential building were 0.51 $MtCO_2e$ (3.64% of total emission) in the base year. Whereas only 2.46% (0.34 $MtCO_2eq$) emitted from commercial building sub-sector. By scope, as shown in **Table 41**, most of emissions were reported in Scope 1, followed by Scope 2. Moreover, estimated 18.24 $MtCO_2eq$ of emissions emitted from power plant located in Rayong and supplied electricity to the national grid which required the city to report, but not including in the BASIC and BASIC+ reporting.

Table 41 *Rayong's greenhouse gas emissions in stationary energy sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
I. Stationary Energy					
I.1	Residential buildings	49,901	465,389	IE	515,291
I.2	Commercial and institutional buildings and facilities	133,441	214,566	IE	348,006
I.3	Manufacturing industries and construction	415,057	4,751,829	IE	5,166,885
I.4.1/2/3	Energy industries	7,772,697	IE	IE	7,772,697
I.4.4	Energy generation supplied to the grid	18,249,384			
I.5	Agriculture, forestry and fishing activities	2,565	14,935.9	IE	17,501
I.6	Non-specified sources	76,247	116,988	IE	193,235
I.7	Fugitive emissions from mining, processing, storage, and transportation of coal	NO			0
I.8	Fugitive emissions from oil and natural gas systems	130,663			130,663
Total		8,580,571	5,563,708	0	14,144,279

Sources required for BASIC reporting
+ Sources required for BASIC+ reporting
Sources included in Other Scope 3
Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)
Non-applicable emissions

4.1.5.2 Transportation

The total emission from the transportation sector was estimated to 2.03 $MtCO_2eq$ which sharing at 9.59 % of total emission in the base year. Emissions from on-road transportation emitted about 1.49 $MtCO_2e$ or 73.26% of total emissions in transportation sector **(Table 42).**

***Table 42** Rayong's greenhouse gas emissions in transportation sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
II. Transportation					
II.1	On-road transportation	1,425,592	IE	67,871	1,493,462
II.2	Railways	NO	NO	363	363
II.3	Waterborne navigation	5,752	NO	473,423	479,175
II.4	Aviation	NE	NO	65,579	65,579
II.5	Off-road transportation	IE	NO		0
	Total	1,431,344	0	607,235	2,038,579

Sources required for BASIC reporting
Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)
\+ Sources required for BASIC+ reporting
Non-applicable emissions
Sources included in Other Scope 3

Waterborne sub-sector emitted about 0.47 $MtCO_2e$ or 23.51% of total emissions from transport sector. The aviation sub-sector emissions contributed around 3.22% of total emissions (65,579) tCO_2eq. **Table 42** also presented the reporting system in the scope level, most of emissions in transportation sector were reported in Scope 1, followed by Scope 3. This can be highlighted that energy consumption in city boundary was a key sources of greenhouse gas emissions, including consumption of LPG, diesel, and gasoline in transportation sector. However, in the Scope 3, the majority of emissions were energy consumption in on-road, railways, waterborne, and aviation subsector which identified to occur outside the city boundary.

4.1.5.3 Waste

The total greenhouse gas emissions in waste sector were 0.39 $MtCO_2eq$ (1.55%). Solid waste disposal sub-sector contributed emissions emitted 0.17 $MtCO_2eq$ (44.13% of total emission), followed by emissions from incineration and open burning sub-sector, 31.86% of total emissions. Wastewater treatment and discharge sub-sector approximately emitted about 93,126 tCO_2eq or 23.85% of total emissions. Only 626 tCO_2eq generated from biological treatment of waste in this sector. In the scope reporting level, all the emissions in the waste sector were reported in Scope 1. It was no emissions reported in Scop 2 and 3. It can be interpreted that there were only greenhouse gas emissions from sources located within the city boundary occurred in waste sector.

***Table 43** Rayong's greenhouse gas emissions in waste sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
III. Waste					
III.1.1/2	Solid waste disposal	172,296		NO	172,296
III.2.1/2	Biological treatment of waste	626		NO	626
III.3.1/2	Incineration and open burning	124,385		NO	124,385
III.4.1/2	Wastewater treatment and discharge	93,126		NO	93,126
III.1.3	Waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary	61,927			
III.2.3	Waste generated outside the city boundary but treated biologically within the city boundary	NO			
III.3.3	Waste generated outside the city boundary but treated within the city boundary	NO			
III.4.3	Wastewater generated outside the city boundary but treated within the city boundary	NO			
Total		328,506	0	0	390,433

Sources required for BASIC reporting — Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

+ Sources required for BASIC+ reporting — Non-applicable emissions

Sources included in Other Scope 3

4.1.5.4 Industrial processes and product uses (IPPU)

The greenhouse gas emissions in IPPU are shown in Table 41 According to the IPPU sector in Rayong, the total greenhouse gas emissions were approximately 4.67 $MtCO_2eq$ in the base year, accounted for 22.00% of total emissions of Rayong in 2015. Interestingly, IPPU sector contributed as the second largest of total emissions profiles after stationary energy sector in Rayong.

***Table 44** Rayong's greenhouse gas emissions in IPPU sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
IV. Industrial Processes and Product Uses (IPPU)					
IV.1	Industrial processes occurring within the city boundary	4,675,920			4,675,920
IV.2	Product use occurring within the city boundary	NO			0
Total		4,675,920	0	0	4,675,920

Sources required for BASIC reporting — Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)

+ Sources required for BASIC+ reporting — Non-applicable emissions

Sources included in Other Scope 3

4.1.5.5 Agriculture, forest and other land use (AFOLU)

In 2015, total greenhouse gas emissions from AFOLU sector were 68,773 tCO_2eq (0.32% of total emission) in Rayong. The largest sources of emissions were land use change sub-sector (38,586 tCO_2eq or 0.18% of total emissions), followed by emissions from livestock sub-sector (26,713 tCO_2eq or 0.13% of total emissions). The rest is emissions came from aggregate sources (0.02%) of total emissions in this section **(Table 45).**

***Table 45** Rayong's greenhouse gas emissions in AFOLU sector in 2015*

GPC ref.	GHG Emission Source	Total GHG Emission (Metic tonnes CO_2e)			
		Scope 1	Scope 2	Scope 3	Total
V. Agriculture, Forestry and Other Land Use (AFOLU)					
V.1	Livestock within the city boundary	26,713			26,713
V.2	Land within the city boundary	38,586			38,586
V.3	Aggregate sources and non-CO_2 emission sources on land within the city boundary	3,474			3,474
Total		68,773	0	0	68,773

- Sources required for BASIC reporting
- Sources required for territorial total but not for BASIC/ BASIC+ reporting (*italics*)
- \+ Sources required for BASIC+ reporting
- Non-applicable emissions
- Sources included in Other Scope 3

4.1.6 Rayong's greenhouse gas projections

According to the projection methodology stated in Chapter III, the projections of the greenhouse gas emissions in this research are considered in three scenarios involving baseline scenario or business-as-usual (BAU), NDC target scenario and 1.5^{o}C pathway scenario.

4.1.6.1 Business-as-usual (BAU) scenario

The result of BAU scenarios found that the greenhouse gas emissions was projected to reach to 19.90 $MtCO_2eq$ in 2030 from 21.25 $MtCO_2eq$ in the base year and expected to increase to 36.02 $MtCO_2eq$ in the target year 2050 **(Table 46).**

***Table 46** Projections of greenhouse gas emissions in Rayong in 2050*

Year	2015	2030	2050
GHGs ($MtCO_2eq$)	21.25	19.90	36.02

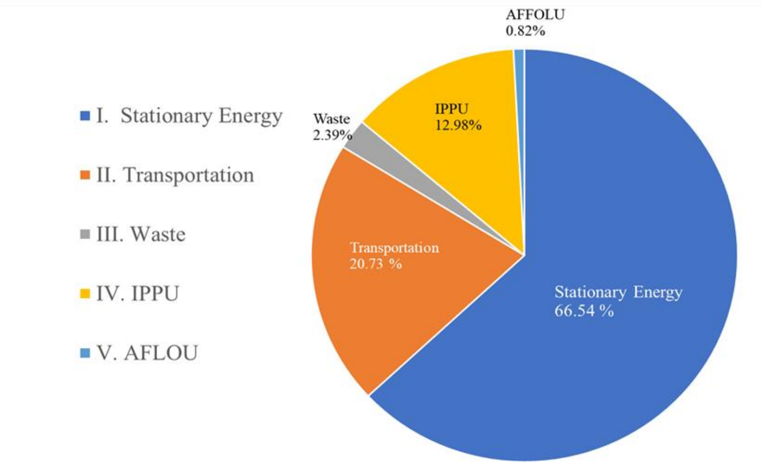


Figure 38 *Rayong's greenhouse gas inventory in target year of 2050*

In 2050, as shown in **Figure 38**, the stationary energy was expected to be the largest contribution in Rayong, particularly from energy and electricity consumption in manufacturing sub-sector (66.54%), followed by transportation sector (20.73%). IPPU sector was expected to emit 4.57 $MtCO_2eq$ or 12.98% of total emissions in the target year. The rest of emissions was expected from AFLOU sector (0.29 $MtCO_2eq$ or 0.82% of total emissions) in the target year. **Figure 39** shows the trend of greenhouse gas emission from 2015 to 2050 in each sector.

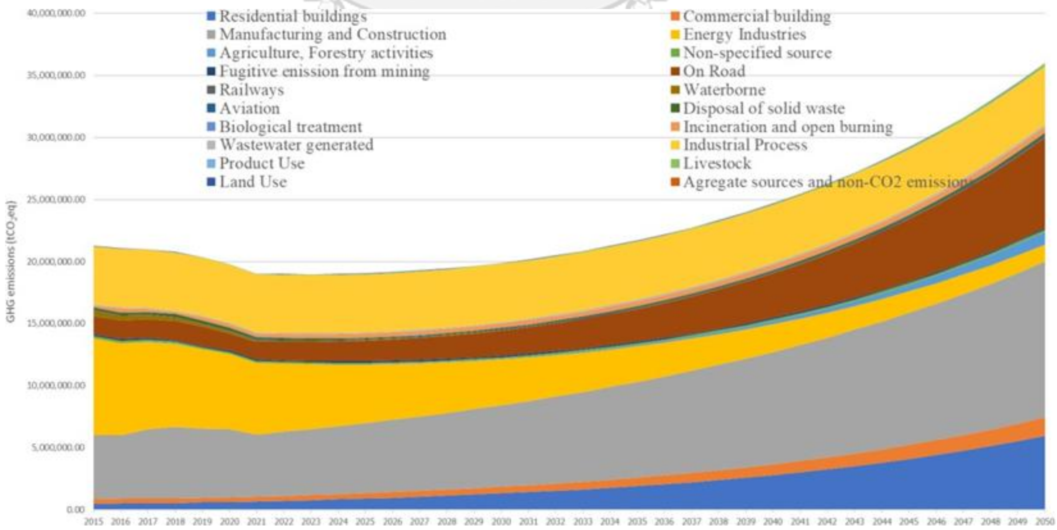


Figure 39 *Rayong's greenhouse gas emission projection under BAU Scenario*

***Table 47** Assumption used in business-as-usual scenario (Rayong)*

Sector	Activity Data	Assumption
Stationary Energy	LPG	Residential sector = -4.0% growth rate Commercial sector = 3.0% growth rate Manufacturing sector = -7.0% growth rate
	Electricity	Residential sector = 8.0% growth rate Commercial sector = 6.0% growth rate Manufacturing sector = 3.0% growth rate Agriculture sector = 1.6% growth rate
	Diesel	Commercial sector = -3.1% growth rate Manufacturing sector = -1.5% growth rate Agriculture sector = -3.0% growth rate
	Fuel oil	Manufacturing sector = -1.0% growth rate
Transportation	LPG	On-road = -1.0% growth rate
	Diesel	On-road = 2.0% growth rate Waterborne = 2.6% growth rate
	Benzene	On-road = -3.0% growth rate
	Gasohol E85	On-road = 5.0% growth rate
	Gasohol E20	On-road = 9.0% growth rate
	Gasohol 91/95	On-road = -3.0% growth rate
Waste	Solid waste	Population = 1.86% growth rate
	Wastewater	Population = 1.86% growth rate
AFOLU	Livestock	GHG emissions = 1.0% growth rate
	Land use	Land use change = -2.0% growth rate
	Non-CO_2	GHG emissions = -2.0% growth rate

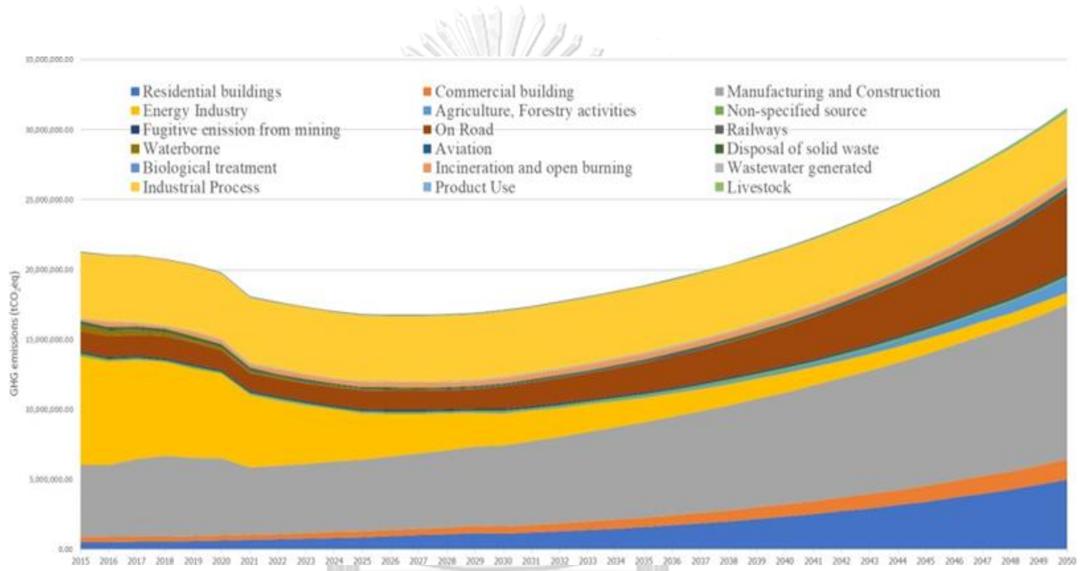
4.1.6.2 NDC target scenario

As expert's comments, the energy efficiency measures in residential and commercial building are recommended. In the transportation sector, increasing the energy efficiency in transportation sector, promoting of biofuel, and shifting the transportation type are suggested. Waste management and source reduction are recommended in the waste sector. The trend of greenhouse gas emission in NDC target scenario is illustrated in the **Figure 40**.

Table 48 Projection of greenhouse gas emissions in Rayong in 2050, NDC

Year	2015	2030	2050
GHGs ($MtCO_2eq$)	21.25	17.12	31.55

The result of NDC scenario analysis showed that the total greenhouse gas emissions are projected to increase to 17.12 $MtCO_2eq$ in 2030 compared to 21.25 $MtCO_2eq$ of emissions in the base year and expected to increase to 31.55 $MtCO_2eq$ in the target year 2050 **(Table 48).**



Note: Considered the mitigation option in National Determined Contribution Roadmap on Mitigation 2021–2030

Figure 40 *Rayong's greenhouse gas emission projection under NDC scenario*

Considering to sub-sector greenhouse emission prediction, **Figure 40** shows the trend of greenhouse gas emission each sub-sector under NDC target scenario. Manufacturing sub-sector is expected to be the largest greenhouse gas contributor in the target year (11.08 $MtCO_2eq$), while the emissions from on-road transportation sub-sector were expected to contribute around 5.83 $MtCO_2eq$. The residential building is expected to emit 5.01 $MtCO_2eq$ of emissions in 2050.

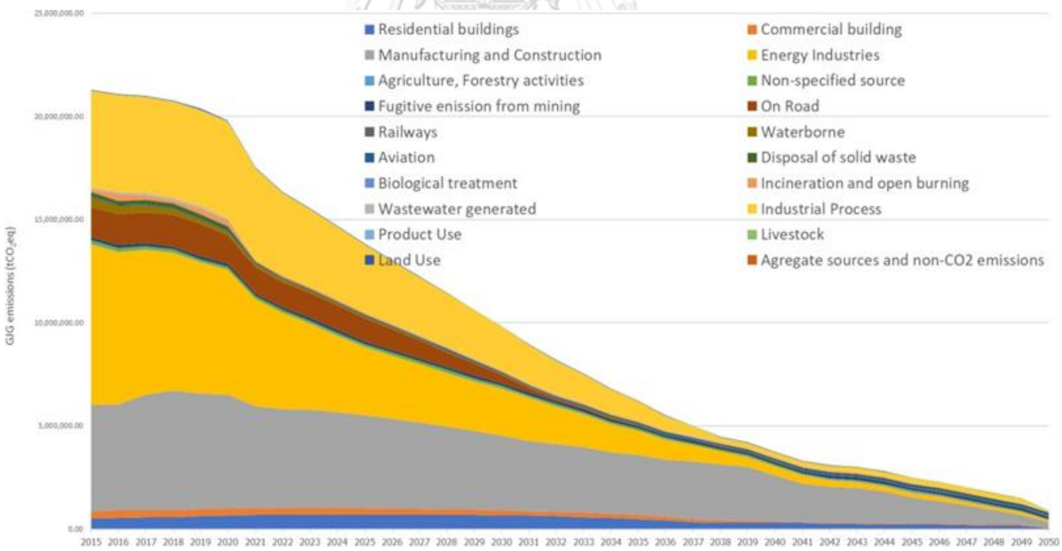
4.1.6.2 1.5ºC pathway scenario

Under 1.5ºC pathways, electricity supply by renewables should be reached 85% by 2050. In the transportation sector, roughly 30% emission reduction in final energy use by 2050 are consistent with limiting 1.5°C. Moreover, 90% reduction are suggested in residential and commercial building sector. According to C40's study, a share of Southeast Asia cities' emission allocation could be at least 0.7 tCO_2eq per capita in 2050 (C40, 2019).

Table 49 *Projection of greenhouse gas emissions in Rayong in 2050, the 1.5°C pathway scenario*

Year	2015	2030	2050
GHGs ($MtCO_2eq$)	21.25	9.84	0.90

As the result of 1.5°C pathway scenario model, it shows that the greenhouse gas emissions were projected to 9.84 $MtCO_2eq$ in 2030 from 21.95 $MtCO_2eq$ in the base year and expected to 0.90 $MtCO_2eq$ in the target year 2050 **(Table 49).**



Note: Assumption based on global 1.5°C pathway target (0.7 tCO2eq/capita), C40

Figure 41 *Rayong's greenhouse gas emission projections under the 1.5°C pathway scenario*

Under the assumption of 1.5°C pathway, the manufacturing sub-sector and on- road transportation was expected as high potential sectors in lowering GHGs in Rayong. In 2050, the manufacturing sub-sector could be allowed to emit around 0.25 $MtCO_2eq$ and it is zero emissions in on-road transportation. Residential building could allow to contribute only 0.05 $MtCO_2eq$ in 2050. **Figure 41** shows the greenhouse gas emission profile under the assumption in 1.5°C pathway scenario.

4.2 Provincial interest in climate mitigation measures

By proposing low carbon policies and mitigation measures for all selected case studies, the country's low carbon development policy and implementation were reviewed by experts under the possibility to implement them at the city level, including the impact of local environment, local economy, local social interest, and local authority. Moreover, best practices in other cities around the world are examined to explore options to the selected cities for their ambition. Finally, the best measures for the cities are identified, factoring in cost effectiveness, for low carbon policy recommendation. The criteria decision framework for climate policy and mitigation measures recommendations is given in **Figure 42.**

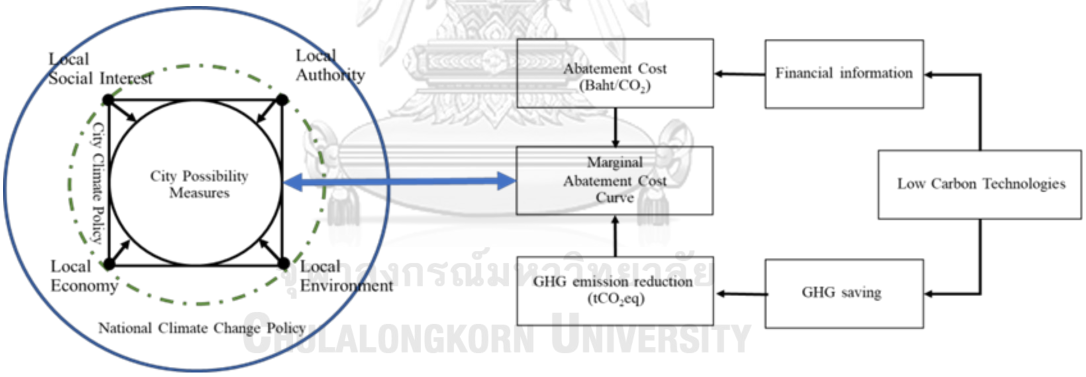


***Figure 42** Criteria decision framework for climate policy and mitigation measures recommendations in selected case studies.*

4.2.1 NDC climate mitigation measures

As mentioned, Thailand's NDC implementation plan represents the national low carbon roadmap to be implemented across the whole country, including the three cities investigated in the research. Thailand's NDC undertakes to reduce emissions by 20% below the Business as Usual (BAU) scenario by 2030. Thailand has launched a road map to implement greenhouse gas emission measures in line with the NDC in specific sectors including energy, transportation, waste and IPPU. The total expected emissions reduction is 115.6 $MtCO_2eq$ countrywide according to fifteen measures in total. The fifteen climate mitigation measures include nine measures in the energy and transportation sectors addressing electricity generation, energy consumption in the residential and commercial buildings sub-sector, energy consumption in industrial production, and energy consumption in transportation. Four measures are planned for the waste sector including municipal solid waste and wastewater. The remaining two measures are to be implemented in IPPU. **Table 50** illustrates the impact of implementing the roadmap at national and sub-national level.

Table 50 *Thailand's NDC Roadmap on Mitigation 2021-2030*

Thailand's NDC measures on mitigation	**National Level**	**Sub-national Level**
Energy Sector		
• Renewable energy in households	✓	✓
• Increase energy efficiency in households	✓	✓
• Renewable generation	✓	x
• Increase power generation efficiency	✓	x
• Increase energy efficiency in transport	✓	✓
• Promote biofuels	✓	x
• Increase energy efficiency in building	✓	✓
• Renewable energy in industry	✓	✓
• Increase industrial energy efficiency	✓	✓
Waste		
• Solid waste management	✓	✓
• Increase biogas from industrial wastewater	✓	✓
• Industrial wastewater management	✓	✓
• Municipal wastewater management	✓	✓
IPPU		
• Clinker substitution	✓	x
• Replacement refrigerants	✓	x

According to the local expert interviews, five of the fifteen national measures on mitigation could not feasibly be promoted and implemented by local authorities, particularly in the research case studies. Two measures in waste sector are strongly supported by the local expert since they align with the existing role of local government. In the energy sector, the energy efficiency measures in household and commercial buildings are more preferable than renewable energy measures at the sub-national level as well as in the local industries.

The Multi Criteria Analysis (MCA) framework is applied for climate measure evaluation in accordance with sustainable development. The key to this framework is a hierarchical criteria tree containing a set of generic criteria against which the climate policies or measures are assessed. It contributes a broad range of climate related, environmental, economic, social, and political and institutional analysis. The MCA climate generic criteria tree is illustrated in **Figure 43.**

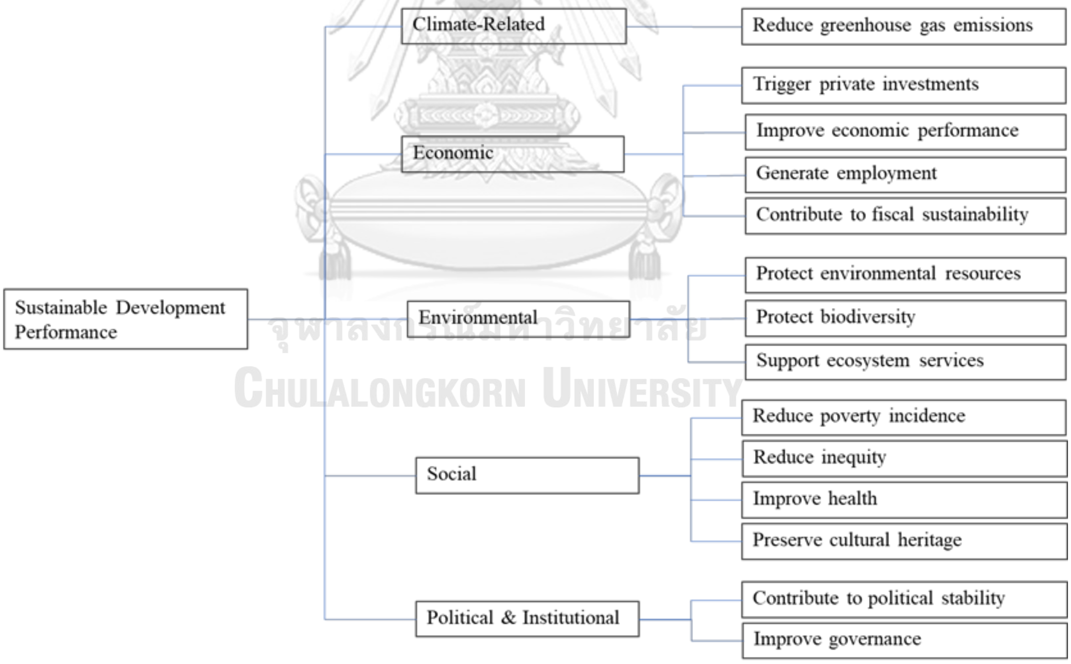


***Figure 43** MCA climate generic criteria tree (modified from UNEP, 2011)*

The original criteria tree was developed by the UN Environment Programme (UNEP) through an intensive process of consultation carried out in close collaboration with a number of international experts. Each performance objective is defined as follows:

- **Reduce greenhouse gas emissions**: the extent to which climate mitigation options or measures affect the annual rate and cumulative emissions of greenhouse gases released in the atmosphere.
- **Trigger private investments**: the potential of the measure to leverage investment from the private sector in the city boundary. This may be further determined at the macroeconomic, industry or sectoral level. Indicators to measure the level of private investment triggered may also be expressed in terms of net investment costs.
- **Improve economic performance**: economic output, competitiveness and technological change effects arising from climate policy. This may refer to a specific industry or region, as well as to the economy at the national level. In addition, competitiveness impacts may relate to price competitiveness.
- **Generate employment**: the direct job creation effects of a measure on a specific industry or region plus indirect knock-on effects throughout the rest of the economy. Distributional employment impacts across categories of the population could be also considered.
- **Contribute to fiscal sustainability**: the effect of climate mitigation actions on the primary and secondary public accounts, including both government revenues and government expenditures.
- **Protect environmental resources**: this covers potential impacts on water, land and air quality and the corresponding natural resource stocks.
- **Protect biodiversity**: biological diversity includes here the variety of living organisms, the genetic differences among them and the diversity of ecosystems that they inhabit.
- **Support ecosystem services**: this refers to the services of natural ecosystems that humans benefit from. These services can be classified into four broad groups: provisioning services, regulatory services, supporting services and cultural services.
- **Reduce poverty incidence:** impacts of a climate policy on the incidence of income poverty, access poverty and empowerment or

social fabric issues.

- **Reduce inequity**: changes in the systematic disparities between groups of population or generation in terms of income and access to resources or services.
- **Improve health**: human-health aspects directly or indirectly affected by climate policy concerning nutrition, vector-borne diseases, water and air- related risks and diseases, and the overall health of the population.
- **Preserve cultural heritage**: this refers to the impacts of climate mitigation measures on cultural assets. In the case of mitigation, cultural assets may be either endangered or may be further preserved.
- **Contribute to political stability**: measure impacts on changes in conflict and violence risks related to water-stress, food security and migration, as well as on energy security.
- **Improve governance**: measures potential impacts on national or local governance structures, including institutional setups and regulator frameworks. For instance, organizing action at the community-level to help manage and adapt to climate change can improve local governance in general, which could bring benefits in dealing with other issues.

For this research, nine NDC mitigation measures were evaluated by five experts in each selected province under the MCA climate generic criteria tree described above. The results of each mitigation measure are presented in **Figure 44** to **Figure 53**.

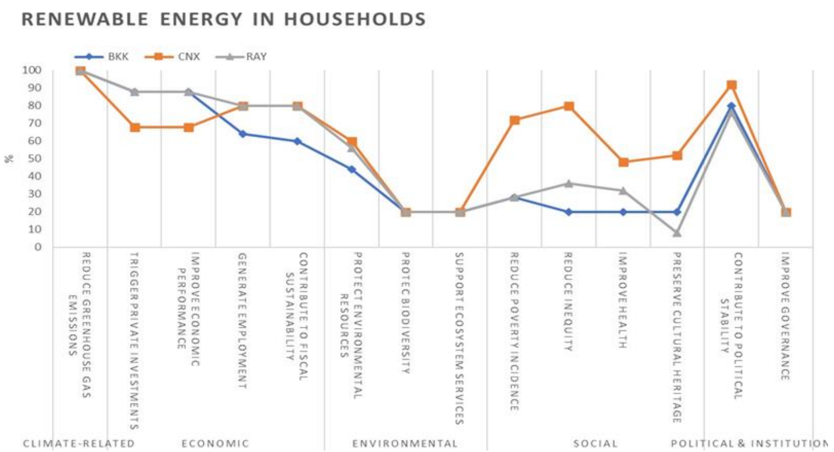


***Figure 44** The result of evaluation around “Renewable energy in households” measures.*

The result presented in **Figure 44** shows that the “Renewable energy in households” option received a high score in climate-related and economic criteria in the three selected provinces. The score given in the social criteria is low in Bangkok and Rayong but is higher in Chiang Mai.

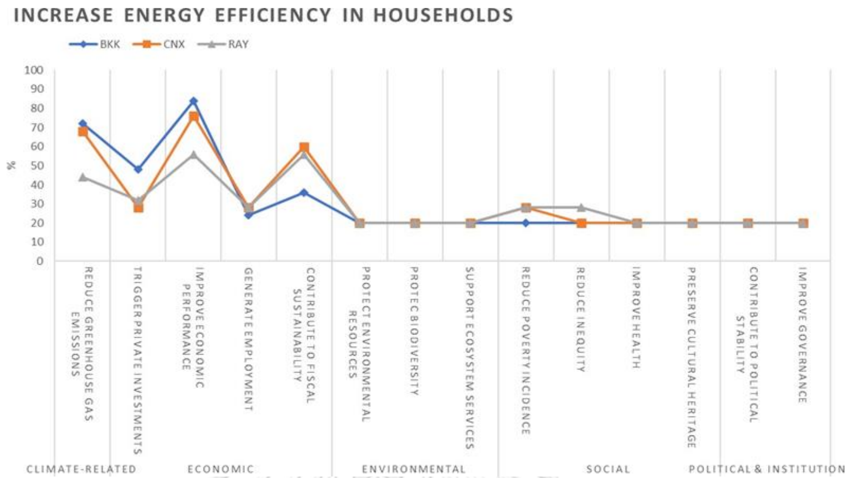


Figure 45 *The result of evaluation around*
“Increase energy efficiency in households” measures.

The result presented in **Figure 45** shows that the “Increase energy efficiency in households” option received a high score in climate-related and economic criteria in the three selected provinces. The score given in environmental, social and political and institutional criteria is low. The local experts agreed that energy efficiency can reduce the greenhouse gas emission in their provinces; however, the level of contribution to other environmental, social and local political issues is low.

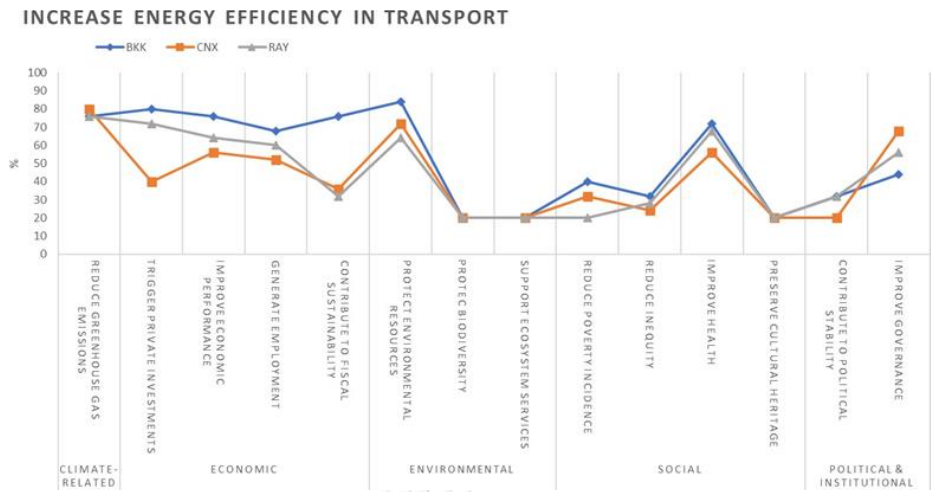


Figure 46 *The result of evaluation of the "Increase energy efficiency in transport" measure.*

Figure 46 shows that the "Increase energy efficiency in transport" option received a high score in climate-related and economic criteria in Bangkok and Rayong. The local experts in Chiang Mai gave a low score in economic criteria, compared to the other two provinces. In environmental criteria, the protected environmental resource sub-criteria showed a high score from the three provinces. This may be because this measure can improve local air-quality as a co-benefit of reducing greenhouse gas emissions, which is consistent with the high score in the improve health sub-criteria.

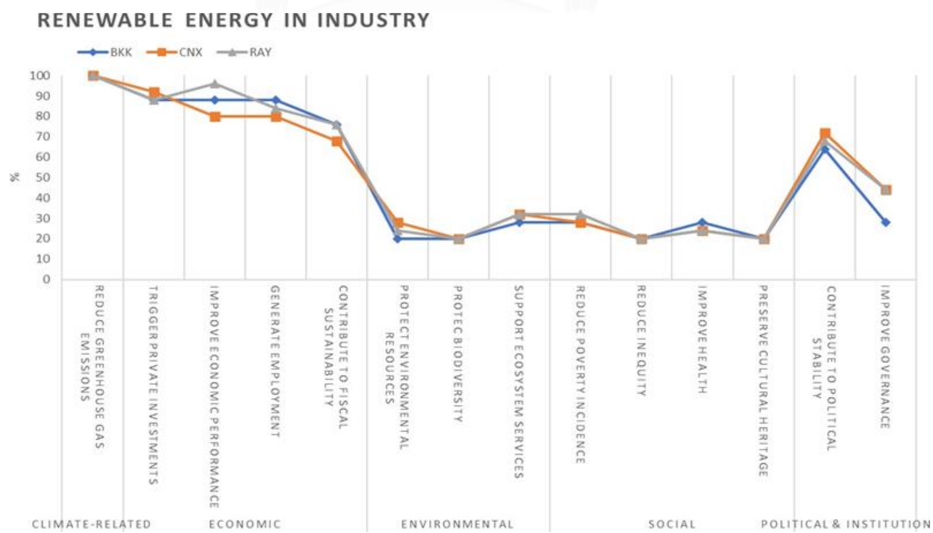


Figure 47 *The result of evaluation around "Renewable energy in industry" measure.*

Figure 47 shows that the "Renewable energy in industry" option received a high score in climate-related and economic criteria in the three selected provinces. However, the experts in these three provinces agree that the measure contributed a low impact in environmental and social criteria. This reflects the fact that the local experts identified that promoting investment or demand in renewable energy in industry has strong impacts on reducing greenhouse gas emissions in their province and increases investment and market competition around the city boundary as well as creating more jobs.

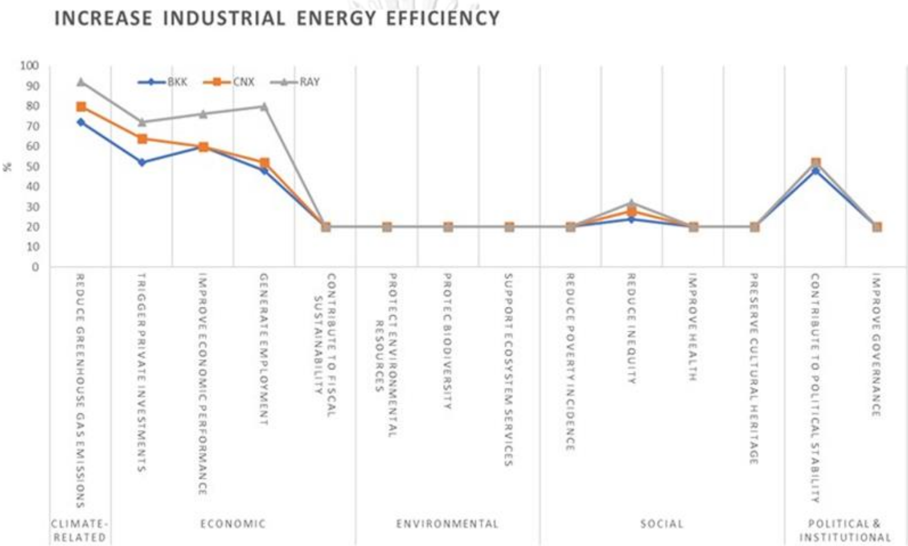


Figure 48 *The result of evaluation of the "Increase industrial energy efficiency" measure.*

"Increasing industrial energy efficiency" option received a high score in climate-related and economic criteria in these three selected provinces **(Figure 48).** However, the experts in these three provinces agree that the measure contributed a low impact in environmental and social criteria as well as the political and institutional criteria. The local experts understand and agree that promoting investment in energy efficiency in industry strongly impacts on reducing greenhouse gas emissions and increasing investment and market competition around the city boundary as well as creating more jobs, particularly in Rayong. This is because Rayong is an industrial base province, so the impact is higher than the other two provinces in climate-related and economic perspectives.

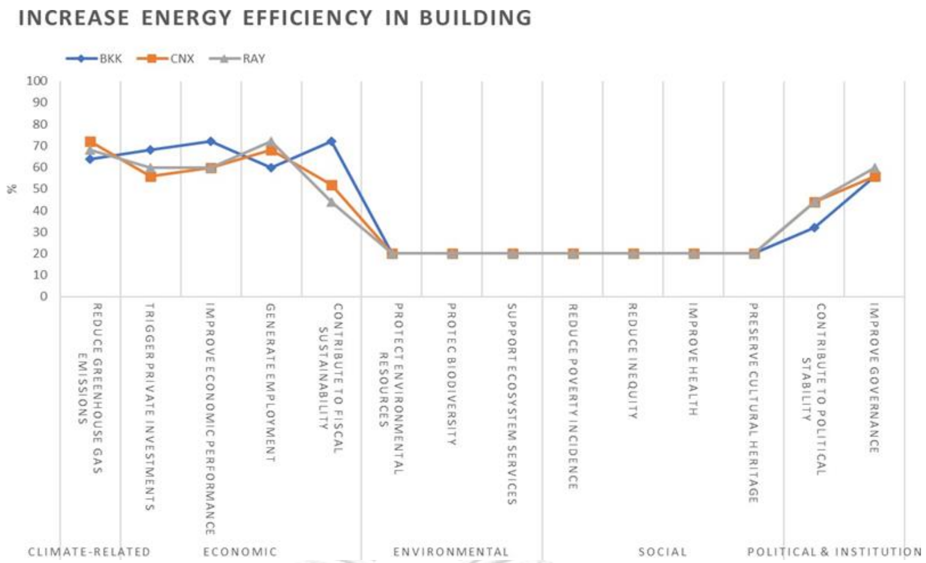


***Figure 49** The result of evaluation of the “Increase energy efficiency in building” measure.*

Figure 49 highlighted that the “Increasing energy efficiency in building” option received a high score in climate-related and economic criteria in the three selected provinces as well as in political and institutional criteria. However, the experts in these three provinces agree that the measure contributed a low impact in environmental and social criteria.

***Figure 50** The result of evaluation around “Solid waste management” measure*

Moreover, “Solid waste management” option received a high score in climate-related and economic criteria in the three selected provinces as well as in political and institutional criteria compared to environmental and social criteria **(Figure 50).** However, the score given to improve health sub-criteria is high in all three provinces. This may be because of the co-benefit of improved local air-quality. Since most solid waste management is invested in and operated by local government, the score in political and institutional criteria is high.

Figure 51 *The result of evaluation around “Increase biogas from industrial wastewater” measure.*

Beside this, “Increase biogas from industrial wastewater” option received a high score in climate-related criteria but with different levels between the provinces **(Figure 51).** Chiang Mai showed the highest score in reducing greenhouse gas emissions sub-criteria since the experts believed that there are a lot of opportunities for biogas in Chiang Mai whereas opportunities are low in Rayong. The impact in economic and environmental criteria is high in all three provinces with Chiang Mai having the highest score.

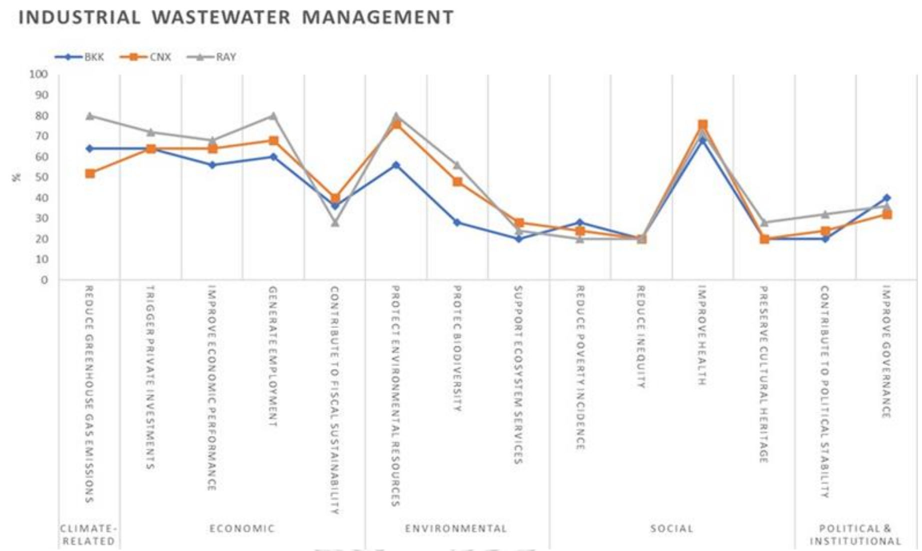


***Figure 52** The result of evaluation around*
"Industrial wastewater management" measure.

Figure 52 shows that the "Industrial wastewater management" option received a high score in climate-related and economic criteria in the three selected provinces as well as in the protecting environmental resources and protecting biodiversity sub-criteria. Also, the experts from all three provinces agree that this measure has a high impact on improving health in their communities.

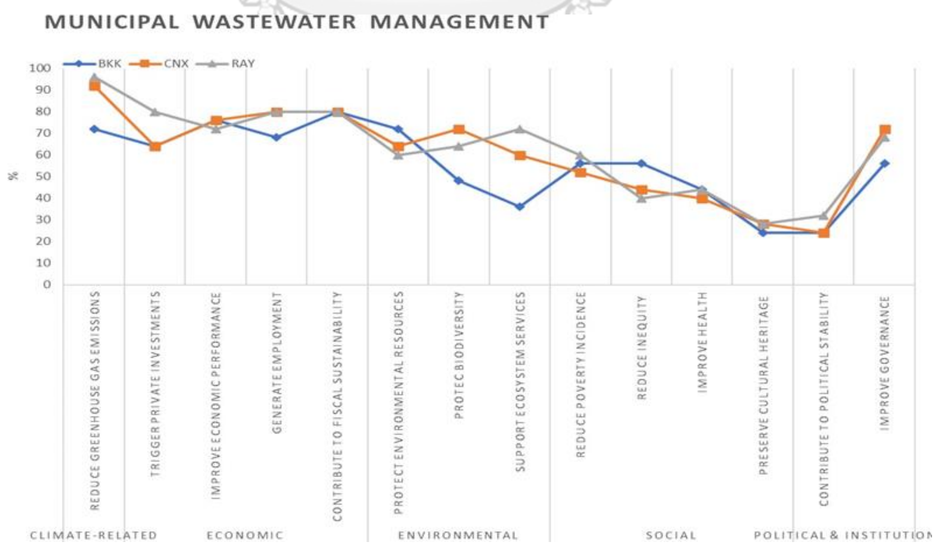


***Figure 53** The result of evaluation around*
"Municipal wastewater management" measure.

Lastly, **Figure 53** highlighted that the option of "Municipal wastewater management" received a high score in most criteria in the three provinces. Implementing this measure strongly contributes to benefits to all sectors in the province, not only greenhouse gas reduction. It also has a high impact for the local government itself because the investment in and operation of municipal wastewater facilities is controlled by them.

4.2.2 Mitigation measures

Recently, potential measures to reduce the greenhouse gas emissions at the city level have been identified. A variety of approaches were used to develop a list of potential technologies, including interviews, brainstorming, and researching experience in the other cities. The initial list has been discussed with various professionals and experts both national and local level. In this section, the proposed technologies are considered both around the NDC implementation plan and the best practices. According to the results of evaluating measures in the previous section, technologies can be grouped by; (a) renewable energy, (b) energy efficiency, (c) low carbon transportation, and (d) efficient waste management. The final list of technologies considered for each selected province's interest, is presented in **Table 51.**

Table 51 *The list of low carbon technologies around NDC implementation plan*

Low carbon technologies	Bangkok	Chiang Mai	Rayong
A. Renewable Energy			
A.1 Solar collectors for water heating	✓	✓	✓
A.2 Solar photovoltaics	✓✓✓	✓✓✓	✓✓✓
B. Energy efficiency			
B.1 Replacement of low efficiency A/C units	✓✓	✓✓	✓✓
B.2 Energy efficient office and home electrical appliances	✓✓	✓✓	✓✓
B.3 Replacement of low efficiency light bulbs	✓✓✓	✓✓✓	✓✓✓
B.4 Light control automation system	✓✓	✓✓✓	✓✓✓

Low carbon technologies	Bangkok	Chiang Mai	Rayong
B.5 Replacement of high efficiency motors in industry	✓	✓✓	✓✓✓
C. Low carbon transport			
C.1 Replacement of old city passenger cars	✓✓	✓✓	✓✓
C.2 City bicycle lane network	✓✓	✓✓✓	✓✓
C.3 New car parking stations	✓✓✓	✓	✓
C.4 Urban buses – replacing the old buses	✓✓	✓✓	✓
C.5 Urban buses – redesign of bus lines	✓✓	✓✓	✓
C.6 Car pooling	✓	✓	✓
C.7 Improving urban traffic	✓✓✓	✓✓✓	✓✓✓
D. Efficient waste management			
D.1 Reduction of solid waste generation	✓✓✓	✓✓✓	✓✓✓
D.2 Extension of waste recycling	✓✓✓	✓✓✓	✓✓✓
D.3 Improving wastewater treatment	✓✓✓	✓✓✓	✓✓✓

Remark: ✓ *level of interest*

The level of interest of each selected province in different low carbon technologies is presented in **Table 51**. The highest interest technologies are in the efficient waste management group. This may indicate that the local authorities in the three provinces see more possibility of efficient waste management implementation than other technologies in the list. In the renewable energy group, solar photovoltaics have higher interest than solar collectors for water heating in all three selected provinces. This may be because of strong promotion from the central government and the cost of technology. In energy efficiency, the replacement of low efficiency light bulbs has a high level of interest in all three provinces. This is because the technology is well known in the market and the cost is low. Improving urban traffic has the highest interest from the three provinces while the car-pool initiative has the lowest interest. New car parking stations have a high interest in Bangkok and low interest in Chiang Mai and Rayong. This may be related to the current BTS development in Bangkok which Chiang Mai and Rayong has not yet considered for urban railway.

4.3 Marginal abatement cost curves

Within the context of the greenhouse gas emission reduction target, policy makers are tasked with the challenge of finding affordable ways to reduce emissions. Therefore, marginal abatement cost (MAC) curves have come into the focus of researchers to illustrate the economic feasibility of climate change mitigation options. Using the MAC curve to identify the economic feasibility at a sub-national level needs a wide range of data and assumptions. In this research, the MAC curve has been developed according to the data available. Demographic and economic historical growth data such as the population growth, households, vehicle, solid waste, and wastewater were taken from national and provincial statistical departments. The history of electricity consumption in Chiang Mai and Rayong was taken from the local Provincial Electricity Authority (PEA) but it was originally from the Metropolitan Electricity Authority (MEA). The cost of each technology has been reviewed in previous studies, government reports, and articles.

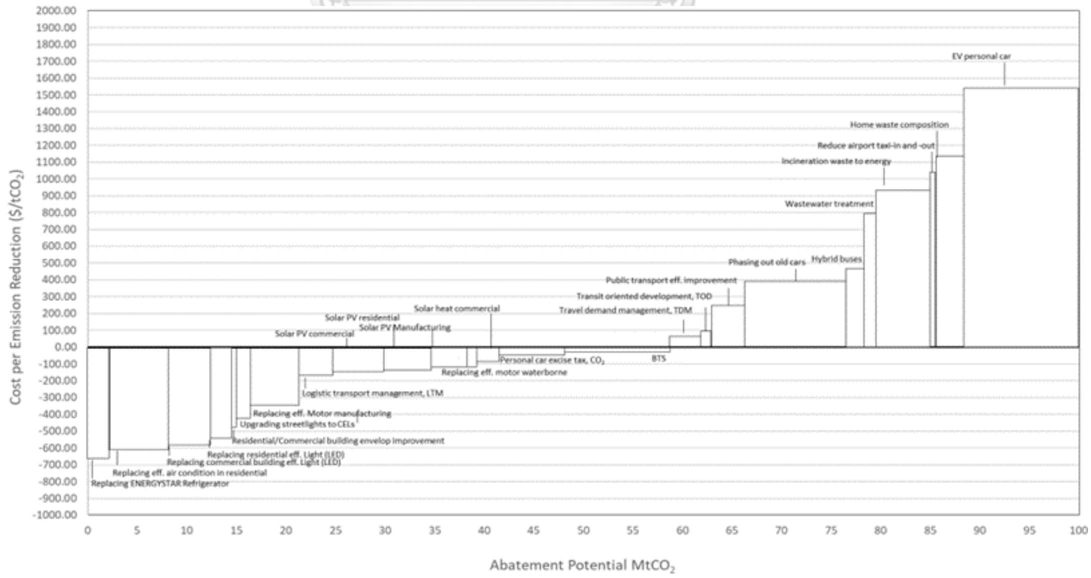


Figure 54 *Bangkok 2050 MAC curve illustrating mitigation measures.*

The MAC curve in **Figure 54** consists of various greenhouse gas mitigation measures at the target year (2050) in Bangkok. The cost effectiveness of proposed mitigation measures ranges from -658 to 1523 $/t$CO_2$eq and could reduce greenhouse gas by around 106 MtCO_2eq for the 1.5^oC pathway target mentioned in the previous chapter. As illustrated in **Figure 54**, replacing energy inefficient refrigerators and light bulbs with efficient devices such as ENERGYSTAR refrigerators, air conditioning units and light emitting diodes (LED) in residential and commercial buildings is the most cost-effective measure in reducing greenhouse gas emissions. These measures could approximately reduce 15 MtCO_2eq and their cost-effectiveness ranges from -658 to -550 $/t$CO_2$eq. The energy efficiency measure of replacing inefficient motors with efficient motors in manufacturing could reduce greenhouse gas emissions by around 6.8 MtCO_2eq and the cost of emission reduction is estimated at -360 $/t$CO_2$eq. For promoting renewable energy technology, particularly solar PV on rooftops of residential and commercial buildings and the manufacturing sub-sector, it is estimated to reduce greenhouse gas emissions by around 21 MtCO_2eq and has cost effectiveness ranging from -195 to -120 $/t$CO_2$eq. For the transportation sector, a small reduction in greenhouse gas emissions is expected from replacing inefficient motors in waterborne transportation with efficient ones. However, the mitigation measures for on-road transportation are expected to reduce greenhouse gas emissions by around 31tCO_2eq with cost effectiveness in the range of -65 to 1523 $/t$CO_2$eq. The promotion of electric personal cars gave the highest cost effectiveness and also provided a huge reduction in greenhouse gas emissions in Bangkok, followed by the phasing out of old cars, and expansion of the BTS route.

In waste sector, the wastewater treatment and implementation of waste incineration for energy generation were key technologies to reduce the greenhouse gas emissions in the sector. The reduction of greenhouse gas emissions from these technologies could be around 7 MtCO_2eq with cost effectiveness from 780 to 920 $/t$CO_2$e. Home waste compositing was proposed in the study, and it could reduce around 2 MtCO_2eq at a cost of 1,120 $/t$CO_2$eq.

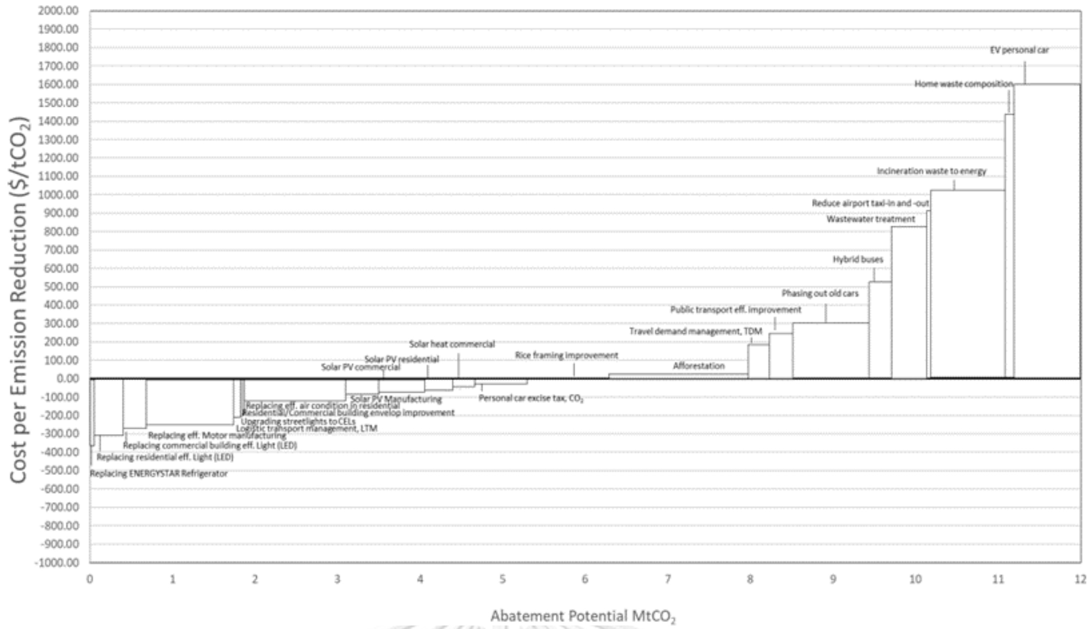


Figure 55 Chiang Mai 2050 MAC curve illustrating mitigation measures.

The MAC curve in **Figure 55** consists of various greenhouse gas mitigation measures at the target year (2050) in Chiang Mai. The cost effectiveness of proposed mitigation measures is in the range of -358 to 1624 $/tCO_2$eq and could reduce greenhouse gas emissions by around 12 $MtCO_2$eq for the 1.5^oC pathway target mentioned in the previous chapter. As illustrated in **Figure 55**, replacing energy inefficient refrigerators and light bulbs with efficient devices such as ENERGYSTAR refrigerators, air conditioning units and LEDs in residential and commercial buildings are the most cost-effective measures in reducing greenhouse gas emissions for Chiang Mai. These measures could reduce greenhouse gas emissions by approximately 2.5 $MtCO_2$eq with cost-effectiveness ranging from -358 to -120 $/tCO_2$eq. The energy efficiency measure of replacing inefficient motors with the efficient motors in manufacturing could result in greenhouse gas emission reduction of around 1.2 $MtCO_2$eq with cost per emission reduction estimated at -240 $/tCO_2$eq. Promoting renewable energy technology, particularly solar PV rooftop in residential and commercial buildings and the manufacturing sub-sector, is estimated to reduce greenhouse gas emissions by around 1.3 $MtCO_2$e with cost effectiveness ranging from -98 to -60 $/tCO_2$eq.

In transportation sector, the mitigation measures for on-road transportation are expected to reduce greenhouse gas emissions by around 1.7 tCO_2eq with cost effectiveness in the range of -65 to 1523 \$/tCO2eq. Promoting electric personal cars gave the highest cost effectiveness and provided potential of greenhouse gas emissions reductions of around 0.8 $MtCO_2eq$. For the waste sector, wastewater treatment and implementing waste incineration for energy generation were key technologies to reduce the greenhouse gas emissions in the sector. The projection of greenhouse gas emissions from these technologies could be around 1.7 $MtCO_2eq$ with cost effectiveness ranging from 810 to 1,020 \$/tCO_2eq. However, reducing waste at source was promoted in several cities. Therefore, home waste composition was proposed in the study, which could reduce around 0.3 $MtCO_2e$ at a cost of 1,420 \$/tCO_2eq.

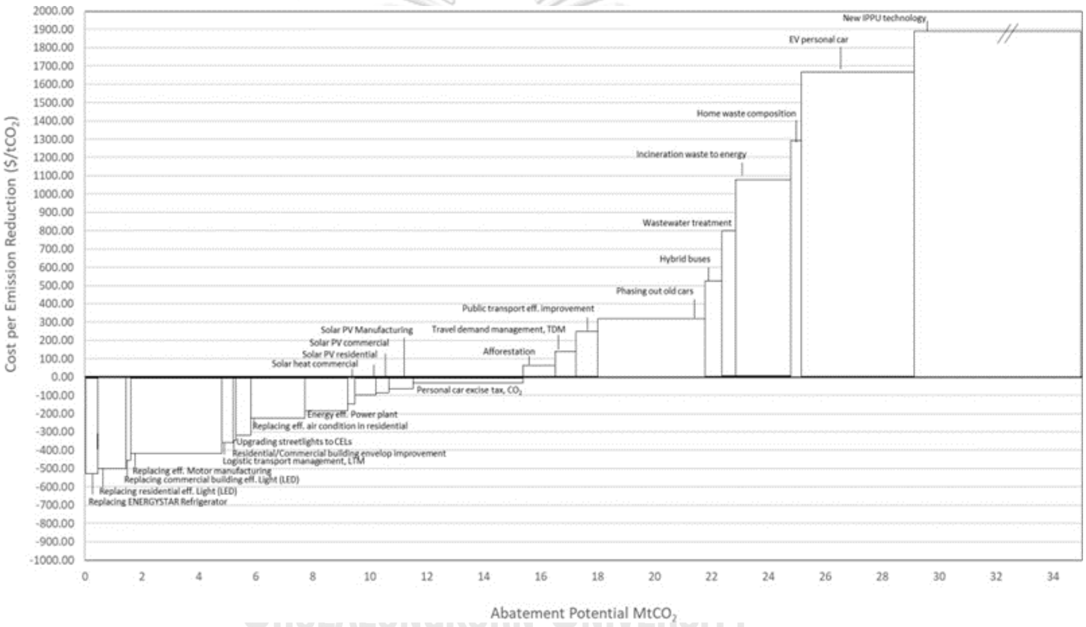


Figure 56 Rayong 2050 MAC curve illustrating mitigation measures.

The MAC curve in **Figure 56** consists of various greenhouse gas mitigation measures at the target year (2050) in Rayong. The cost effectiveness of proposed mitigation measures is in the range of -520 to more than 2,000 \$/tCO_2eq and could reduce greenhouse gas emissions by around 35 $MtCO_2eq$ for the 1.5^oC pathway target mentioned in the previous chapter.

As illustrated in **Figure 56,** replacing energy inefficient refrigerators and light bulbs with efficient devices such as ENERGYSTAR refrigerators, air conditioning units and LEDs in residential and commercial buildings are the most cost-effective measures for reducing greenhouse gas emissions. These measures could reduce emissions by approximately 4.2 $MtCO_2eq$ and their cost-effectiveness ranges from -520 to -220 $\$/tCO_2eq$. The energy efficiency measure of replacing inefficient motors with efficient motors in manufacturing could reduce greenhouse gas emissions by around 5.2 $MtCO_2eq$ with the cost per emission reduction estimated at -410 $\$/tCO_2eq$. Promoting renewable energy technology, particularly solar PV on rooftops in residential and commercial buildings and the manufacturing sub-sector, is estimated to reduce greenhouse gas emissions by around 5.2 $MtCO_2eq$ with cost effectiveness ranging from -210 to -70 $\$/tCO_2eq$.

In transportation sector, the mitigation measures on-road transportation is expected to reduce greenhouse gas emissions by around 7.4 tCO_2eq with cost effectiveness in the range of -65 to 1,523 $\$/tCO_2eq$. Promoting electric personal cars gave the highest cost effectiveness and provided potential for greenhouse gas emissions reduction of around 3.8 $MtCO_2e$. For the waste sector, wastewater treatment and implementation of waste incineration for energy generation were key technologies to reduce greenhouse gas emission. The reduction of greenhouse gas emissions from these technologies could be around 2.5 $MtCO_2eq$ with cost effectiveness ranging from 810 to 1,670 $\$/tCO_2eq$. However, the reducing waste at source was promoted in several cities. Therefore, home waste composition was proposed in the study, and it could reduce around 0.3 $MtCO_2eq$ at a cost of 1,320 $\$/tCO_2eq$. In Rayong, there is potential to reduce greenhouse gas emissions in the IPPU sector, in petrochemical and carbon black production and iron and steel production. However, low carbon technologies in these industrial processes are not available commercially at the period of this study. Thus, the cost effectiveness of the options for these processes is expected to be more than 2,000 $\$/tCO_2eq$.

4.4 Discussions

This section considers the findings from the research results. The discussions on the results of greenhouse gas inventories and projections in each selected case study were given. In addition, the recommended low carbon measures were highlighted.

4.4.1 Greenhouse gas inventory in cities

While analyses have compared greenhouse gas inventory methodologies across cities to help refine the methodologies (N. Ibrahim et al, 2012), the GPC was nominated to evaluate greenhouse gas emissions in the selected provinces in this research. The research examined the greenhouse gas inventory at the base year (2015) of three provinces: Bangkok, Chiang Mai and Rayong. Although the national greenhouse gas inventory mainly relied on the IPCC Guidelines for National Greenhouse Gas Inventories, the principle of evaluation is not much different. Therefore, the result of this research is likely to be comparable as a resource for policy makers. Figure 57 shows the three selected provinces' contribution of greenhouse gas emissions to the national greenhouse gas inventory in 2015. Bangkok contributed the most, followed by Rayong and Chiang Mai. The total contribution of three provinces was 69.34 $MtCO_2eq$ (20.32% of total national emissions in 2015). This was less than half of national greenhouse gas emissions.

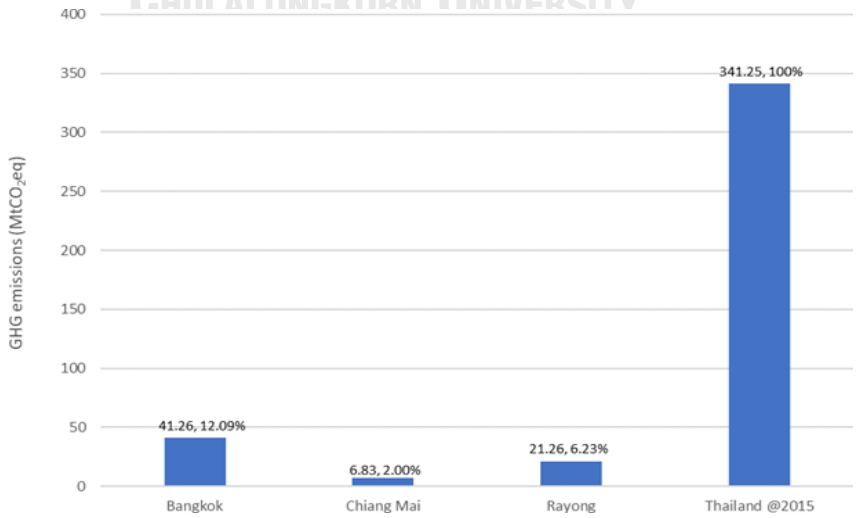
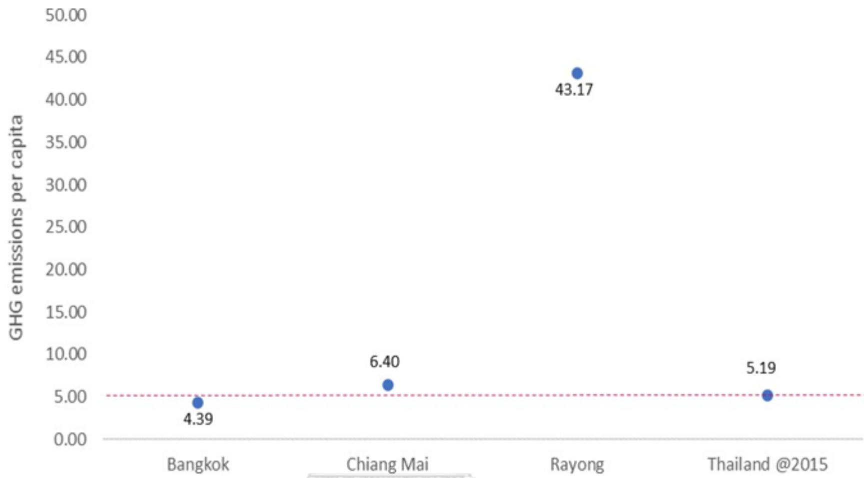


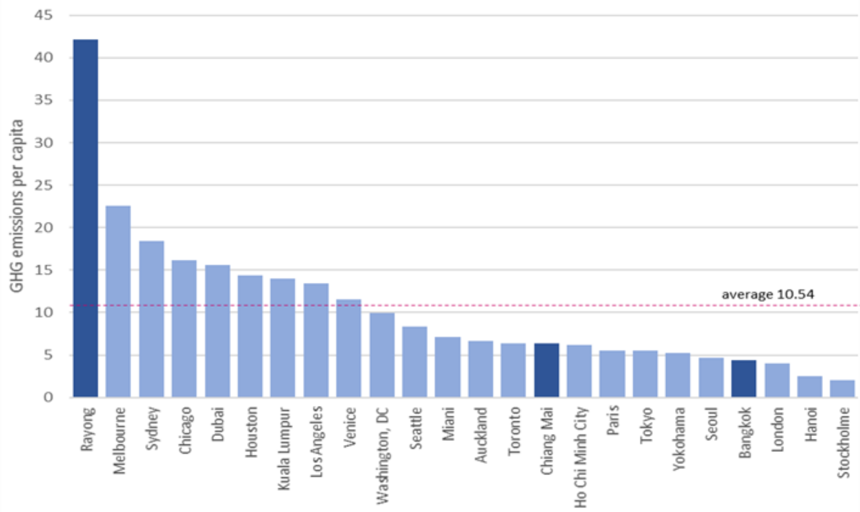
Figure 57 *The share of greenhouse gas emissions in three provinces to the national inventory, 2015*

Figure 58 shows greenhouse gas emissions per capita for the three selected provinces in this study and for the whole country. In 2015, the per capita emissions level for the country was 5.19 tCO_2eq/capita while the per capita emission levels in Bangkok, Chiang Mai and Rayong were 4.39, 6.40 and 43.17 tCO_2eq per capita respectively. Rayong has the highest emission per capita, and it is significantly higher than the country level. However, per capita emission levels in Bangkok and Chiang Mai are around the country level.



(Note: Estimated based on registered population in 2015)

Figure 58 *Comparative results of greenhouse gas emissions per capita in three provinces and country-wide in 2015*



(Note: assumption may difference in some cities, C40)

Figure 59 *Greenhouse gas emissions per capita in selected provinces compared to other cities (C40, 2021)*

By comparing the results of this research with other cities over the world using C40 data **(see Figure 59)**, Rayong had the highest emission per capita by far. It was significantly higher than the city average, while Chiang Mai and Bangkok were lower. Considering only cities in the Southeast Asia region, the emissions per capita level in Chiang Mai and Bangkok were lower than in Kuala Lumpur, while Hanoi was the lowest emission per capita in the region.

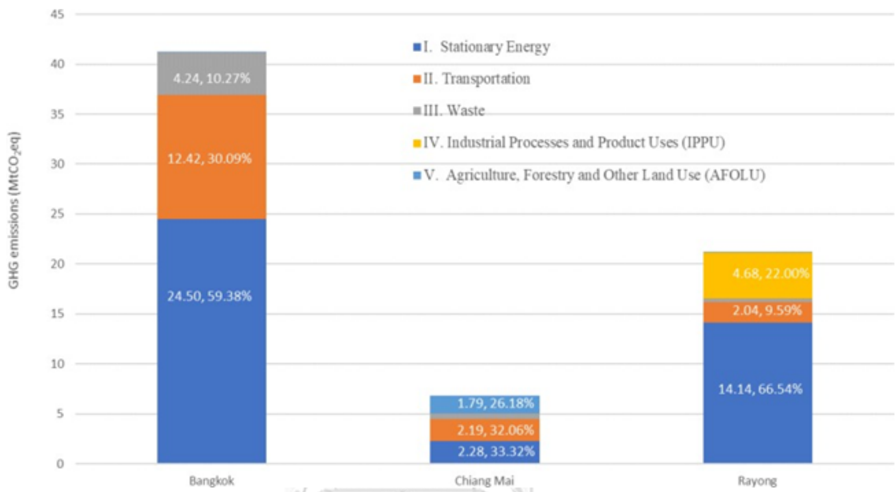


Figure 60 *Greenhouse gas emissions in three selected provinces in 2015, by sector*

The individual results of greenhouse gas emissions were presented in the beginning of this chapter. The stationary energy was a significant source of greenhouse gas emissions in all three provinces. Transportation was the second largest greenhouse gas contributor in Bangkok and Chiang Mai, while IPPU was the second GHGs emitter in Rayong. It is remarkable that the results showed different sources in the third rank of greenhouse gas emission sources for all three provinces. For Bangkok this was the waste sector, while it was AFOLU in Chiang Mai and transportation in Rayong. In conclusion, the city's characteristics likely affect the greenhouse gas management precedent or development of the city's low carbon strategies.

However, in developing a city's low carbon plan, the local government cannot avoid the results of greenhouse gas inventory at sub-sector level because it is one of the important factors to identify the most effective emission reduction measures. In Bangkok, on-road transportation, commercial and residential building sub-sectors were three major sources distributing greenhouse gas at sub-sector level (see Figure 61).

Therefore, from a greenhouse gas reduction perspective, the Bangkok's government should target and provide all potential supports to these three sub-sectors in their low carbon development plan.

Chiang Mai (see **Figure 62**), like Bangkok, had on-road transportation as a sub-sector generating significant greenhouse gas in 2015. The land use and land-use change sub-sector was also a significant greenhouse gas emission source for Chiang Mai and it related to the province's characteristics. It aligns with increasing agricultural area and decreasing forest area during the study period, according to data provided by the Royal Forest Department and the Office of Agricultural Economics. The commercial buildings and manufacturing sub-sectors contributed approximately the same amount of greenhouse gas emissions in 2015. This could be an important consideration for the local government to target these sub-sectors and identify potential measures which can reduce emissions in those sub-sectors.

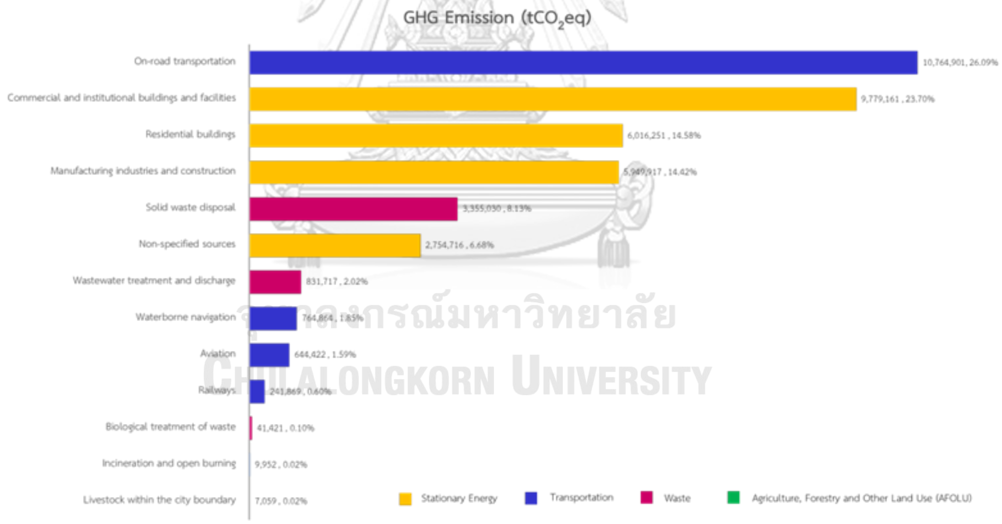


Figure 61 *Greenhouse gas emissions in Bangkok by sub-sectors in 2015*

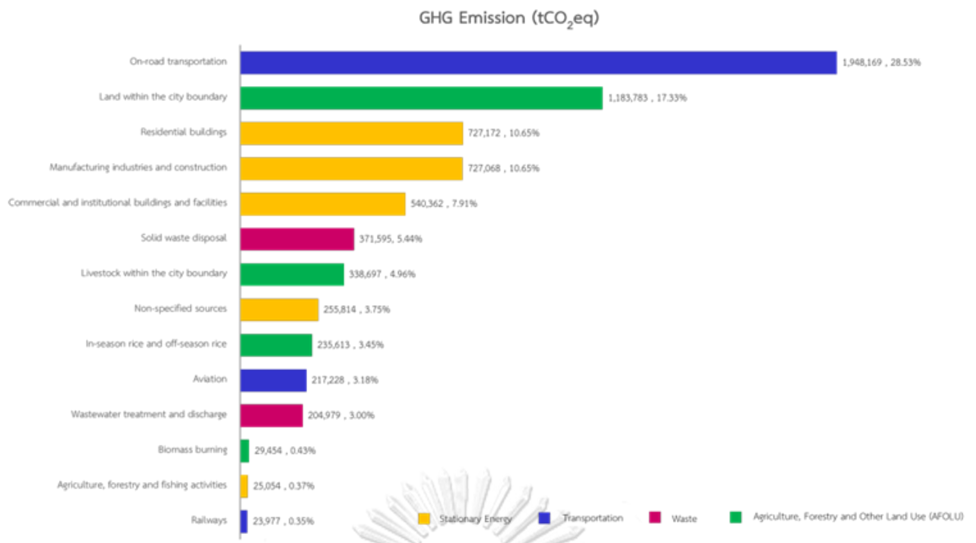


Figure 62 *Greenhouse gas emissions in Chiang Mai by sub-sectors in 2015*

At the sub-sector level, the results for Rayong's GHG inventory show a different pattern to Bangkok and Chiang Mai. The results show that the energy industry was a significant source of greenhouse gas emissions in Rayong. This confirmed that the greenhouse gas emission reduction is also needed the individual concern from the local authorities. Of the three provinces in the study, energy industries related activities occurred only in Rayong. In addition, since Rayong is a center of industries in Thailand, the manufacturing sub-sector was the second largest emission contributor, followed by the industrial process sub-sector. Transport seems not to be a significant source for Rayong.

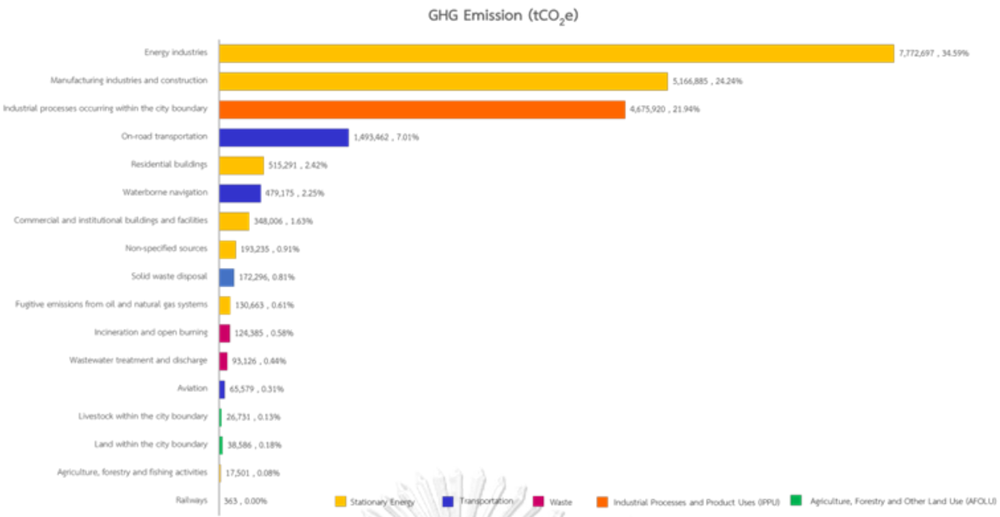


Figure 63 *Greenhouse gas emissions in Rayong in 2015 by sub-sectors*

4.4.2 Assessment of greenhouse gas projections in case studies

There are three scenarios considered for each selected province in this study. The result confirmed that the role of cities in climate change mitigation is critical to achieving national and international climate goals. To understand the trends of greenhouse gas emission under different assumptions it is important for the local government to set up an emissions target and identify reduction measures effectively.

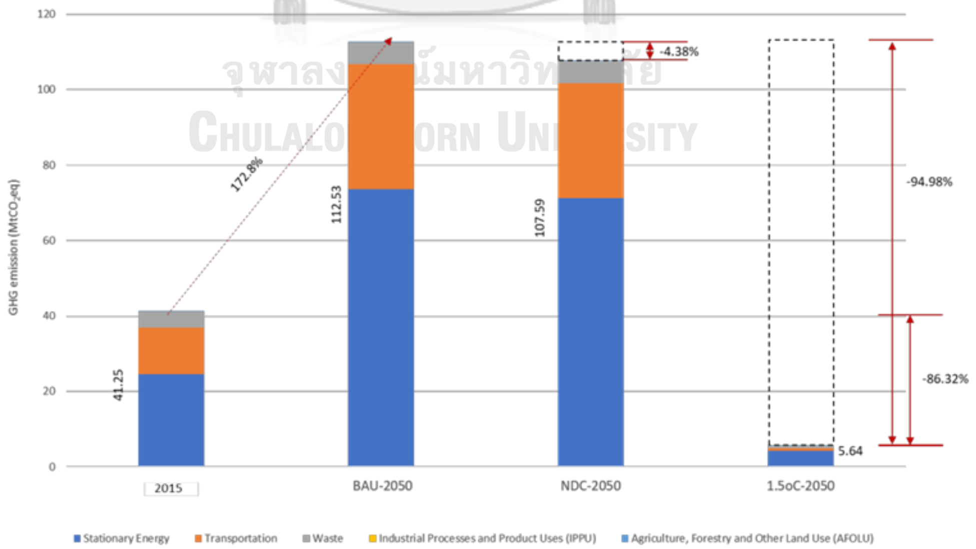


Figure 64 *Estimated greenhouse gas emission projections in three scenarios in Bangkok*

As per the assumptions for each scenario described in the methodology section, greenhouse gas emissions are expected to increase to 112.53 $MtCO_2eq$ or by 172% at 2050 from the base year under a business-as-usual scenario, which is based on socio-economic projections without any mitigation plan. In the growth of greenhouse gas emissions, the stationary energy, transportation, and waste sectors were three significant sectors for Bangkok. Mitigation options indicated in Thailand's NDC Roadmap (2020) were expected to lower their emissions by around 4.38% in 2050 compared with the business-as-usual scenario. However, a reduction of 94.98% of greenhouse gas emissions in Bangkok compared to the business-as-usual scenario was needed to reduce in line with a 1.5^{o}C pathway scenario, compared with the business-as-usual scenario or a reduction of 86.32% from the base year **(see Figure 64)**. 48.99% of the total reduction in the NDC scenario was expected in the stationary energy sector and 51.01% of total reduction in the NDC scenario was projected to come from the transportation sector. In the 1.5^{o}C pathway scenario, the expected reduction from the stationary energy sector was projected at 64.95% of total reduction required in the 1.5^{o}C pathway scenario. This is followed by the transportation sector which was projected to provide 30.25% of the total reduction required in this scenario. The waste sector was expected to reduce around 4.85% of total reduction required in the 1.5^{o}C pathway scenario. According to the expected reduction in the 1.5^{o}C pathway scenario, the per capita level of greenhouse gas emission in Bangkok in 2050 would be 0.38 tCO_2eq per capita.

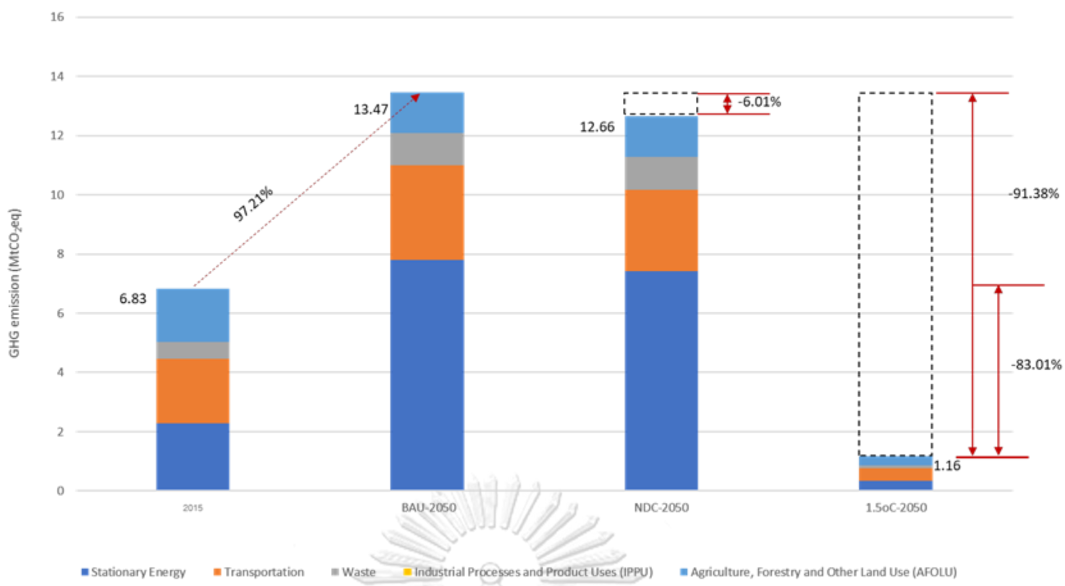


***Figure 65** Estimated greenhouse gas emission projections in three scenarios in Chiang Mai*

Figure 65 shows the assessment of the three greenhouse gas emissions scenarios in Chiang Mai compared with greenhouse gas emissions in the base year. Based on socio-economic projections without any mitigation plan, the greenhouse gas emissions were estimated to increase from 6.83 $MtCO_2eq$ in 2015 to 13.47 $MtCO_2eq$ in 2050 (a 97.21% increase). The key greenhouse gas emission sources were the stationary energy, transportation, AFOLU and waste sectors. The highest increase was in the stationary energy sector, followed by the transportation sector. Under Thailand's NDC roadmap, the total emissions in 2050 were forecast to increase from 6.83 $MtCO_2eq$ in 2015 to 12.66 $MtCO_2eq$ in 2050. This is a reduction of 6.01% from the business-as-usual scenario or 0.81 $MtCO_2eq$. The reduction was expected to come from the transportation sector rather than the stationary sector, as specified by the mitigation options in Thailand's NDC roadmap. The transport sector was expected to contribute around 0.42 $MtCO_2eq$ reduction or 48.15% of the emission reduction needed, with 0.39 $MtCO_2eq$ from the stationary sector or 51.85% of emission reduction needed in the NDC scenario.

In the 1.5oC pathway scenario, Chiang Mai could generate greenhouse gas of 1.16 $MtCO_2eq$ from all activities, which is approximately 83.01% reduction from the base year. In addition, this is expected to reduce greenhouse gas emissions of 12.31

$MtCO_2eq$ or 83.01% from the business-as-usual scenario. The stationary energy sector is required to lower greenhouse gas emissions by 7.48 $MtCO_2eq$, which accounted for 60.76% of total greenhouse gas emissions reduction expected. The greenhouse gas emissions were projected to reduce by 2.75 $MtCO_2eq$ in the transportation sector or 22.34% of the total expected greenhouse gas reduction needed in 2050. The AFOLU sector was required to reduce the greenhouse gas emission by approximately 1.08 $MtCO_2eq$ or 8.77% of total expected greenhouse gas emission reduction in 2050. The waste sector was forecast to reduce 1.00 $MtCO_2eq$ or 8.12% of total expected greenhouse gas emission reduction. According to the expected reduction in the 1.5^{o}C pathway scenario, the per capita level of greenhouse gas emission in Chiang Mai in 2050 would be 0.71 tCO_2eq per capita.

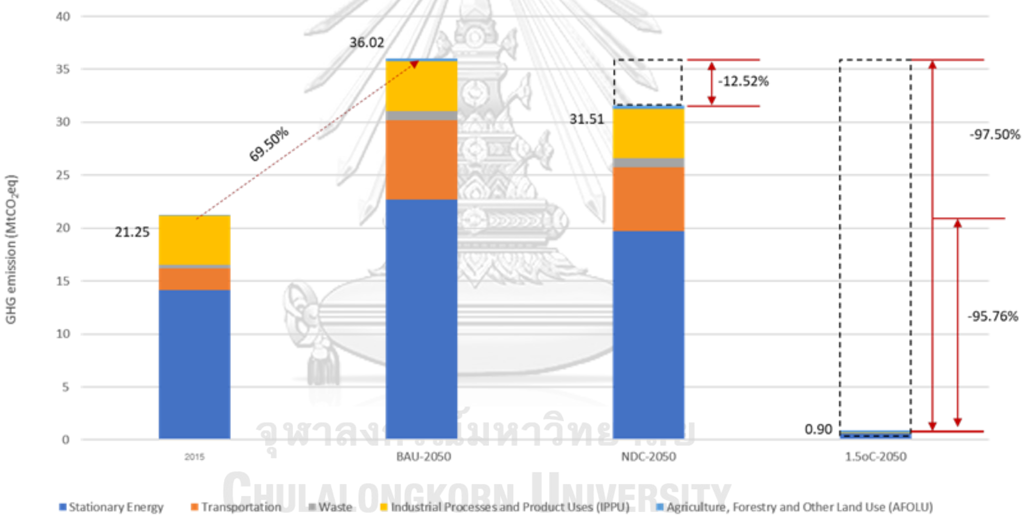


Figure 66 *Estimated greenhouse gas emission projections in three scenarios in Rayong*

In Rayong's case (see Figure 66), the greenhouse gas emissions were forecast to increase by 69.50% from 2015 to 2050, which amounted to 14.77 $MtCO_2eq$. In 2050, the business-as-usual scenario results showed that the stationary energy, transportation and IPPU sectors were still the main emission sources in Rayong, as in the base year. Assuming to implement the mitigation measures identified in Thailand's NDC roadmap, the emissions were expected to reduce by 12.52% from the emission level in business-as-usual or 4.51 $MtCO_2eq$. As in Bangkok and Chiang Mai, the reduction was expected to come mainly from the stationary energy and transportation sectors. Around

3.01 $MtCO_2eq$ or 67.34% of the total expected greenhouse gas emission reduction needed should come from the stationary energy sector and 1.46 $MtCO_2eq$ or 32.66% of total expected greenhouse gas emission reduction needed should come from the transportation sector.

In the 1.5^{o}C pathway scenario, Rayong could generate greenhouse gas from all activity of 0.9 $MtCO_2eq$, which is around a 95.76% reduction from the base year. In addition, this is expected to reduce the greenhouse gas emissions 35.12 $MtCO_2eq$ or 97.50% reduction from the business-as-usual scenario. Most of the reduction went to the stationary energy sector which was estimated to provide around 22.11 $MtCO_2eq$ or 62.96% of the total expected greenhouse gas emission reduction. This was followed by the transportation sector, which was projected to reduce around 7.44 $MtCO_2eq$ or 21.18% of the total expected greenhouse gas emission reduction. IPPU was expected to reduce around 4.63 $MtCO_2eq$ or 13.19% of the total expected greenhouse gas emission reduction. The waste sector also needed to reduce around 0.09 $MtCO_2eq$ or 0.26% of the total expected greenhouse gas emission reduction. According to the expected reduction in the 1.5^{o}C pathway scenario, the per capita level of greenhouse gas emission in Rayong in 2050 would be 1.08 tCO_2eq per capita.

4.4.3 Assessment of climate mitigation measures in case studies

The results presented in the previous chapter shows that some national climate mitigation measures are not applicable to local government actions and the degree of interest differs between the selected provinces. Five of the fifteen national climate mitigation measures are not applicable to local action and interests according to local expert suggestions. Two mitigation measures in the waste sector have particularly strong interest from the local government compared to others: solid waste management and municipal wastewater management. The national climate mitigation measures in the energy sector are applicable but the degree of interest is lower than for the waste sector. This is because of limitations of local government authorities and structures; they can only implement methods using the local government's own assets, for example the city hall. The local government needs to collaborate with other local government agencies. In addition, in residential and commercial buildings, the local government needs a lot of partnership with the local private sector and their general population.

4.4.3.1 Multi criteria analysis

The result of the multi criteria analysis confirmed the degree of interest of each national climate mitigation measure is based on characteristics of provinces or cities. However, it found that there is a common degree of interest in some measures, particularly in climate-related criteria **(see Figure 67)**. This can imply that the local experts realize that all national climate mitigation measures can reduce greenhouse gas emissions in their province according to high scores given in climate-related criteria in each measure. In addition, the score of interest in social criteria is the lowest in many measures. This means the proposed climate mitigation measures do not serve to provide social benefit in the thought of local experts. This analysis shows that national policy makers should pay more attention to social benefits to design effective and sustainable climate mitigation actions. Of the proposed national climate mitigation measures, solid waste management is an outstanding interest in these three provinces, followed by the promotion of renewable energy in households, particularly in Chiang Mai. This is because of a high score in social criteria. The local experts in all provinces advised that promoting renewable energy in households could contribute to a better life in the rural area, especially if people could not access the electricity grid, including schools and hospitals located in rural areas. The degree of interest in municipal wastewater management in these three provinces is roughly at the same level. This is because the municipal wastewater system development is in all the provincial development strategies. According to the interviews, barrier of these three provinces is a technical barrier.

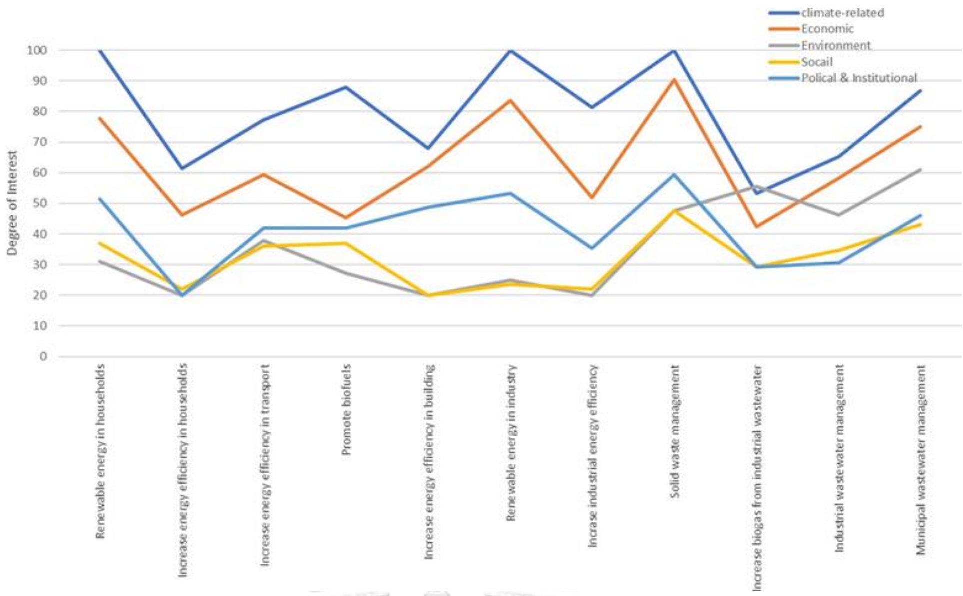


Figure 67 *Degree of interest in national climate mitigation measures by MCA criteria*

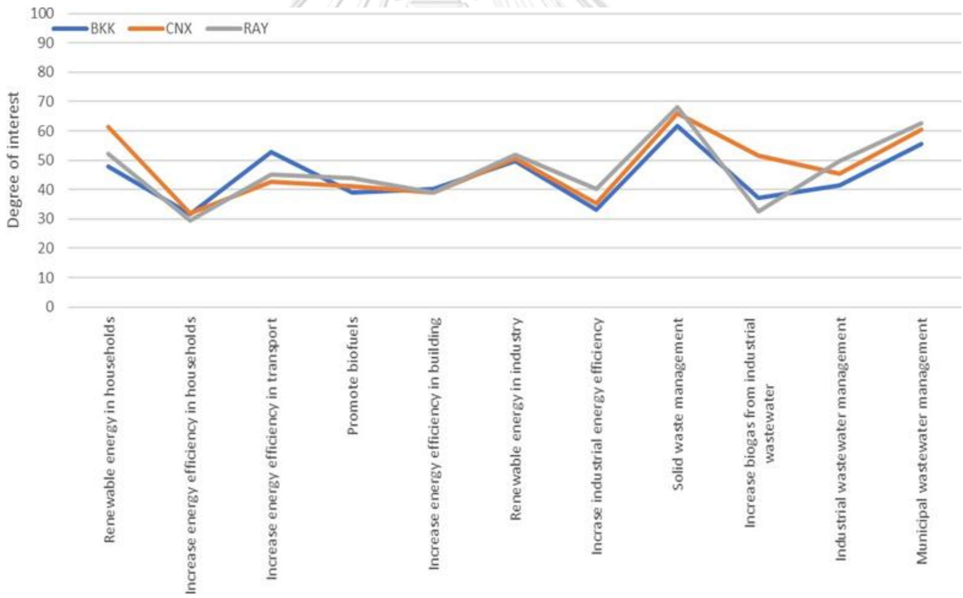


Figure 68 *Degree of interest in national climate mitigation measures by provinces*

Increasing efficiency in transport is more interesting to Bangkok compared to the other two provinces, even though the transportation sector is a major greenhouse gas emission source in all three provinces. Promoting biogas from industrial wastewater is of more interest in Chiang Mai compared to Bangkok and Rayong. It aligns with the characteristics of Chiang Mai industry, which is mostly food and agriculture production.

4.4.3.2 Marginal abatement cost curves

The MAC curve normally presents a simple picture to identify the effectiveness of greenhouse gas emission in economic terms. This section discusses the usefulness of various climate mitigation measures proposed in this study. In terms of policy, the MAC curve can be divided into incentive based and non-incentive-based instruments. For the study, non-incentive-based instruments are considered and discussed since they can offer the possibility to differentiate between technologies and sectors.

Researchers generally judge non-incentive-based instruments to be less cost-efficient and flexible than market-based instruments. However, they can be necessary in areas where market-based instruments are ineffective in the presence of failures and barriers in many relevant markets (R.W. Hahn and R. N. Stavins, 1992). Non-incentive-based instruments provide two different levels of policy: command-and-control policies and research and development policies. The command-and-control policies do not give the market a choice, but the government can regulate specific technologies or sectors. For example, the government can regulate or ban the use of inefficient technologies in a specific sector. Command-and-control instruments play an important role concerning the reduction of greenhouse gas emissions where market-based instruments fail.

Research and development policies primarily aim to foster innovation and bring down the costs of technologies with high marginal abatement costs. Therefore, the government needs to support funding on specific technologies in the high marginal abatement costs, for example wastewater treatment, home waste composting and electric vehicles, as described in this study.

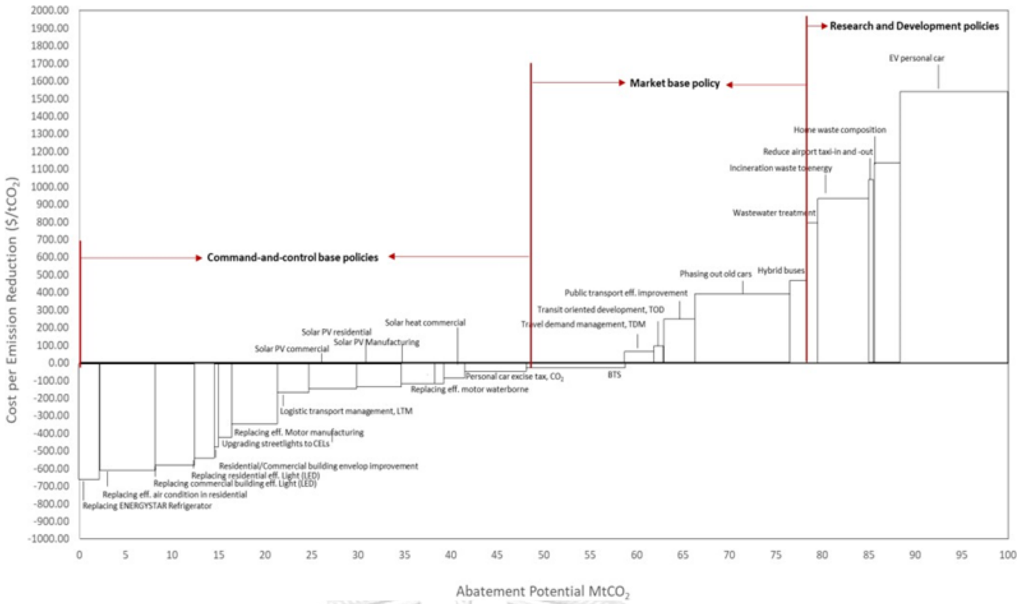


Figure 69 *Policy instrument recommendation based the MAC curve in Bangkok*

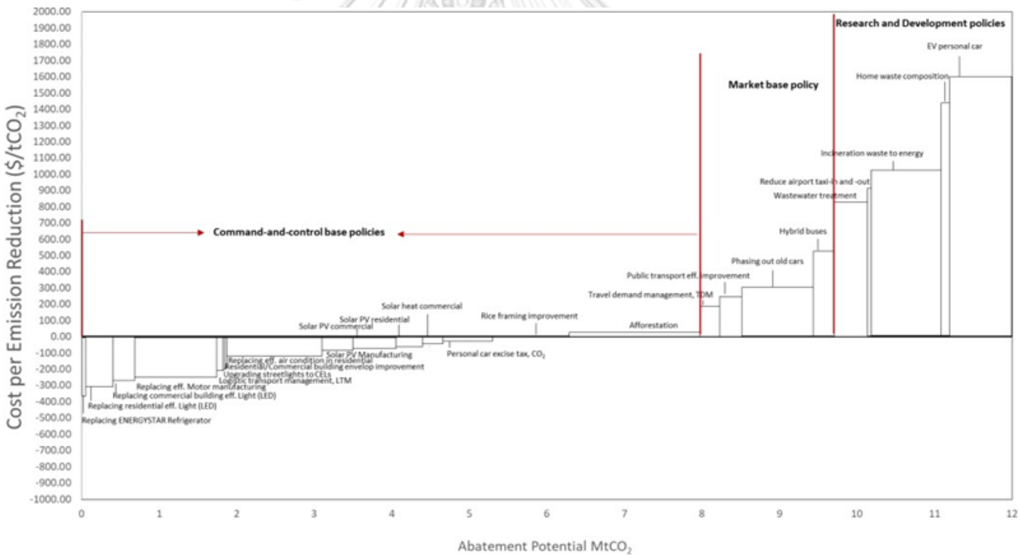


Figure 70 *Policy instrument recommendation based the MAC curve in Chiang Mai*

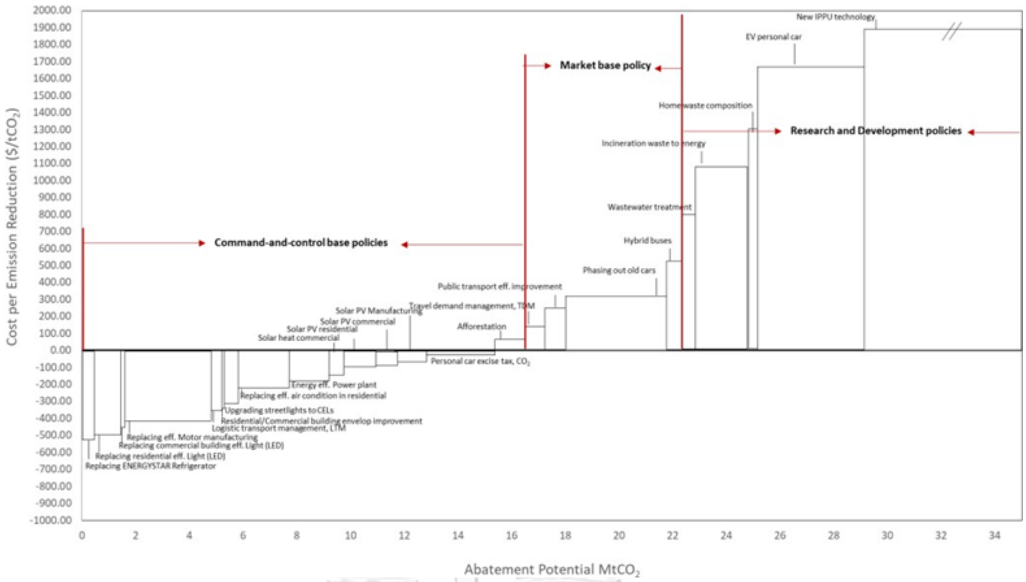


Figure 71 *Policy instrument recommendation based the MAC curve in Rayong*

Figures 69 to 71 show that most energy efficiency and renewable energy measures are command-and-control base policies. Emission reduction measures in the transportation sector are largely in the market-based policies and the high marginal abatement cost instruments are in the research and development policy. However, he measures are different, such as afforestation in Chiang Mai and Rayong. Although afforestation has a positive abatement cost which should be in the market base policy, it is considered a command-and-control based policy because of national regulation in forest protection areas. In the same logic, the BTS instrument in Bangkok has a negative abatement cost which should be a command-and-control base policy but is considered a market policy because the technology is available and operated by the private sector. However, the recommendation above is based mainly on theoretical discussion. In practice, the local government cannot regulate the measures in the command-and-control base policies. For research and development policies, the local government needs support from international or national agencies to provide funding for specific studies. In conclusion, this could reflect the fact that MAC curves may not contribute practical information to the local context. Alternatively, it provides better understanding to national policy makers to design the instruments supporting climate mitigation measures effectively.

4.4.3.3 SWOT analysis

Although mainstreaming at national level expected to trickle down to sub-national level, implementation at local level has limited. Step taken to address city level climate change mitigation issues may seem recent and this is due to roles local governance system and institutional structure. The SWOT analysis indicated the strengths, weaknesses, opportunities, and threats involved in the climate change mitigation policy in this study.

According to analysis, the researcher found the finding from these three provinces were identified issues which described in **Table 52** to **54**.

Table 52 *SWOT analysis (Bangkok)*

Strengths: • Local authorities (BMA) clearly understand the overall situation of greenhouse gas emissions and its trend. • Availability of greenhouse gas emission target and climate change mitigation implementation plan according to scientific data. • Availability of database on the key main sources of greenhouse gas emission at the city level. • Existence of communication platform for local government and key stakeholders in driving climate change mitigation and related activities at the city level. Planned coordination between relevance sectors and administrative levels. • Existing research on climate change related topics in Bangkok
Weaknesses: • Lack of knowledge and skills of local government officers to support climate change mitigation planning. Inadequate local climate change experts. • Weak institutional capacity and coordination with other stakeholders to foster climate change mitigation policies and implementation. • Lack of monitoring and measurement schemes to support both climate change mitigation plans, related strategies and implementation. • Authority mandate overlapping

• Lack of human and financial resources
Opportunities: • International concern on climate change and also GHGs emissions per capita in Bangkok as the world's next mega-city. • Wider coverage of impacted areas with climate change (i.e., flooding) • Increasing knowledgeable organizations (i.e., institutions, universities, international organizations, NGOs) working in climate change related topics in Bangkok. • International and regional bonds and connections. • Receiving attention from the central government to tackle climate change problems in cross cutting national and sub-national government agencies as the capital city • Execution for climate change policies, greenhouse gas reduction target and mitigation options with national government and other stakeholders, including international stakeholders. • Availability of national experts to support the planning and implantation of climate change policies as well as GHGs reduction targets
Threats: • Lack of capacity building opportunities in climate change. • Rapidly growing urbanization and climate change related impacts.

Table 53 *SWOT analysis (Chiang Mai)*

Strengths: • Local authorities understand the overall situation of greenhouse gas emissions and its trend. • Availability of database on the key main sources of greenhouse gas emission at the city level. • Recognition of local government on the importance of climate change mitigation and greenhouse gas reduction related activities. • Existence of communication platform for local government and key stakeholders in driving climate change mitigation and related activities at the city level. • Existing research on climate change both mitigation and related impact
Weaknesses: • Lack of knowledge and skills of local officers in climate change mitigation planning. • Lack of awareness at the provincial administrative organization to foster climate change policies implementation. • Lack of budget to support climate mitigation implementation at the local level. • Weak institutional capacity to support and promote climate change mitigation strategies and GHGs reduction targets • Lack of coordination and collaboration between sectors and stakeholders involved in climate mitigation and GHGs target setting. • Unclear responsibilities between administrative levels for driving climate change related policies at the local level • Authority mandate overlapping and its structure. • Lack of human and financial resources Lack of capacity building opportunities in climate change

Opportunities: • Increasing knowledgeable organizations/universities working in climate change related topics in Chiang Mai. • International and regional bonds and connections.
Threats: • Absence of clear-cut policies by the central governments regarding climate change mitigation and GHGs reduction target setting. • Rapidly growing urbanization and climate change related impacts. • Lack of institutionalization

Table 54 *SWOT analysis (Rayong)*

Strengths: • Availability of database on the key main sources of greenhouse gas emission at the city level.
Weaknesses: • Related stakeholders pay less attention on climate change mitigation compared to other topics (i.e., economic growth and pollution control). • Weak institutional capacity to support and promote climate change mitigation strategies and GHGs reduction targets • Limitations of measurement and monitoring of city-wide GHGs emissions • Limited data support on carbon reduction schemes for all relevant sectors (i.e., IPPU) • Lack of coordination and collaboration between sectors and stakeholders involved in climate mitigation and GHGs target setting. • Lack of adequate stakeholder engagement • Unclear responsibilities between administrative levels for driving climate change related policies at the local level • Lack of knowledge and skill in climate change mitigation planning. • Lack of awareness in provincial administrative organization.

• Lack of budget support on climate change mitigation implementation. • Inadequate local climate change experts. • Low climate change awareness level among related stakeholders at local scale
Opportunities: • Wider coverage of impacted areas with climate change (i.e., drought and water security). • Existence of communication platform for local stakeholders in supporting environmental abatement activities at the city level. • Increasing knowledgeable universities working in climate change mitigation in high-potential sectors (i.e., IPPU and waste) in Rayong.
Threats: • Absence of clear-cut policies by the central governments regarding climate change mitigation and GHGs reduction target setting. • Rapidly growing environmental and climate change impacts problems. • Lack of institutionalization

Effectiveness of climate change mitigation implementation depends on many factors and need more collaboration to all relevant stakeholders including national and sub-national level both public and private sectors. The SWOT analysis reflected a clearly understand of existing greenhouse gas emissions and long-term projection in the city was a common strength for three provinces since no selected provinces in this study have not have the long-term greenhouse gas emission projection, particularly for 1.5ºC pathway. In addition, the result of this research can help local government to consider their greenhouse gas emission target and improve their communication on climate mitigation actions. In the weakness, the result of SWOT analysis demonstrated that inadequate of climate change experts in the local level is a major issue as well as stakeholder’s communication and involvement. Bangkok shared a good point on lack of monitoring and measures process on climate mitigation implementation. Moreover, it could have opportunities to raise awareness on climate change in local level and start executing and communication local stakeholders including local private sector. Also, it is a chance to build the capacity of local experts. However, authority mandate overlapping, and institutional structure are a current key threat of local climate mitigation action. In the long-term, the capacity building is the most important to improve local knowledge and skill on local climate mitigation policy and planning.

CHAPTER V
CONCLUSION

The research was to investigate the greenhouse gas emissions in three selected provinces in Thailand: Bangkok, Chiang Mai, and Rayong and recommend the development of long-term climate mitigation implementation strategy. In addition, the gap between national mitigation plans and local needs and suggested for further development.

5.1 The city-wide greenhouse gas emissions and target

This study confirms that the provincial or city level plays a crucial role in achieving a country's Paris Agreement commitment. Thailand has committed to reduce 20% of greenhouse gas emissions by 2030 compared with a business-as-usual (BAU) scenario. Currently, there is no specific reduction target or climate mitigation plan at provincial level in Thailand.

This research provided recommendations on implementation of climate change mitigation policy and related mitigation target for the selected three provinces. As indicated in the first research objective, the results found that Bangkok's GHGs emissions were 41.25 $MtCO_2eq$ in base year of 2015. The trend of emissions was expected to increase to 112.53 $MtCO_2e$ in target year of 2050 compared to the BAU scenario. The major source of greenhouse gas emissions was from stationary sector, followed by transportation. Waste sector was considered the third largest contributor. Mitigation options indicated in Thailand's NDC Roadmap (2020) were expected to lower their emissions by around 4.38% in 2050 compared with the BAU scenario. Commercial and residential building have a high potential to reduce greenhouse gas emission under the NDC scenario. In the 1.5^{o}C pathway scenario, Bangkok should set limits on their greenhouse gas emissions for 5.64 $MtCO_2eq$ in 2050, decrease by 94.98% compared to the BAU. High-potential sectors in reducing greenhouse gas emission in this scenario were expected from on-road transportation, commercial building, and residential sub-sector, respectively.

In Chiang Mai, the total greenhouse gas emissions in 2015 were 6.83 $MtCO_2eq$ and projected to increase to 13.47 $MtCO_2eq$ in 2050 in BAU, 97.21% increasing from the base year. The major source of greenhouse gas emission was stationary energy, followed by transportation and AFOLU, respectively. In the NDC scenario, emissions were 12.66 $MtCO_2eq$ in 2050, decrease by about 6.01% relative to the BAU. The most of greenhouse gas emission reduction in this scenario were from residential and manufacturing sub-sector. In the 1.5^{o}C pathway scenario, Chiang Mai need to consider limiting GHGs emissions for 1.16 $MtCO_2eq$ in 2050 or 91.38% reduction compared to the BAU scenario. High-potential sectors expected to lower greenhouse gas emissions from this scenario were manufacturing, residential and commercial building, respectively.

Rayong's GHGs emissions in 2015 was 21.25 $MtCO_2eq$. Emissions of GHGs in Rayong were expected to increase to 36.02 $MtCO_2eq$ in 2050 in BAU. The major sources of greenhouse gas emissions were stationary energy, followed by IPPU, and transportation, respectively. In the NDC scenario, the city's emissions were projected to decrease to 31.51$MtCO_2eq$ or 12.53% compared to the BAU scenario. Manufacturing and commercial building sub-sector emitted the largest share of emissions. Rayong should limit their GHGs emissions in 2050 at 0.90 $MtCO_2eq$ to achieve 97.50% of emissions reductions from BAU in the 1.5^{o}C pathway scenario. Manufacturing, residential building, and industrial process sub-sector presented as high-potential sectors in driving low carbon city scheme.

5.2 Policy development recommendation

In this section, the development of long-term climate mitigation implementation strategy was recommended in these three provinces.

5.2.1 Bangkok

As mentioned earlier, the following policy recommendations are given for Bangkok to potentially achieve 94.98% emission reduction in the 1.5 IPCC scenario. The advance technologies and collaboration with private and national government are importantly suggested:

- Existing climate change mitigation master plan should be revised by considering and establishing long-term mitigation strategy.
- The long-term climate mitigation strategy should be more focused on the following high-potential sectors: stationary energy, transportation, and waste sectors.
- Mitigation measures on energy efficiency and renewable energy in residential and commercial building should be more promoted based on multi-stakeholder collaboration.
- Improving efficiency in transportation and promoting the use of electric vehicle are recommend as mitigation measures in transportation sector.
- In term of greenhouse gas emission, the contribution of waste and wastewater management is small, but it is recommended to indicate as one of mitigation strategies as environmental co-benefits.
- The roles and responsibilities of BMA government agencies and other stakeholders related to climate mitigation implementation should be clearly defined.
- Financial support on climate mitigation implementation should be provided.
- Knowledge and skills of local officers should be enhanced, especially the monitoring, reporting and verification system for GHG at the local level.

5.2.2 Chiang Mai

As the results this study, to meet 91.38% of greenhouse gas reduction by 2050, the following recommendations are given:

- Local governor can play the role in setting their own provincial greenhouse gas emission target and developing climate mitigation strategy and contributing to municipality agencies.
- Long-term climate mitigation plan should be more considered the opportunities to reduce greenhouse gas emissions in the following high-potential sectors: stationary energy, transportation and AFOLU.
- Energy efficiency and renewable energy measures in residential and

commercial building sectors should be more promoted and collaborated among various stakeholders.

- Improving energy efficiency and promoting electric vehicle are recommend in transportation sector.
- Afforestation is strongly introduced as the mitigation options in AFOLU sector.
- Local municipality level should be more engaged in the planning for climate change policy and target setting.
- The roles and responsibilities of local governors and other stakeholders related to climate mitigation implementation should be clearly defined.
- Financial support on climate mitigation implementation should be provided.
- Knowledge and skills of local officers should be enhanced, especially the monitoring, reporting and verification system for GHG at the local level.

5.2.3 Rayong

The following recommendations are provided for Rayong to possibly achieve 97.50% of their greenhouse gas reduction by 2050 as the long-term climate mitigation:

- Local governor can play the role in setting their own provincial greenhouse gas emission target and developing climate mitigation strategy and contributing to municipality agencies.
- Long-term climate mitigation plan should be more emphasized the roles and opportunities to reduce greenhouse gas emissions in the following high-potential sectors: stationary energy, IPPU and transport.
- Both energy efficiency and renewable energy mitigation measures should be more promoted and implemented in the IPPU sectors with active collaboration with multi-stakeholders in the city.
- Emission reduction in the IPPU sector should be more focused by setting the long-term climate mitigation plan for industrial production processes, particular in the glass and chemical production.
- Improving efficiency and promoting electric vehicle are recommend as

mitigation measures in transportation sector.

- Local municipality level should be more engaged in the planning for climate change policy and target setting.
- The roles and responsibilities of local governors and other stakeholders related to climate mitigation implementation should be clearly defined.
- Financial support on climate mitigation implementation should be provided.
- Knowledge and skills of local officers should be enhanced, especially the monitoring, reporting and verification system for GHG at the local level.

5.2.4 National level

- Both technical and financial supports related to climate mitigation strategy and GHGs reduction target should be adequately provided for local authorities. Technical knowledge, skills and capacity of local staff at the provincial level should be more enhanced.
- Enabling environment for climate mitigation implementation should be strengthened and enhanced at the provincial level, especially budgets and revenue integration with climate aspects.
- Financial instruments to provincial climate mitigation implementation should be more decentralized and allocated, for example, provincial climate mitigation fund.
- Closing the gap and increasing the opportunities of provincial engagement on national climate mitigation plan and target setting.
- Establishing provincial monitoring, reporting and verification standard and system for GHGs measurement at the local level.

5.3 Research contributions

The contributions of this research provide firstly the understanding of provincial greenhouse gas emissions in the base year and its trends in three scenarios which align with national and international target. In addition, the study delivers potential climate mitigation options for lowering greenhouse gas emissions in three selected provinces in Thailand. These case studies intend to be an example for other provinces in Thailand. Furthermore, the research findings contribute knowledge for local governments to support Thailand's NDC target and 1.5°C limit pathway. In summary, the recommendations for both national and local policy makers was provided to reduce the gap in design of climate mitigation plan. This research also contributes local policy options to address to SDG 13 "Climate Action", providing the co-benefits to the sustainable goals related to poverty, hunger, health, water and sanitation, cities, and ecosystem (SDG 1,2,8,11,14 and 15).

5.4 Limitations and future study

Limitations should be noted in this study. Developing greenhouse gas inventory and its projection requires a lot of data; for example, data on socio-economic factors, fuel consumption, electricity grid consumption, waste and wastewater generation, number of animals, forest, and other land-use areas. Data availability was a major limitation of this study in the expectation and projection of greenhouse gas emissions. Interpolation and extrapolation were needed in some cases regarding the data available. The findings from this study are considered empirical in the three selected provinces; however, the study framework and conceptual framework proposed in the study could be generalized for other provinces. This study does not include the impact of electricity grid emission factor. There are several limitations of using Marginal Abatement Cost (MAC) curves for economic analysis of the mitigation measures, such as having no representation of dependency of each measure, being limited to one point in time, lacking transparency of assumptions, and there being no integration of behavioral factors. Under the current COVID-19 pandemic restrictions, most expert interviews could not be in person so virtual and phone interviews were requested. The planned group interviews could not be conducted as plan.

This suggests that future work on provincial climate mitigation strategies study should look at more provinces in different characteristics such as agricultural- and tourism- base province. Advanced or disruptive technologies and financial measures could be taken into accounted such as hydrogen technology, carbon tax, and carbon trading scheme. It is essential to explore the impact of socioeconomic variables on implementation of climate mitigation options to identify areas of improvement, problems, and gaps. To improve economic analysis, the limitations of the MAC curve could be considered, particularly on the impact of policy interaction and behavioral factors. This will assist policy makers in designing applicable and sustainable initiatives.

APPENDICES

Appendix A: Default data for CO2 emissions factors for incineration and open burning

Parameters	Management practice	MSW	Industrial Waste (%)	Clinical Waste (%)	Sewage Sludge (%)	Fossil liquid waste (%)
Dry matter content in % of wet weight		(see Note 1)	NA	NA	NA	NA
Total carbon content in % of dry weight		(see Note 1)	50	60	40-50	80
Fossil carbon fraction in % of total carbon content		(see Note 2)	90	40	0	100
Oxidation factor in % of carbon input	Incineration	100	100	100	100	100
	Open burning (see Note 3)	58	NO	NO	NO	NO

Source: *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 5: Incineration and Open Burning of Waste*

Note 1: *Use default data from Default data available in 2006 IPCC Guidelines, Vol. 5, Ch.2, Table 2.4 in Section 2.3 Waste composition and equation 5.8 (for dry matter), Equation 5.9 (for carbon content) and Equation 5.10 (for fossil carbon fraction) in 2006 IPCC Guidelines, Vol.5, Ch. 5.*

Note 2: *Default data by industry type is given in 2006 IPCC Guidelines, Vol. 5, Ch.2 Table 2.5 in Section 2.3 Waste composition. For estimation of emissions, use equations mentioned in Note 1.*

Note 3: *When waste is open-burned, refuse weight is reduced by approximately 49 to 67 percent (US-EPA, 1997, p.79). A default value of 58 percent is suggested.*

Appendix B: CH_4 emissions factors for incineration of MSW

Type of premises	Temporary	Permanent
Continuous incineration	stoker	0.2
	fluidized bed	0
Semi-continuous incineration	stoker	6
	fluidized bed	188
Batch type incineration	stoker	60
	fluidized bed	237

***Source**: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 5: Incineration and Open Burning of Waste*

> ***Note:** In the study cited for this emission factor, the measured CH_4 concentration in the exhaust air was lower than the concentration in ambient air.*

Appendix C: Default N_2O emission factors for different types of waste and management practices

Type of waste	Technology/ Management practice	Emission factor (gN_2O/ t waste)	Weight basis
MSW	continuous and semi-continuous incinerators	50	wet weight
MSW	batch-type incinerators	60	wet weight
MSW	open burning	150	dry weigh
Industrial waste	all type of incineration	100	wet weight
Sludge (expect sewage sludge)	all type of incineration	450	Wet weight
Sewage sludge	incineration	900	dry weight
		900	Wet weight

***Source:** 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 5: Incineration and Open Burning of Waste*

Appendix D: Calculating chemical industry emissions.

Emission sources	GHG emissions		Simplest approach for qualifying emissions	Source of active data	Link to default emission factor calculation
Ammonia production	CO_2	-	Ammonia production multiplied by default emission factor	• Contact the operators or owners of the industrial facilities at which the processes occur and obtain relevant activity data. • Contact national inventory complier to ask for specific production data within the city boundary.	Table 3.1 of Page 3.15 from Chapter 3 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Nitric acid production	N_2O	-	Nitric acid production multiplied by default emissions factor		Table 3.3 of Page 3.23 from Chapter 3 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Adipic acid production	N_2O	-	Adipic acid production multiplied by default emission factor		Table 3.4 of Page 3.30 from Chapter 3 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Caprolactam production	N_2O	-	Caprolactam production multiplied by default emission factor		Table 3.5 of Page 3.36 from Chapter 3 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Carbride production	CO_2	CH_4	Carbride production multiplied by default emission factor		Table 3.7 and 3.8 of Page 3.44 from Chapter 3 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Titanium dioxide production	CO_2	-	Titanium slag production multiplied by default emission factor		Table 3.9 of Page 3.49 from Chapter 3 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Soda ash production	CO_2	-	Soda ash production, or Trona used, multiplied by default emission factor		Page 3.52 from Chapter 3 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories

***Source**: Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*

Appendix E: Calculating metal industry

Emission sources	GHG emissions		Simplest approach for qualifying emissions	Source of active data	Link to default emission factor calculation
Metallurgical coke production	CO_2	CH_4	Assume that all coke made onsite at iron and steel production facilities is used onsite. Multiply default emission factors by coke production to calculate CO_2 and CH_4 emissions	Governmental agencies responsible for manufacturing statistics, business or industry trade associations, or individual iron and steel companies	Table 4.1and 4.2 from Chapter 4 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Iron and steel production			Multiply default emission factors by iron and steel production data		Table 4.5 and 4.6 from Chapter 4 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Ferroalloy production	CO_2	CH_4	Multiply default emission factors by ferroalloy product type	Aluminum production facilities	Table 4.10 from Chapter 4 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Magnesium production	CO_2	SF_6	Multiply default emission factor by magnesium production by raw material type. For SF_6, assume all SF_6 consumption in the magnesium industry segment is emitted as SF Estimate SF_6 by multiplying default emission factors by total amount of magnesium casted or handled.	The magnesium production, casted/ handled data and raw material type may be difficult to obtain. Inventory complier may consult industry associations.	Table 4.19 and 4.20 from Chapter 4 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Lead production	CO_2	-	Multiply default emission factors by lead productions by sources and furnace type	Governmental agencies responsible for manufacturing statistics, business or industry trade associations, or individual lead and zinc producers	Table 4.21 from Chapter 4 of Volume 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Zinc production	CO_2	-	Multiply default emission factors by zinc production		Table 4.20 from Chapter 4 of Volume 3 of 2006 IPCC Guidelines

Emission sources	GHG emissions		Simplest approach for qualifying emissions	Source of active data	Link to default emission factor calculation
					for National Greenhouse Gas Inventories

Source: *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*

Appendix F: Use of notation keys

Notation key	Definition	Explanation
IE	Included elsewhere	GHG emissions for this activity are estimated and presented in another category of the inventory. That category shall be noted in the explanation.
NE	Not estimated	Emissions occur but have not been estimated or reported, justification for exclusion shall be noted in the explanation.
NO	Not Occurring	AN activity or process does not occur or exist within the city
C	Confidential	GHG emissions which could lead to the disclosure of confidential information and can therefore not be reported.

Source: *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*

Appendix G: GWP of major GHG gases

Name	Formula	GWP values for 100-year time horizon
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
Sulfur hexafluoride	SF_6	23,500
HFCs	HFC	12,400
CFCs	CFC	4,600-13,900
Nitrogen trifluoride	NF_3	16.100

Source: *IPCC 2013, IPCC Fifth Assessment Report: Climate Change 2013*

Appendix H: Emission Factor

No	Name	Units	Emission Factors ($kgCO_2eq$)	Reference
Stationary Combustion				
1	Natural gas	scf	0.0573	IPCC Vol.2 table 2.2, DEDE, AR5
2	Natural gas	MJ	0.0562	IPCC Vol.2 table 2.2, DEDE, AR5
3	Lignite	kg	1.0619	IPCC Vol.2 table 2.2, DEDE, AR5
4	Fuel oil A	litre	3.2198	IPCC Vol.2 table 2.2, PTT, AR5
5	Fuel oil C	litre	3.2455	IPCC Vol.2 table 2.2, PTT, AR5
6	Gas/Diesel oil	litre	2.7076	IPCC Vol.2 table 2.2, DEDE, AR5
7	LPG	litre	2.7076	IPCC Vol.2 table 2.2, DEDE, AR5
8	LPG	kg	3.1133	IPCC Vol.2 table 2.2, DEDE, AR5
Mobile Combustion (on-road)				
9	Motor Gasoline - uncontrolled	litre	2.2373	IPCC Vol.2 table 3.2.1, 3.2.2, DEDE, AR5
10	Gas/ Diesel Oil	litre	2.7403	IPCC Vol.2 table 3.2.1, 3.2.2, DEDE, AR5
11	Compressed Natural Gas	kg	2.2540	IPCC Vol.2 table 3.2.1, 3.2.2, PTT, AR5
12	Liquified Petroleum Gas	litre	1.7273	IPCC Vol.2 table 3.2.1, 3.2.2, DEDE, AR5
13	Liquified Petroleum Gas	kg	3.1988	IPCC Vol.2 table 3.2.1, 3.2.2, DEDE, AR5
Mobile Combustion (off-road)				
14	Diesel-agriculture	litre	2.9790	IPCC Vol.2 table 3.3.1, DEDE, AR5
15	Diesel-forestry	litre	2.9790	IPCC Vol.2 table 3.3.1, DEDE, AR5
16	Diesel-industry	litre	2.9790	IPCC Vol.2 table 3.3.1, DEDE, AR5
17	Diesel-household	litre	2.9790	IPCC Vol.2 table 3.3.1, DEDE, AR5
Motor Gasoline – 4 strokes				
18	Gasoline-agriculture	litre	2.2688	IPCC Vol.2 table 3.3.1, DEDE, AR5
19	Gasoline-forestry	litre	2.1816	IPCC Vol.2 table 3.3.1, DEDE, AR5
20	Gasoline-industry	litre	2.2423	IPCC Vol.2 table 3.3.1, DEDE, AR5
21	Gasoline-household	litre	2.3040	IPCC Vol.2 table 3.3.1, DEDE, AR5
Motor Gasoline – 2 strokes				
22	Gasoline-agriculture	litre	2.3083	IPCC Vol.2 table 3.3.1, DEDE, AR5
23	Gasoline-forestry	litre	2.3347	IPCC Vol.2 table 3.3.1, DEDE, AR5
24	Gasoline-industry	litre	2.2995	IPCC Vol.2 table 3.3.1, DEDE, AR5
25	Gasoline-household	litre	2.3436	IPCC Vol.2 table 3.3.1, DEDE, AR5
Electricity, grid mix				
26	Electricit0.4y	kWh	0.5986	Thai National LCI Database, TGO
Industrial process				
27	Steel	tonne	432.10	TGO

***Source**: Thailand Greenhouse Gas Management (Organization), 2020*

Appendix I: List of contributors and interviewees

No	Organization
National level	
1	Energy Policy and Planning, Ministry of Energy
2	Department of Alternative Energy Development and Efficiency
3	Department of Energy Business
4	Office of Natural Resources and Environmental Planning
5	Royal Forest Department
6	Department of National Parks, Wildlife and Plant Conservation
7	Thailand Greenhouse Gas Management (Organization)
8	Office of Transport Planning
9	Industrial Estate Authority of Thailand
10	Office of Agricultural Economic
11	Electricity Generation Authority of Thailand
12	Metropolitan Electricity Authority
13	Provincial Electricity Authority
14	Department of Local Administration
Provincial level	
Bangkok	
1	Environmental Policy and Planning Office
2	Solid Waste Management Office
3	Air and Noise quality Office
4	Bangkok Mass Transit Authority
5	Japan International Cooperation Agency - JICA
6	The Creagy Company
7	Thailand Greenhouse Gas Management (Organization)
8	GIZ
9	British Embassy Bangkok
10	UNDP
Chiang Mai	
1	Provincial Industrial Office
2	Provincial Electricity Authority (Chiang Mai)
3	Provincial Energy Office
4	Small and Medium Enterprises (SME) Support and Rescue Center
5	Land management office Area 16 Chiang Mai
6	Provincial Livestock Office
7	Provincial Agriculture Office
8	Provincial Transport Office
9	Provincial Statistic Office
10	Regional Environmental Office 1 (Chiang Mai)
11	Chiang Mai University
12	USAID
Rayong	
1	Provincial Industry Office
2	Provincial Electricity Authority (Rayong)
3	Provincial Energy Office
4	Land management office Area 2 (Rayong)
5	Provincial Livestock Office

No	Organization
7	Provincial Agriculture Office
8	Provincial Transport Office
9	Provincial Statistic Office
10	Regional Environmental Office 13 (Chonburi)
11	Provincial Environmental Office (Rayong)
12	Map Ta Phut Industrial Estate

Appendix J: Marginal Abatement Cost (MAC) Curve Input

No.	Mitigation Measures	Life (years)	Economic Cost Input and Assumptions	Bangkok		Chiang Mai		Rayong	
				GHG Abatement in 2050 ($MtCO_2eq$)	Cost Abatement in project start year (2021) ($/$tCO_2eq$)	GHG Abatement in 2050 ($MtCO_2eq$)	Cost Abatement in project start year (2021) ($/$tCO_2eq$)	GHG Abatement in 2050 ($MtCO_2eq$)	Cost Abatement in project start year (2021) ($/$tCO_2eq$)
1	Replacing ENERGYSTAR Refrigerator	11	USD 833/unit 382 kWh annual saving	2.72	-658	0.12	-358	0.50	-520
2	Replacing eff. Air condition in residential	15	USD 1,245/unit 2315 kWh annual saving	5.84	-590	1.70	-140	0.98	-245
3	Replacing eff. Light Bulbs (LED) in commercial building	20	USD 52/unit 23 W, 50,000 h (lifetime) 8 hr/day 224 kWh annual saving	3.30	-570	0.50	-320	0.20	-430
4	Replacing eff. Light Bulbs (LED) in residential building	20	USD 52/unit 23 W, 50,000 h (lifetime) 8 hr/day 224 kWh annual saving	2.84	-564	0.25	-285	1.30	-480
5	Residential/Commercial building retrofit improvement	30	USD 7,000/unit 18.13% energy reduction [1]	0.31	-550	0.30	-248	0.20	-330
6	Upgrading eff. streetlight to CFLs	6	USD 5.93/unit 26 W; 8,000 h (lifetime) 4 hr/day 56 kWh annual saving	1.47	-415	0.06	-242	0.6	-310
7	Replacing eff. Motor manufacturing	30	579 USD/unit Replacing by IE3 or higher [6] 70% electricity consumption Variable speed drive 54% energy saving	6.80	-360	1.20	-280	3.24	-415

No.	Mitigation Measures	Life (years)	Economic Cost Input and Assumptions	Bangkok		Chiang Mai		Rayong	
				GHG Abatement in 2050 ($MtCO_2eq$)	Cost Abatement in project start year (2021) ($/$tCO_2eq$)	GHG Abatement in 2050 ($MtCO_2eq$)	Cost Abatement in project start year (2021) ($/$tCO_2eq$)	GHG Abatement in 2050 ($MtCO_2eq$)	Cost Abatement in project start year (2021) ($/$tCO_2eq$)
8	Logistic transport management, LTM	30	2.5 Million USD [2] 3.78% energy reduction per year [2]	0.50	-210	0.24	-240	0.56	-360
9	Solar PV in commercial building	30	1,000 USD/kW [7] 10kW/unit 80% decreasing electricity consumption	7.46	-195	0.85	-83	0.70	-95
10	Solar PV in residential building	30	1,000 USD/kW [7] 10kW/unit 80% decreasing electricity consumption	4.39	-180	0.27	-87	1.2	-110
11	Solar PV in manufacturing	30	1,000 USD/kW [7] 10kW/unit 80% decreasing electricity consumption	6.97	-170	0.47	-110	0.8	-97
12	Replacing eff motor waterborne	30	800 USD/unit 100% successful rate	0.53	-160	-	-	-	-
13	Solar heating system in commercial building	30		2.18	-120	0.30	-98	0.7	-180
14	Personal car excise tax, CO_2	30	8 Million USD [2] 0.3% annual fuel saving	6.80	-67	0.89	-28		
15	Afforestation	30	Ref: ERM-Siam (2010)	-	-	1.70	20	0.80	78
16	Expansions of BTS	30	17,000 Million USD [2] 100% expansion by 2029 [2] 10% reducing travel rate per year	12.20	-20	-	-	-	-
17	Travel demand management, TDM	30	20 Million USD [2] 40% personal car reduction in zoning area [2]	2.60	51	0.34	170	1.2	140

No.	Mitigation Measures	Life (years)	Economic Cost Input and Assumptions	Bangkok		Chiang Mai		Rayong	
				GHG Abatement in 2050 ($MtCO_2eq$)	Cost Abatement in project start year (2021) ($\$/tCO_2eq$)	GHG Abatement in 2050 ($MtCO_2eq$)	Cost Abatement in project start year (2021) ($\$/tCO_2eq$)	GHG Abatement in 2050 ($MtCO_2eq$)	Cost Abatement in project start year (2021) ($\$/tCO_2eq$)
18	Transit oriented development, TOD	30	13 Million USD [2] 50% car reduction to compact area	0.90	75	-	-	-	-
19	Phasing out old car	30	1 Million USD [2] 100% new car 35% decreasing of GHG emissions [2]	9.20	390	1.20	320	3.40	310
20	Hybrid buses	30	300 Million USD [2] 100% successful rate	1.80	480	0.40	520	1.10	520
21	Wastewater treatment	30	400 Million USD [3] 100% successful rate	1.30	720	0.60	810	0.30	790
22	Incineration waste to energy	30	330 Million USD [4] 1,000 tone/day, 30 MW	4.80	950	1.20	1,220	0.85	1,090
23	Reduce airport taxi-in and -out	30	3 Million USD [2] 30% energy reduction	0.40	1,050	0.04	820	-	-
24	Home waste composting	30	300 USD/unit [8] 250 kg waste reduction/home	2.84	1,120	0.35	1,430	0.48	1,300
26	Promoting the use of EV car	30	10,500 Million USD [2] 100% successful rate	12.30	1,523	1.30	1,624	4.50	1,670

Note: *1. Thailand average tariff for residential and commercial buildings in approximately USD 0.12 per kWh. (Seeley C| 2021)*
2. Office of Transport Planning, OTP 2020
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Appendix K: Example of local expert interview

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