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A Study on Strategic Urban Energy Use and Carbon Management towards Low-Carbon City in Thailand

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Abstract – **The energy provision and utilization has not been a strategic priority for urban authorities. Urban areas are centers of growth, production and consumption. They represent potential pathways to achieve a low-carbon society. This paper presents the development of a strategic energy and carbon management in urban areas in Thailand. The objective of this study is to analyze strategic urban energy use and carbon management while satisfying required demands. Future energy demand and energy-related CO_2 emissions are calculated using the Long-range Energy Alternatives Planning (LEAP) system based on end-use scenario methodology with taking into consideration of two scenarios. The business as usual scenario assumes that no specific measures will be applied to influence the trends of urban energy demand. The countermeasures scenario is generated to assess the effects of policy measures for energy savings and CO_2 emission reductions. The energy use, energy-related CO_2 emissions and potential for energy-savings and emission reductions are estimated for a planning horizon of 2009–2020, with 2008 used as the base year. The findings indicated that the transport sector has the largest abatement potential. The cleaner technology measure is the most effective in terms of energy-savings and CO_2 emission reductions. In addition, GIS is also implemented for local governments to achieve the contribution of information.**

Keywords – Carbon Management, GIS, Low-Carbon City, Scenario Analysis, Urban Energy Use

1. Introduction

Responding to climate change mitigation and urban energy management is placing new and complex issues for urban decision-makers. Targets for CO_2 emission mitigation are now urgent and imply major reconfiguration of urban energy systems. The world is gradually going to be completely urbanized and more than half of the people already live in urban areas [1–2]. Internationally, many cities have been working to mitigate CO_2 emissions at a city level. A previous study has investigated that more than 50 cities around the world have their own emission reduction targets and certain plans. Many of them aim to reduce emissions more than 50% compared to their current emissions [3].

Urban energy studies have been increasing attention worldwide. Some studies have examined greenhouse gas (GHG) emission profiles of different cities, and considered the view of urban metabolism but few have concentrated on urban energy alone [4]. Urban decision-makers are now called to develop strategies for managing energy use and climate change mitigation at the same time.

Cities in developing countries will face tremendous challenges of an uncontrollable urbanization, which may generate a huge suffering to the residents [5]. It was suggested that cities play an important role in achieving low-carbon futures [6–8]. In the studies of ten global cities by [9–10] which accounted the consumption of electricity, heating and industrial fuels, transport fuels, and waste. These studies relied on direct energy use data, fuel sale data and down scaling approach. Later, the studies by [11–12] have conducted preliminary studies on energy use, carbon emissions and land use change of cities in Pakistan using integrated approach, including econometric, environmental and remote sensing. The studies compiled information of sectoral energy use on historical trends and current situation. Both studies used the autoregressive integrated moving average (ARIMA) model for their forecasts.

However, international experiences are difficult to be applied due to the access of urban energy data in Thailand where energy statistics are commonly reported at a national level and rarely found at an urban level. Historically, energy provision and utilization has not been a strategic priority for local governments in Thailand. This study aims to provide the insights on how policy interventions might affect the urban energy demand and energy-related CO_2 emissions in the future. The scope of this study is limited to two case studies of urban areas in Thailand (Mueang Nakhon Ratchasima and Pattaya) to assess countermeasures for energy and carbon management. It considers as initial work on how city can move towards low-carbon city and the available measures. It looks into the implications of policy measures at the urban scale for energy-savings and energy-related CO_2 emission reductions. This study is based on an initiative pilot project granted by the National Research Council of Thailand. The selected case studies are represented a general urban characteristic and a tourism urban area in Thailand.

2. METHODOLOGY

In Thailand, the energy accounting at national level attributes the energy use to different economic sectors, including agriculture, commercial, residential, industry, and transport sectors. At a city level, the energy accounting predominantly deals with total energy use of different fuel types and usually does not provide separate statistics for primary, secondary and final energy use. Energy data are not always collected at an urban scale. This situation is consistent with many cities in developing countries. Consequently, urban energy data have to be modeled or inferred from higher-level energy accounts using relevant regional statistics or by scaling from regional or provincial data [4, 10, 13]. Furthermore, details on the effect of energy measures have to be derived through some form of additional analysis. Therefore, the end-use methodology combined with trend analysis is often used and found in the literature. This paper attempts to evaluate policy measures at an urban level to manage the energy use and energy-related CO_2 emissions from urban economic activities. A bottom-up scenario-based energy modeling was applied to assess energy policy measures at the urban scale.

2.1 Low-Carbon Development

At a macro level, the main drivers effecting the growth of CO_2 emissions are population size, structure of an economy, amount of energy use per unit of activity, and carbon emissions of the fuel mix. Researchers often refer to Kaya Identity [14] when discussion about drivers and indicators of low-carbon development. The Japanese scholar Kaya proposed a formula to calculate the carbon emissions of production activities, as shown in Equation (1).

$$CO_2 Emissions = Pop \times \frac{GDP}{Pop} \times \frac{Energy \quad Use}{GDP} \times \frac{CO_2 \quad Emissions}{Energy \quad Use} \qquad (1)$$

According to Equation (1), the low-carbon development should focus on a reduction in energy intensity and a shift in the energy mix to lower carbon content fuels. Drivers of the energy demand can be grouped into three main categories. The first is the size of population (Pop). The second is how and to what extent to meet the energy requirements. The third is the pattern of development, including technological levels.

Population is a fundamental driver of activities. GDP (Gross Domestic Product) per capita tracks changes in how wealthy countries or cities are. Growth in per capita GDP is accompanied by rising demand for energy services. Final energy use per GDP represents the final energy use in an economy per unit of value added produced. It is an indicator of the intensity of the energy use compared to the evolution of GDP. The ratio of CO_2 emissions per unit of primary energy represents the fuel mix in an economy.

The Kaya Identity helps to understand the relationship of energy use and energy-related CO_2 emission drivers [14]. To achieve the goal of this study, the Kaya Identity is redefined to reflect the interest in quantifying urban energy use and CO_2 emissions. The redefined Kaya Identity used in this study is shown in Equation (2).

$$CO_2 Emissions = f(Energy \quad Demand, \quad Activity, \quad EI) \qquad (2)$$

Energy demand is driven by activity levels and energy intensity (EI) of the specific energy-consuming activities. Activity levels are defined differently in end-use sectors, for example production levels in industrial sector, number of households in residential sector, floor areas in commercial sector, and vehicle-kilometers travelled (VKT) in transport sector. Energy intensity (EI) is related to the characteristics of specific technologies and other drivers. Based on the redefined Kaya Identity, the model for urban energy systems was developed to assess the implications of policy measures.

2.2 Modeling Approach

The modeling of urban energy systems in this paper was developed based on the Long-range Energy Alternatives Planning (LEAP) system framework. LEAP is widely used by various research groups and energy agencies throughout the world [15]. LEAP is a generic purpose energy modeling tool that can be used for a wide variety of tasks, for example the preparation of energy balances, energy demand and supply forecasting and policy analysis (e.g., policy interventions, demand-side management and CO_2 mitigation strategies). LEAP is a scenario-based energy and environmental modeling. The model structure is based on a comprehensive accounting of how energy is converted and utilized in a given region under a range of assumptions.

Demand module in LEAP model uses the end-use driven approach. In this paper, the model structure is built on the previous work done by [16]. The tree structure is disaggregated into a hierarchical format based on four levels: sector, sub-sector, end-use, and device levels. The energy analysis tree is prepared in LEAP, where energy demand is the parent branch and energy-related CO_2 emissions estimated through an emission factor approach. Details of energy demand tree structure can be found in [16].

Due to different characteristics of the case studies, the urban energy model was developed separately for Muang Nakhon Ratchsima and Pattaya. Energy intensity values along with type of fuels in each device are required to estimate the energy requirements at sector, sub-sector and end-use levels. The model calculates energy demand of each sector and thereby the total energy demand. The emission factors in the Technology and Environmental Database (TED) module in LEAP are linked to the device level to appraise the environmental emissions from energy utilization during the planning horizon. The model is used to simulate how energy demand might develop in a general urban area and tourism urban area. The study period starts in 2009 and ends 2020, with 2008 used as the base year. This is due to data available from the case studies and the interest in medium-term energy planning. Demand sectors are classified into commercial, residential, industrial, and transport sectors.

The commercial sector is consisted of six building types: office, hospital, hotel, department store, educational institution, and miscellaneous. The end-use services in each building type include HVAC (Heating, Ventilation and Air-conditioning) systems, lighting and others. To disaggregated energy use in commercial sector, energy intensity is determined in terms of energy use per unit floor area. This can be expressed in Equation (3). The energy demand is calculated from the number of floor spaces, share of end-use services within building type, efficiency of devices, and energy intensity, which is based on floor space basis for each end-use.

$$E_{CB} = A_{CB} \times \sum_{k} EI_{CB,k} \tag{3}$$

E_{CB} is the final energy demand in commercial buildings, k is energy types, A_{CB} represents total commercial floor areas in m^2, and $EI_{CB,k}$ is the average floor area's energy intensity of energy type k in kWh/m^2.

In the residential sector, energy services are driven by the size and number of households, income levels, living standard, and other factors. The end-use services are organized into six categories: cooking, lighting, space conditioning, refrigeration, water heating, and others. The number of households is served as a main driver. The disaggregation identifies energy use per type of energy services, as in Equation (4).

$$E_{RES} = \sum_{k} \sum_{m} \frac{P_m}{F_m} \times \left[\left(\sum_{j} p_{m,j} \times UEC_{m,j} \right) + SC_m + C_m + W_m + L_m + R_m \right] \tag{4}$$

E_{RES} is the final energy demand, k is energy type, m is a locale, P_m is population in locale m, F_m is number of persons per household in locale m, $p_{m,j}$ is penetration rate of appliance or device j in percentage of household owning appliance in locale m, $UEC_{m,j}$ is average energy intensity of appliance j, SC_m is space conditioning (air-conditioner and fan) energy intensity, C_m is average cooking energy use, W_m is average water heating energy use, L_m is average lighting energy use, and R_m is average refrigeration energy use. The energy intensity is formulated as a function of the number of appliances, capacity of appliances and average usage hours. It is expressed in toe/household-year or kWh/household-year.

The main driver in industrial sector is the production of commodities. The disaggregation introduces physical energy intensities in terms of energy use per gross provincial product (GPP). The industrial energy use is divided into nine manufacturing sub-sectors: food and beverage, textile, wood and furniture, paper, chemical, non-metallic, basic metal, fabricated metal, and others. Physical production valves for each industry are multiplied by industrial average physical intensity. This can be expressed in Equation (5). The end-use services in each industrial sub-sector are divided into heat and electricity usages. The model calculates the energy demand as a function of the GPP, proportion of energy utilization, device efficiency, and useful energy intensity in each sub-sector. Then, it sums to derive total industrial energy demand.

$$E_{IND} = \sum_{k} \left(\sum_{c} Q_c \times EI_{c,k} \right) \tag{5}$$

E_{IND} is industrial energy demand, k is energy type, c is commodity type, Q_c is quantify of commodity c, and $EI_{c,k}$ is average intensity of energy type k for producing industrial commodity c in toe/million Thai Baht.

Only road transport is considered due to its high influence on total energy demand in the transport sector. Transport energy demand is comprised of a variety of transport modes and technologies. Passenger travel is disaggregated into several modes, such as car, microbus, pickup, van, and motorcycle. Transport energy demand can be expressed in Equation (6). Thus, the energy demand is calculated as a function of number of vehicles, average travel distances, proportion of vehicle types, and fuel economy of the vehicle.

$$E_{TRAN} = \sum_{k} \sum_{r} Q_r \times EI_{k,r} \tag{6}$$

E_{TRAN} is transport energy demand, k is energy type, r is mode of transportation, Q_r is quantity of transport service mode of transport r in VKT, and $EI_{k,r}$ is average energy intensity of energy type k for mode of transport r in liter per km. The VKT is exogenously estimated in spreadsheet. Predicted number of vehicles is estimated using multiple regression analysis of past number of vehicles, past and future population, and past and future expected economic growth.

2.3 Data Collection

To attribute the information for contribution by local governments, data are stored in database and converted in GIS view. Using Google map and mash-up technique, a simple GIS can be implemented as shown in Fig. 1. Local governments can easily access the information via Internet and GIS.

Data collection is the central issue of energy modeling because the energy model structure and scenario generation are largely depended on the available data. Data were collected in collaboration with city officials (Mueang Nakhon Ratchasima and Pattaya). This study intends to account only direct energy use and energy-related CO_2 emissions. The methodologies for data collecting were combined of random sampling technique, down scaling method, officer interview, and literature review. Officials were able to access and provide some statistic data but mostly at the provincial level. Some necessary data were scaled from provincial statistic to an urban context.

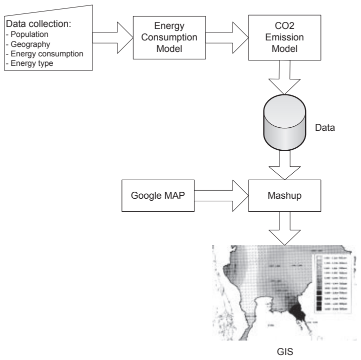


Figure 1 Implementation of GIS for local governments

Socio-economic data were taken from city officials, the Department of Provincial Administration, Ministry of Interior and the Office of the National Economic and Social Development Board. Energy statistics were derived from unpublished city's statistical books and Ministry of energy database. In the case of absent historical data, the end-use approach was used to capture the energy use patterns of various appliances. The energy use of end-use device was done based on the frequency of utilization and power required by the device.

2.4 Scenario Generation

LEAP model allows energy systems analysis in terms of technological specifications and end-use details in various scenarios. The energy scenarios are used as a series of "what if" questions, for example what if more high efficient appliances are introduced in households. The scenarios in LEAP are generated to encompass any factor that is anticipated to change over time [17–18]. Two scenarios were developed in LEAP under different sets of measures in order to analyze the possible effects of policy measures for energy-savings and CO_2 emissions mitigation. These scenarios are the business as usual scenario (BAU) and countermeasure scenario (CM). The policy measures and assumptions in two scenarios are given in Table 1. All scenarios start from a base year (2008), which is named as the current accounts in LEAP model. The alternate scenario is inherited from the BAU scenario. Thus, it reflects sensitivities on the original scenario.

3. FINDINGS

3.1 Projections of Energy Demand

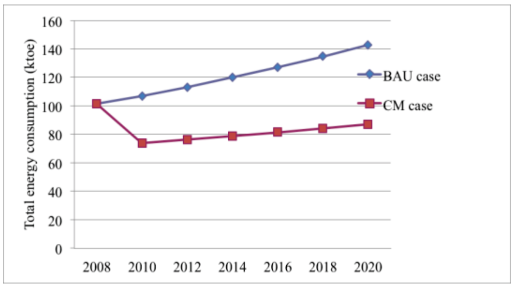
Based on the assumptions and parameters for scenario analysis in LEAP model, total energy use for the BAU and CM scenarios is shown in Fig. 2. Total energy demand in Mueang Nakhon Ratchasima under the BAU case will increase from 102 ktoe in 2008 to 143 ktoe in 2020, with an annual growth rate of 3.86%. Under this scenario, the transport sector will be accounted for the largest share of energy demand (47.3%) and followed by industry (26.6%), residential (16.9%) and commercial (9.2%) sectors. The energy mix will consist of petroleum products (49.5%), electricity (23.1%), biomass (19%), LPG (7.9%), and others (0.5%). Coal will have a relative less share to meet the energy demand in Mueang Nakhon Ratchasima. Under the CM scenario, the energy demand in 2020 is expected to be 87 ktoe, which is lower than the BAU scenario 39.3%.

Table 1 Measures and assumptions for scenarios.

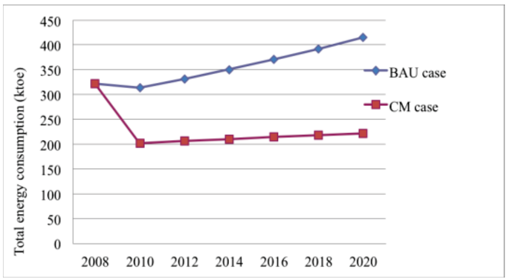
Scenario	Measures	Assumptions
BAU	No specific measure to be implemented	The energy demand and CO_2 emissions are depended on the driving factors in each sector. It is assumed that local and central government will do nothing to influence the trends of urban energy demand.
CM	Residential energy efficiency improvements	Improving final energy intensity by 2020. The energy use per unit of device is reduced by 15% starting in 2009. These devices are rice cooker, electric cooking, LPG stove, air-conditioner, refrigerator, and electric fan.
	Green building	Improving efficiency of HVAC and lighting systems 20% by 2020 in every building type.
	Industrial energy efficiency improvements	Increasing energy efficiency targeted of 10% by 2020. The improvements are from lighting, compressed air, motor, and boiler and steam system.
	Fuel switching in industrial sector	Thermal energy supplied by fuel oil in industries switches to natural gas starting in 2010.
	Improving fuel economy in transport sector	Only road transportation is considered in the model. It is assumed that the improving fuel economy of gasoline vehicles and diesel vehicles 10% by 2020.
	Cleaner technology in transport sector	Introducing compressed natural gas (CNG) to fixed route bus with penetration rate of 50% by 2020. Switching to gasohol in gasoline vehicles starting in 2009. This measure applies to sedan, microbus and passenger van, van and pickup, and motorcycle. Switching to biodiesel in diesel vehicles starting in 2009. This measure applies to sedan, microbus and passenger van, van and pickup, fixed route bus, non-fixed route bus, private bus, and others.
	Modal shift from private passenger to public transport	Increasing the share of public transport by reducing the use of sedan by 30% and van and pickup by 10% starting in 2009.

The energy demand in Pattaya under the BAU scenario will increase from 322 ktoe in 2008 to 415 ktoe in 2020, with an annual growth rate of 2.87%. Under the CM scenario, total energy demand in 2020 will decrease by

53.5% as compared to the BAU case. Disaggregated energy demand by sector under the BAU case is similarly to Mueang Nakhon Ratchasima. The transport sector will be responsible for 53.2% of total energy demand in 2020. The rest will be shared by commercial (24.6%), industry (11.6%) and residential (10.6%) sectors. In terms of energy mix, petroleum products will be responsible for 56.5% and followed by electricity (38%) and LPG and CNG (4.4%). The share of traditional fuels, such as wood and charcoal, will have a relative less share in the energy demand in Pattaya.



Mueang Nakhon Ratchasima



Pattaya

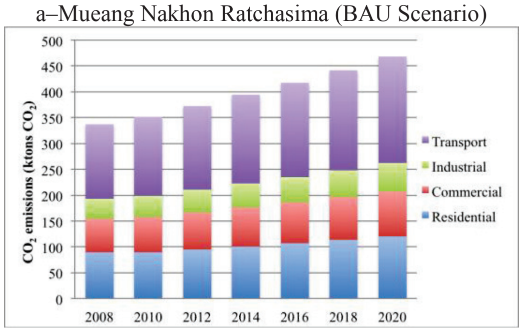
Figure 2 Projections of energy demand under different scenarios

3.2 Projections of Energy-related CO_2 Emissions

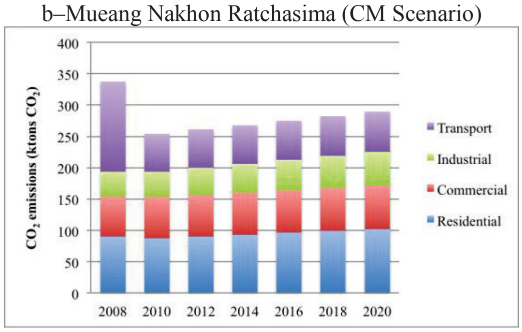
The emissions from embodied energy, waste and land-use change were not taken into consideration. Energy-related CO_2 emissions under BAU and CM scenarios in two cases are presented in Fig. 3. The emissions under both scenarios are in line with the energy demand trends. In Mueang Nakhon Ratchasima, CO_2 emissions in 2008 were 337 ktCO_2, and under the BAU scenario it would increase to 468 ktCO_2 in 2020 with an annual growth rate of 3.7%. Under the CM scenario, the emissions would be 289 ktCO_2 in 2020 with significant lower emissions as compared to BAU case. Under the CM scenario, the emissions would be decreased by 38% in 2020 due to the introduction of several measures. This indicates that policy measures have significant effects on emission reductions. Sectoral emissions in all scenarios are observed that the transport sector is the largest contribution of CO_2 emissions. It is expected to contribute 44% in the BAU case by 2020 and followed by residential (26%), commercial (18%) and industrial (12%) sectors.

Under the BAU scenario, Pattaya would emit CO_2 approximately 1.3 times in 2020 compared with 2008 level. CO_2 emissions would increase from 1,349 ktCO_2 to 1,787 ktCO_2 with an annual growth rate of 3.17%. Emissions from commercial sector are responsible for the largest source (37.8%), and followed by transport (36.9%), residential (12.8%), and industrial (12.5%). This is due to Pattaya is a tourism area where a number of hotels and other commercial facilities are located. Under the CM scenario, the emissions would reach 1,154 ktCO_2 in 2020. This suggests significant emission mitigation effects from the policy measures adopted under the CM scenario.

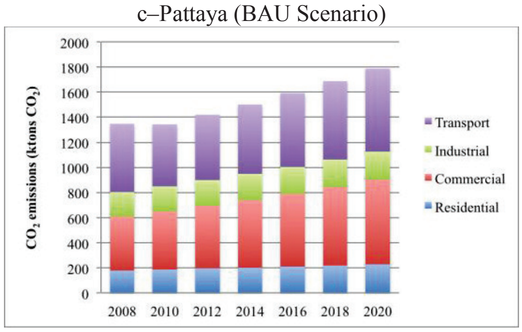
a–Mueang Nakhon Ratchasima (BAU Scenario)



b–Mueang Nakhon Ratchasima (CM Scenario)



c–Pattaya (BAU Scenario)



d–Pattaya (CM Scenario)

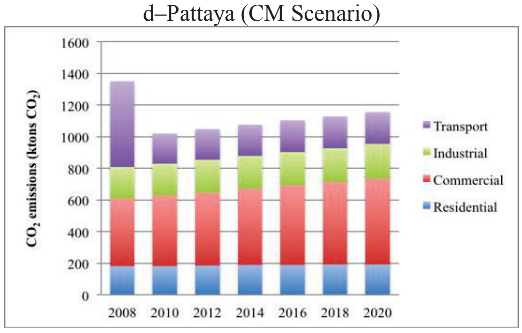


Figure 3 Projections of CO_2 Emissions under different scenarios: (a, c) business-as-usual scenario; and (b, d) countermeasures scenario

The sample of GIS view of CO_2 emissions under different scenarios is shown in Fig. 4. This simple GIS can help local government to manage their policy measures.

a–Mueang Nakhon Ratchasima

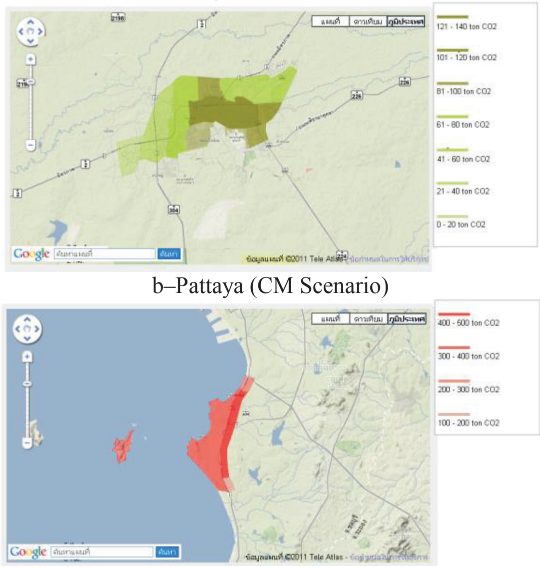


Figure 4 GIS views of CO_2 emissions

3.3 Reduction Potentials of Energy Demand and CO_2 Emissions

An understanding of the attributed energy utilization and energy-related CO_2 emissions will help to identify the suite for energy-savings and mitigation measures. The reduction potentials of total energy demand and the contribution of each measure are presented in Table 2. Findings show that the energy-saving potentials in two cases will gradually increase with the implementation of a series of measures.

Table 2 Reduction potentials of energy demand under the CM scenario compared with the BAU scenario (%).

	2012	2016	2020
Mueang Nakhon Ratchasima			
- Residential energy efficiency improvements	2.53	4.62	6.37
- Green building	1.90	3.40	4.60
- Industrial energy efficiency improvements	0.40	0.73	1.00
- Fuel switching in industry	0.03	0.02	0.04
- Fuel economy improvements in transport	4.69	8.56	11.83
- Cleaner technology in transport	90.46	82.67	76.16
- Total	100	100	100
Pattaya			
- Residential energy efficiency improvements	1.56	2.66	3.47
- Green building	3.77	7.10	10.08
- Industrial energy efficiency improvements	0.17	0.28	0.36
- Fuel economy improvements in transport	4.57	8.29	11.38
- Cleaner technology in transport	89.93	81.68	74.71
- Total	100	100	100

Among all measures, the contribution of the measures for transport sector would have the largest share, accounting for about 88% in Mueang Nakhon Ratchasima in 2020. This follows by the measures for residential (6%), commercial (5%) and industry (1%). For Pattaya, the measures for transport sector would have the largest share about 85% in 2020. This follows by the commercial (11%) and residential (4%) sectors. The measure for industrial sector is less significant. The negative value in modal shift indicates that this measure will not reduce the energy demand but it has the effect on CO_2 emission reductions.

The mitigation potentials of CO_2 emissions and the contribution of each measure are listed in Table 3. Findings reveal that the reduction potentials under the CM scenario compared with BAU scenario will increase year by year. This indicates that emission reductions will be amplified with the implementation of policy measures planning. For different measures, the greatest contribution of CO_2 emission reductions is the cleaner technology in transport sector, which promises a contribution rate of more than 80% for Mueang Nakhon Ratchasima and 70% for Pattaya. The fuel economy improvements in transportation, residential energy efficiency improvements and green building measures also have important contributions, while other measures have less significant in Mueang Nakhon Ratchasima. The green building and fuel economy measures have high contributions in Pattaya. In terms of sectoral analysis, the transport sector has the highest potential of CO_2 emission reductions, as it is affected by cleaner technology and fuel economy improvement measures.

Table 3 Reduction potentials of CO_2 emissions under the CM scenario compared with the BAU scenario (%).

	2012	2016	2020
Mueang Nakhon Ratchasima			
- Residential energy efficiency improvements	4.02	7.13	9.64
- Green building	3.99	6.96	9.21
- Industrial energy efficiency improvements	0.18	0.32	0.44
- Fuel switching in industry	0.69	0.62	0.56
- Fuel economy improvements in transport	4.52	8.03	10.85
- Cleaner technology in transport	86.59	76.94	69.31
- Total	100	100	100
Pattaya			
- Residential energy efficiency improvements	2.58	4.15	5.20
- Green building	7.93	14.25	19.50
- Industrial energy efficiency improvements	0.25	0.39	0.48
- Fuel switching in industry	0.27	0.22	0.18
- Fuel economy improvements in transport	4.31	7.48	9.88
- Cleaner technology in transport	84.67	73.51	64.75
- Total	100	100	100

4. CONCLUSIONS AND POLICY IMPLICATIONS

In this paper, the strategic urban energy use and carbon management based on LEAP framework is first introduced. The LEAP model was developed to estimate the energy demand and energy-related CO_2 emissions in Mueang Nakhon Rachasima and Pattaya for a time frame of 2008–2020. The model was used to assess the reduction potentials of energy demand and CO_2 emissions. Two scenarios were designed to analyze the strategic pathways of energy futures in the case studies. The urban areas presented in this paper are examples of two unique urban circumstances. It was found that total energy demand and CO_2 emissions in both case studies will continue to grow and different policy measures have significant impacts on energy demand and CO_2 emission reductions. Under the BAU scenario, the average annual growth rate of energy demand is 3.86% in Mueang Nakhon Ratchasima, while Pattaya is 2.87%. CO_2 emissions will increase with an annual growth rate of 3.70% in Mueang Nakhon Ratchasima and 3.17% in Pattaya. Under the CM scenario, the energy demand and CO_2 emissions in Mueang Nakhon Ratchasima will decrease approximately by 39% and 38% in 2020, while in Pataya the energy demand and CO_2 emissions will decrease by 46% and 35% in 2020. The analysis is shown that the CM scenario in Mueang Nakhon Ratchasima and Pattaya has the reduction potentials of energy demand approximately 56 ktoe and 193 ktoe in 2020, respectively.

The analysis of the case studies revealed a number of interesting findings regarding urban energy use and CO_2 emissions. It showed that the transport sector would play a key role in increasing energy demand and CO_2 emissions in urban areas. This indicates that local policy measures focused on the transport sector can have significant effects on both energy demand and CO_2 emissions. The commercial and residential sectors have significant contributions to decrease energy demand and CO_2 emissions. However, specific measures should be designed and may be planned in such a way that reduction in energy demand, CO_2 emission mitigation and indoor environmental quality can be obtained. The study recommended that the central government policy should support the move to localism and to provide incentives for low-carbon measures. Local governments could make an important contribution in facilitating energy efficiency improvements and mitigation of CO_2 emissions. Local governments should also free to decide which measures to be implemented based on their urban circumstances. The present study can also be used as a basis strategic energy and carbon management for other urban areas both in Thailand and others.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] J. Beall and S. Fox, *Cities and development*, London: Routledge, 2009.

[2] S. Dhakal and R. M. Shrestha, “Bridging the research gaps for carbon emissions and their management in cities,” *Energy Policy*, vol. 38, pp. 4753-4755, 2010.

[3] A. Phdungsilp, “A policy framework of city carbon budgets: Science and policy mechanism linkages,” in Proc. *the 7th Conference on Energy Network of Thailand (E-NETT2011)*, 3-5 May 2011, Phuket, Thailand, Paper No. DEN02.

[4] T. Baynes, M. Lenzen, J. Steinberger, and X. Bai, “Comparison of household consumption and regional production approaches to assess urban energy use and implications for policy,” *Energy Policy*, vol. 39, pp. 7298-7309, 2011.

[5] M. M. P. Rana, “Urbanization and sustainability: Challenges and strategies for sustainable urban development in Bangladesh,” *Environment, Development and Sustainability*, vol. 13, pp. 237-256, 2011.

[6] H. Bulkeley, V. Castan Broto, M. Hodson, and S. Marvin (Eds.), *Cities and Low Carbon Transitions*, London: Routledge, 2010.

[7] C. S. E. Bale, T. J. Foxon, M. J. Hannon, and W. F. Gale, “Strategic energy planning within local authorities in the UK: A study of the city of Leeds,” *Energy Policy*, vol. 48, pp. 242-251, 2012.

[8] Asian Development Bank (ADB), “Green Urbanization in Asia: Key Indicators for Asia and the Pacific,” Manila, the Philippines, 2012.

[9] C. Kennedy, J. Steinberger, B. Gasson, Y. Hansen, T. Hillman, M. Havránek, D. Pataki, A. Phdungsilp, A. Ramaswami, and G. V. Mendez, “Greenhouse gas emissions from global cities. *Environmental Science and Technology*, vol. 43, pp. 7297-7302, 2009.

[10] C. Kennedy, J. Steinberger, B. Gasson, Y. Hansen, T. Hillman, M. Havránek, D. Pataki, A. Phdungsilp, A. Ramaswami, and G. V. Mendez, “Methodology for inventorying greenhouse gas emissions from global cities,” *Energy Policy*, vol. 38, pp. 4828-4837, 2010.

[11] G. Ali and V. Nitivivattananon, “Exercising multidisciplinary approach to assess interrelationship between energy use, carbon emission and land use change in a metropolitan city of Pakistan,” *Renewable and Sustainable Energy Reviews*, vol. 16, pp. 775-786, 2012.

[12] G. Ali, V. Nitivattananon, H. Mehmood, M. Sabir, S. Sheikh, and S. Abbas, “A synthesis approach to investigate and validate carbon sources and sinks of a mega city of developing country,” *Environmental Development*, vol. 4, pp. 54-72, 2012.

[13] S. Dhakal, “Urban energy use and carbon emissions from cities in China and policy implications,” *Energy Policy*, vol. 37, pp. 4208-4219, 2009.

[14] Y. Kaya, “Impacts of Carbon Dioxide Emissions on GDP Growth: Interpretation of Proposed Scenarios,” Paper presented at IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris, France, 1990.

[15] C. G. Heaps, “Long-range Energy Alternative Planning (LEAP) system,” Stockholm Environment Institute, Somerville, MA, USA. www.energycommunity.org, 2012.

[16] A. Phdungsilp, "Integrated energy and carbon modeling with decision support system: Policy scenarios for Bangkok towards low-carbon city development," *Energy Policy*, vol. 38, pp. 4808-4817, 2010.
[17] K. Kadian, R. P. Dahiya, and H. P. Garg, "Energy-related emissions and mitigation opportunities from the household sector in Delhi," *Energy Policy*, vol. 35, pp. 6195-6211, 2007.
[18] J. Lin, C. Bin, C. Shenghui, W. Wei, and B. Xuemei, "Evaluating the effectiveness of urban energy conservation and GHG mitigation measures: The case of Xiamen city, China," *Energy Policy*, vol. 38, pp. 5123-5132, 2010.