Scenario-Based Assessment of Energy Savings in Thailand: A Long-range Energy Alternative Planning Approach

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Abstract

In 2005, the residential, small commercial building, and small industrial sectors totally consumed about 16,022 ktoe, accounting for 25.68% of total energy consumption in Thailand. In terms of electricity consumption, these three sectors consumed about 54,197 GWh, accounting for 44.68% of total electricity consumption in Thailand. This paper presents the assessment of energy efficiency improvement and renewable energy substitution in the three main economic sectors in Thailand. The energy consumption in the base year was analyzed by using an end-use model, called the "Long-range Energy Alternative Planning system" or LEAP model. The business-as-usual (BAU) scenario was developed on the basis of historical and current trends of energy consumption in the sectors. In this study, the base year in the BAU is 2005 and the planning period is 2006-2020. In this study the efficiency improvement scenarios for long-range energy planning are 1) energy efficient programs such as demand-side management programs, 2) improved biomass cooking stoves, 3) improved LPG cooking stoves, and 4) improved boilers in industries. Results of analyses are presented of the potential of long-term energy savings in both electric and non-electric devices, and corresponding CO_2 emissions. In the efficiency improvement scenarios, the efficient end-use devices could contribute energy savings of 7,798 ktoe, accounting for 8.4% of total energy consumption in these sectors in 2020.

Keywords: residential sector, small buildings and industries, demand-side management, energy efficiency, long-range energy alternative planning, CO_2 emission

1. Introduction

The population of Thailand rose with an average annual growth rate of 1.12% from 1981 to 2005 (DEDE, 2005) while the annual growth of the Gross Domestic Product (GDP) was equal to 6.02% in the same period (DEDE, 2005). The increasing of population and economic expansion results in rapid growth in energy consumption. Consequently, the total final energy consumption in Thailand increased from 47,806 ktoe in 2000 to 62,395 ktoe in 2005, and accounted for an average annual growth rate of 5.47%, while the annual growth rate of gross domestic product (GDP) was equal to 5.02% in the same period. During 1985-2001, the elasticity of energy demand, which is defined as the ratio of percentage of change in energy demand to percentage of change in GDP, was found to be 1.4:1, and decreased to 1.2:1 during 2002-2004. In terms of total electricity consumption in Thailand, it grew from 87,932 GWh in 2000 to 121,229 GWh in 2005, and accounted for an average annual growth rate of 6.6%.

In 2005, the Ministry of Energy set a target to promote renewable energy and energy efficiency in the Renewable Portfolio Standard (RPS) and increase usage of renewable energy from 0.5% to 8% before the year 2011, and reduce energy elasticity to 1:1. To achieve the target, the Thai government has to overcome barriers in promotion of renewable energy and energy efficiency. For renewable energy utilization, there are several barriers, for instance, high investment cost, lack of proper technology, little local expertise, low capability in development of renewable energy technology, and lack of clearness in the government policy. Though the promotion of energy conservation has been supported by the government, the energy saving is still lower than the expected target due to lack of adequate information in technology and investment. Consequently, an assessment of energy saving potential is required in order to properly promote renewable energy utilization and increase energy efficiency in the main economic sectors. In this paper, energy efficient end-use devices and renewable energy options are employed in the residential sector, small buildings and small industries. Results are presented of long-term energy savings compared to the business-as-usual scenario.

2. Methodology

2.1 Residential Sector

The energy consumption in the residential sector is defined in Eq (1).

$$E_R = \sum N_{i,j} \cdot P_{i,j} \cdot M_{i,j} \cdot I_{i,j} \quad ...(1)$$

Where:

E_R = residential energy consumption, toe

$N_{i,j}$ = number of households owning end-use device i in income class j,

$P_{i,j}$ = penetration levels of devices for end-use device i in income class j,

$M_{i,j}$ = usage hours for end-use device i in income class j, hours

$I_{i,j}$ = intensity of end-use device i in income class j, toe/device

i = end-use device, $i = 1,2,3,...,n$

j = income class, $j = 1,2,3,...,m$

n = number of end-use devices = 6

m = number of income classes

A disaggregated model for the residential sector is presented in Figure 1, and it is presumably classified into four income classes: household incomes of 0-10,000, 10,001-30,000, 30,001-70,000 and above 70,000 Baht/month. The residential model includes six main end-use devices: lighting, electric heating devices, electric motors, electric cooling devices, electric loads, and cooking stoves (DEDE, 2003). The forecast of energy demand in the residential sector is based on the projection of end-use types; for example biomass, electricity, wood, etc.

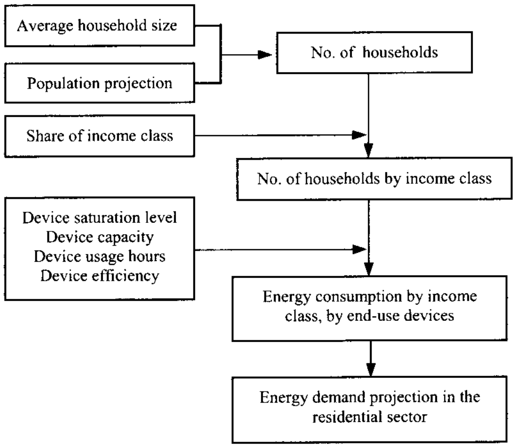

Figure 1. Flow diagram in the residential model.

2.2 Small Commercial Buildings

The energy consumption in the small commercial buildings is defined in Eq (2).

$$E_C = \sum N_{i,j} \cdot P_{i,j} \cdot M_{i,j} \cdot I_{i,j} \quad ...(2)$$

Where:

E_C = energy consumption in small buildings, toe

$N_{i,j}$ = number of buildings owning end-use device i in building type j,

$P_{i,j}$ = penetration levels of end-use device i in building type j,

$M_{i,j}$ = usage hours for end-use device i in building type j, hours

$I_{i,j}$ = intensity of end-use device i in building type j, toe/device

i = end-use devices, $i = 1,2,3,...,n$

j = building type, $j = 1,2,3,...,m$

n = number of end-use devices = 4

m = number of building types, $m = 6$

For the commercial sector, the energy demand model is also the disaggregated model. In this study, the small buildings are classified into six types: office, hotel, hospital, retail stores, education, and others. Electricity is the only form of energy that was considered in this sector, since it shares the largest energy consumption in the small buildings. Therefore, in this study the improvements of electricity end-use devices in four categories are analyzed: which are air-conditioning systems, lighting systems, computers, and other devices. The end-use approach of the model is shown in Figure 2.

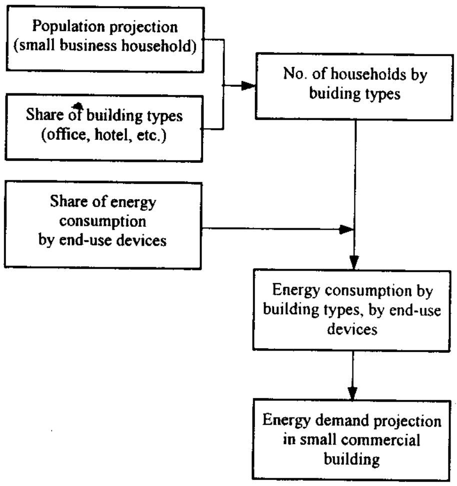

Figure 2. Flow diagram in the small building model.

2.3 Small Industries

The energy consumption in small industries can be defined in Eq (3):

$$E_I = \sum N_{i,j} \cdot P_{i,j} \cdot M_{i,j} \cdot I_{i,j} \quad ...(3)$$

where:

E_I = energy consumption in small industry, toe

$N_{i,j}$ = total number of end-use device i in the sub-sector j

$P_{i,j}$ = penetration levels of end-use device i in the sub-sector j

$M_{i,j}$ = tons of product in end-use device i in the sub-sector j requiring energy

$I_{i,j}$ = energy intensity of end-use device i in the sub sector j, toe/device

i = end-use devices, $i = 1,2,3,...,n$

j = industrial sub-sector, $j = 1,2,3,...,m$ and $m = 9$

n = number of end-use devices = 5

m = number of industrial sub-sectors

The energy demand model for small industries is also a disaggregated model. In this study, nine sub-sectors are classified according to the Thai Industrial Standard Code (TISC); namely food and beverage, textile, wood and furniture, paper, chemical, non-metal, basic metal, fabricated metal, and others (DEDE, 2005).

Five electric end-use devices; namely, lighting systems, electric heating devices, electric motors, electric cooling devices and others, are included in the model. There is only one analysis for a non-electric device, which is the boiler and furnace. The flow diagram in the model of small industries is shown in Figure 3.

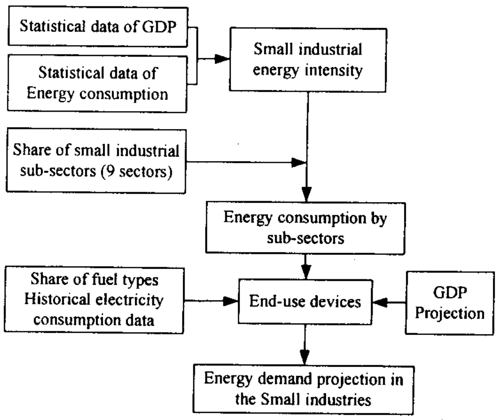

Figure 3. Flow diagram in the model for small industries.

3. Long-range Energy Alternatives Planning System (LEAP) Model

The LEAP model was developed by the Stockholm Environment Institute (SEI), Boston centre and used to evaluate energy development policies (SEI, 2006). The concept of LEAP is an end-use driven scenario analysis. Additionally, the model includes a technology and environmental database (TED) to estimate environmental emissions of the energy utilization. The LEAP model framework is disaggregated in a hierarchical structure of four levels: sector, sub-sector, end-use, and device. The model contains two main modules: energy demand module and TED module. In the energy demand module, the energy intensity values along with the type of fuel used in each device are required to estimate the energy requirements at sector, sub-sector, and end-use levels. The emission factors of different pollutants in the TED module are linked to the device level to appraise the environmental emission from the energy utilization during the planning horizon. The model requires data for at least the base year and any of the future years by extrapolation or growth rate methods. In this study, the energy situation was created in the base year and the scenarios were developed.

4. Scenarios in the Study

4.1 Business as Usual (BAU) Scenario

The baseline scenario or business-as-usual (BAU) scenario is the scenario with non development action in the national energy system. The BAU scenario starts from 2005 as the base year.

The energy consumption data for various end-use devices and the population in Thailand have been taken from the report of energy consumption trend in the residential sector (DEDE, 2003). In the BAU scenario, the assumptions of the annual growth rate of GDP is 5.50% (NESDB, 2005) and the average annual population growth rate is 0.39% (based on the average growth rates of population forecasted by NESDB during period 1997-2005).

The energy demand projection in the BAU scenario for this study is based on the historical trend, from the annual report of Thailand Energy Situation (DEDE, 2005). In this study, the penetration levels of all end-use devices are assumed to be 100% within 10 years using a linear interpolation.

4.2 Energy Efficiency Improvement Scenarios

The energy efficiency improvement (EE) scenarios include energy savings of end-use devices in the specified sector. In the EE scenario, each existing end-use device is replaced by available efficient devices (EGAT, 2006). Thus, the reduction in final energy consumption and corresponding environmental emission could be determined.

There are totally 16 EE scenarios: 6 scenarios in the residential sector, 4 scenarios in small commercial buildings, and 6 scenario sin small industries. In this study, the penetration rates of efficient end-use devices are assumed according to the energy plans in the three periods: 2006-2011, 2012-2016, and 2017-2020.

4.2.1 Residential Sector. In the residential sector, six end-use devices include lighting, heating devices, motors, other electric loads, cooling and cooking devices are considered as EE scenarios. For each scenario, the replacement rate or penetration rate of the efficient device is assumed to be linear. The lighting scenario has three periods of penetration rates while other scenarios have only two. In the first period (2006-2011) of all efficiency improvement scenarios, only efficient device#1, which has a higher efficiency than the conventional one, will replace the conventional device at the given penetration rate. In the other periods (2012-2020), efficient device#2 will substitute the conventional one and increase the shares until all household devices own efficient devices. (see Tables 1 and 2)

Table 1. Energy efficiency improvement in the lighting scenario in the residential sector.

Lighting scenario	Penetration rate (%)		
	Period 1 2006-2011	Period 2 2012-2016	Period 3 2017-2020
FL 16W	+10	+25	+50
FL 18W	-10	-25	-50
FL 32W	+10	+25	+50
FL 36W	-10	-25	-50
INC 60W	-5	-12.5	-25
CFL 12W	+5	+12.5	+25
INC 100W	-5	-12.5	-25
CFL 20W	+5	+12.5	+25

Note: FL stands for conventional fluorescent lamp.
INC stands for incandescent lamp.
CFL stands for compact fluorescent lamp.

For the cooking stoves scenario, only charcoal, LPG, and wood stove are considered since they have the largest share of non-electricity consumption in the households.

4.2.2 Small Commercial Buildings. The main energy used in small commercial buildings is electricity. Hence, in this study energy savings are related to the efficiency improvement of electric end-use devices. The four electric end-use devices considered in this sector are lighting systems, computers, air-conditioners and others. Similar to the residential sector, the replacement of efficient devices or the penetration rates in each sector is assumed to be linear. Each device has efficiency improvement in two periods:

2006-2011 for the first period and 2012-2016 for the second period. (see Table 3)

Table 2. EE scenarios in the residential sector.

EE scenario	% EI	Period 1 2006-2011	Period 2 2012-2020
Heating devices			
- Conventional	0	40	0
- Efficient device#1	10	60	60
- Efficient device#2	15	0	40
Electric motors			
- Conventional	0	40	0
- Efficient device#1	3	60	60
- Efficient device#2	5	0	40
Electric loads			
- Conventional	0	40	0
- Efficient device#1	15	60	60
- Efficient device#2	20	0	40
Cooling devices			
- Conventional	0	40	0
- Efficient device#1	10	60	60
- Efficient device#2	15	0	40
Cooking stoves			
- Conventional	0	40	0
- Efficient device#1	5	60	60
- Efficient device#2	10	0	40

Note: EI stands for efficiency improvement.

Table 3. EE scenarios in small buildings.

EE scenario	% EI	Period 1 2006-2011	Period 2 2012-2020
Lighting			
- Conventional	0	40	0
- Efficient device#1	10	60	60
- Efficient device#2	15	0	40
Computers			
- Conventional	0	40	0
- Efficient device#1	5	60	60
- Efficient device#2	10	0	40
Air conditioners			
- Conventional	0	40	0
- Efficient device#1	10	60	60
- Efficient device#2	15	0	40
Other devices			
- Conventional	0	40	0
- Efficient device#1	5	60	60
- Efficient device#2	10	0	40

Note: EI stands for efficiency improvement.

4.2.3 Small Industries. The penetration rates of efficient devices in all scenarios in the small industrial sector are assumed to be linear during the planning period. It requires high investment to modify any equipment or systems in industries; therefore in each scenario, each device has only one efficiency improvement as shown in Table 4. The saturations of efficiency improvement are 5% for motors, 10% for lighting, 10% for heating devices, 15% for cooling devices, 10% for boilers, and 5% for other devices.

Table 4. EE scenarios in small industries.

EE scenario	% EI	Period 1 2006-2011	Period 2 2012-2020
Motors			
- Conventional	0	40	0
- Efficient device#1	5	60	100
Lighting systems			
- Conventional	0	40	0
- Efficient device#1	10	60	100
Heating devices			
- Conventional	0	40	0
- Efficient device#1	10	60	100
Cooling devices			
- Conventional	0	40	0
- Efficient device#1	15	60	100
Other devices			
- Conventional	0	40	0
- Efficient device#1	5	60	100
Boiler			
- Conventional	0	40	0
- Efficient device#1	10	60	100

Note: EI stands for efficiency improvement.

The summary of all scenarios in this study is shown in Table 5.

Table 5. Summary of all scenarios.

Case studies	Description
BAU	Business-as-usual assumption
EEF (RES)	BAU plus energy efficiency improvement in the residential sector
EEF (SCOM)	BAU plus energy efficiency improvement in small commercial buildings
EEF (SIND)	BAU plus energy efficiency improvement in small industries

Note: EEF stands for energy efficiency improvement.
RES stands for residential sector.
SCOM stands for small commercial buildings.
SIND stands for small industries.

5. Results and Discussion

Results of the scenario-based analyses from the LEAP model are presented into two parts; energy efficiency perspective, and environmental emission perspective.

5.1 Energy Efficiency Perspective

5.1.1 BAU Scenario. The projected final energy demand for residential, small buildings and small industries are 22,948, 30,955, and 39,325 ktoe in 2011, 2016, and 2020, respectively. In the residential sector, energy demand is projected to increase from 9,446 ktoe in 2006 to 20,627 ktoe in 2020 with an average annual growth rate of 5.7%. The shares of electricity demand in the residential sector are 24.47% in 2006 and 24.93% in 2020. The projections of energy demand in small commercial buildings are 3,026, 3,990, and 4,979 ktoe in 2011, 2016, and 2020, respectively, with an average annual growth rate of 5.69%. Electricity is the main form of energy used in small commercial buildings. The share of non-electricity in small industries is about 86.7% of total energy demand in small industries during the study period. The energy demand is projected to increase from 5,270 ktoe in 2006 to 13,719 ktoe in 2020. The average annual growth rate of energy demand is 7.08%.

5.1.2 EE Scenarios. The baseline scenario is compared with sixteen EE scenarios from the three sectors. Results of EE analyses are as follows.

Residential Sector. The most effective scenario for saving electricity is the efficiency improvement in air-conditioners and refrigerators, called efficient cooling devices. This results in electricity savings of 1,569, 6,067, and 7,624 GWh in 2011, 2016, and 2020, respectively, and accounts for approximately 76% of total electricity savings in this sector.

When all EE scenarios of electric devices are considered, the saving is 10,380 GWh in 2020, accounting for 17.35% of total electricity demand in the residential sector (see Table 6).

Table 6. Energy savings in the residential sector.

Scenario	Energy saving (ktoe)		
	2011	2016	2020
Efficient lighting	8	28	67
Heating devices	10	41	53
Electric motors	3	12	16
Electric loads	20	81	103
Cooling devices	135	521	656
Cooking stoves	234	616	769
Total savings	410	1,299	1,664

The largest amount of electricity saving comes from high income households. The savings are 1,105, 4,372, and 5,733 GWh, and accounted for 3.08%, 9.19%, and 9.59% of total electricity demand in the residential sector in 2011, 2016, and 2020, respectively.

Low-income households are the main group that consumes the most energy for cooking. Therefore, the large saving from using the efficient cooking stoves, comes from the low-income class. Therefore, the most effective scenario resulting in the largest energy saving is the cooking stove scenario. The savings are 235, 617, and 768 ktoe, and accounts for 57.4%, 47.5%, and 46.2% of total energy saving in households in 2011, 2016, and 2020, respectively. It was found that saving from the low-income class shares over 61.0% of total energy saving in this sector.

Small Commercial Buildings. In small commercial buildings, the most effective scenario in energy saving is the efficiency improvement in air conditioning systems, which results in electricity savings of 1,326, 1,930, and 2,419 GWh in 2011, 2016, and 2020, respectively, accounting for 51.74% of total electricity saving in small buildings in 2020 (see Table 7).

The efficient lighting scenario is the second effective scenario, resulting in electricity savings of 314, 988, and 1,233 GWh in 2011, 2016, and 2020, respectively. When all EE scenarios are considered, approximately 4,675 GWh, accounting for 9.61% of total electricity consumption in small buildings, could be saved in 2020.

Table 7. Electricity savings in small buildings.

Scenario	Electricity saving (GWh)		
	2011	2016	2020
Efficient lighting	314	988	1,233
Computers	23	58	81
Air conditioners	1,326	1,930	2,419
Other devices	221	756	942
Total savings	1,884	3,733	4,675

Small Industries. The electricity savings in small industries mainly come from efficiency improvement of cooling devices, electric heating devices and lighting systems. The most effective EE scenario that results in the largest amount of reduction in electricity demand in this sector is the efficient cooling scenario. The savings are 233, 651 and 872 GWh, and account for 1.97%, 3.83%, and 3.84% of total electricity demand in small industries in 2011, 2016, and 2020, respectively (see Table 8).

Table 8. Energy savings in small industries.

Scenario	Energy saving (ktoe)		
	2011	2016	2020
Boilers	331	953	1,272
Motors	4	11	15
Lighting systems	8	22	30
Heating devices	12	36	48
Cooling devices	20	56	75
Other devices	5	14	19
Total savings	380	1,092	1,459

Heating from non-electricity is the main consumer of energy in this sector, therefore, the substitution of efficient boilers is the most effective scenario. This could reduce energy demand by 331, 953, and 1,272 ktoe, and account for 4.33%, 8.67%, and 8.67% of total energy demand in the small industries in 2011, 2016, and 2020, respectively.

When all EE scenarios are applied, they could save more than 1,459 ktoe, and account for 9.95% of total energy demand in small industries in 2020.

5.2 Environmental Emission Perspective

The environmental emissions considered in this study are carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and methane (CH_4). In the BAU scenario, there was no reduction in the environmental emissions. In this study, emission factors for CO_2, CO, NO_x, SO_2, and CH_4 are obtained from Thailand Energy Situation report (DEDE, 2005).

5.2.1 BAU Scenario. The amount of environmental emissions is related to energy utilization. CO_2 is the main pollutant considered in this study since it results in global warming. The CO_2 emissions in the residential sector are estimated to be 18.81 million tonnes in 2005 and increased to 44.07 million tonnes in 2020 (see Table 9). CO_2 emissions in the residential sector mainly come from electricity consumption.

Table 9. CO_2 emissions in the BAU scenario.

Sector	CO_2 emission (million tonnes)			
	2005	2011	2016	2020
Residential	18.81	26.44	35.12	44.07
Small buildings	13.44	18.73	24.70	30.82
Small industries	9.63	14.77	21.04	27.86

In small buildings, CO_2 emissions are estimated to increase from 13.44 million tonnes in 2005 to 30.82 million tonnes in 2020. CO_2 emission in small industries is projected to be 14.77, 21.04, 27.86 million tonnes in 2011, 2016, and 2020, respectively. The emissions by pollutant type are shown in Table 10.

Table 10. Emissions by pollutant type in the BAU scenario.

Sector	Emissions (thousand tonnes)			
	2005	2011	2016	2020
RES	195	258	342	429
NO_x	76	101	133	167
SO_2	47	63	84	105
CO	9	13	17	21
CH_4	62	82	108	134
SCOM	86	114	150	188
NO_x	38	51	67	83
SO_2	39	52	68	85
CO	8	10	14	17
CH_4	1	1	1	2
SIND	85	120	169	222
NO_x	40	56	79	104
SO_2	24	34	48	63
CO	3	4	6	7
CH_4	17	25	35	45

Note: *RES stands for residential sector*
SCOM stands for small buildings
SIND stands for small industries.

5.2.2 EE Scenarios. CO_2 mitigation in the residential sector is estimated to be 1.33, 5.0, 6.53 million tonnes, and accounted for 5.04%, 14.24% and 14.82% of CO_2 emissions in the residential sector in 2011, 2016, and 2020, respectively. CO_2 emissions in small buildings could be mitigated by 1.10, 2.18, 2.73 million tonnes, and account for 5.87%, 8.82%, and 8.85% of CO_2 emissions in small buildings in 2011, 2016, and 2020, respectively. The reduction in CO_2 emissions in small industries equals 4.89%, 9.73%, and 9.74% of CO_2 emission in small industries in 2011, 2016, and 2020, respectively (see Table 11).

Table 11. Total CO_2 mitigation.

Sector	CO_2 mitigation (million tonnes)		
	2011	2016	2020
Residential sector	1.33	5.00	6.53
Small buildings	1.10	2.18	2.73
Small industries	0.72	2.05	2.71

The reduction in nitrogen oxide (NO_x) and sulfur dioxide (SO_2) emissions were found to be high in the residential sector, approximately 22 thousand tonnes of NO_x and 18 thousand tonnes of SO_2 could be reduced in 2020. Total air emissions reduction in small commercial buildings is estimated to be 18 thousand tonnes in 2020. In 2020, the NO_x mitigation from small industries is estimated to be 8 thousand tonnes, and account for 10.1% of NO_x emission in this sector (see Table 12).

Table 12. Emission mitigation in EE scenarios.

Sector	Emission mitigation (thousand tonnes)		
	2011	2016	2020
Residential sector			
NO_x	4	17	22
SO_2	4	14	18
CO	1	3	4
CH_4	2	8	10
Small buildings			
NO_x	3	6	8
SO_2	3	7	8
CO	1	1	2
CH_4	0	0	0
Small industries			
NO_x	3	8	10
SO_2	2	5	6
CO	0	1	1
CH_4	1	3	5

6. Conclusion

In the residential sector, since non-electricity is the main form energy consumed in this sector, the energy efficiency improvement for cooking stoves in the low- income level is the most effective scenario, resulting in the largest amount of energy saving (769 ktoe), and account for 46.21% of total energy saving in the residential sector in 2020. The efficiency improvement of electric cooling devices in households could also save electricity (about 10,380 GWh) in 2020. In small commercial buildings, the efficient cooling scenario is the most effective scenario, resulting in electricity saving of 208 GWh, and account for 8.07% of energy demand in small commercial buildings in 2020. In small industries, the main energy consuming device is boilers. Thus, saving in the efficient boiler scenario is about 1,272 ktoe, and account for 8.67% of energy demand in small industries in 2020. For electricity, the efficient cooling scenario could save 2,175 GWh in 2020. In 2020, the total savings from the three sectors is 3,525 ktoe, and account for 8.75% of total energy consumption in the three sectors.

In the environmental perspective, CO_2 mitigation in the residential sector is found to be 1.33, 5.0, 6.53 million tonnes, and account for 5.04%, 14.24% and 14.82% of total CO_2 emission in the residential sector in 2011, 2016, and 2020, respectively. In small commercial buildings, CO_2 mitigation is about 1.10 million tonnes in 2011 and about 2.73 million tonnes in 2020. The EE scenarios in small industries could also help in the reduction of CO_2 emissions by 0.72, 2.05, 2.71 million tonnes in 2011, 2016, and 2020, respectively. Total CO_2 mitigation in the three sectors is estimated to be 3.15, 9.23, and 11.97 million tonnes, and account for 5.26%, 11.41%, and 11.65% of total CO_2 emissions in 2011, 2016, and 2020, respectively. In addition to CO_2 mitigation in EE scenarios, other air emissions are also mitigated in all sectors.

7. Acknowledgement

The authors would like to thank the Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi for providing the funds for this study. The authors also would like to thank the Stockholm Environmental Institute (SEI-US), Boston Center for supporting the LEAP model and Thailand Research Fund for the support of technical information.

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