IMPACTS OF EFFICIENT ELECTRIC END USES ON POWER GENERATION PLANNING AND EMISSIONS: A Case Study of Residential Sector in Thailand

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ABSTRACT

The assessment of energy savings of the efficient electric end uses in the residential sector and their impacts on electricity generation planning is presented, and the corresponding emissions of power plants in Thailand are investigated. The energy analysis in the residential sector shows the annual electricity consumption for space cooling, cooking, lighting and refrigeration. The income classes, dwelling types and appliance saturation are also taken into account in determining the annual energy consumption in the planning horizon. Scenarios of the efficient electric end uses of the demand-side-management (DSM) programs in Thailand are applied to the residential sector to investigate the potential of energy savings. Finally, a least-cost electricity expansion model is used to generate new generation plans. The generation mix with DSM implication reveals less additional capacity and airborne emissions of fossil fired power plants.

Keywords : end-use model, demand-side management, energy demand analysis and forecasting, least-cost electricity generation planning, emissions.

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INTRODUCTION

The development of the electric load in Thailand has traditionally been dominated by residential load growth due to continuing rural electrification. The daily load shape patterns with the evening peaks remained unchanged for two decades. Since 1996, the afternoon peaks have been recorded frequently. In 1996, electricity consumption in the residential sector was 16,000 GWh, accounted for 21% of the total electricity consumption for the whole country, and energy demand of the residential sector was 11,137 ktoe*, accounted for 21.07% of the total energy demand [1]. Due to the economic crisis in Thailand in 1997, an annual average GDP of 2% is assumed for the next five years. In addition, the annual electricity-consumption growth levels around 5% are forecasted for the next decade. In this paper, the programs on efficient electric end uses are applied to the residential sector, and the electricity demand analysis takes account of nine appliances, five dwelling types, and income levels. The demand-side-management (DSM) plan set up in 1993 by the electric utilities includes programs to promote efficient electric appliances, but the power development plan (PDP) of the generating utility does not account for the DSM plan [7]. Results of the end-use analysis of energy consumption in the residential sector are used to form system load shapes. A computer program is used to find out the optimal expansion plans for both the reference scenario and the efficiency-oriented scenario. Results show many benefits of efficient electric appliances and their impacts on system peak load reduction, system capacity expansion and emissions.

METHODOLOGY

Electricity Demand Projection

The electricity demand projection in this study is classified into two scenarios: the reference scenario (RFS) and the efficiency-oriented scenario (EOS). The energy demand projection in the reference scenario considers no implication of efficiency improvement of electric appliances while the efficiency-oriented scenario introduces more advanced and efficient end-use equipment in order to reduce electricity consumption.

The objective of the study is to assess the impacts of the efficient electric end-use appliances on electricity generation expansion planning and emissions.

The electricity consumption in the residential sector is assumed to be a function of household numbers, number of end-use devices, capacity of devices and usage of devices, called the end-use models. The end-use models with forecasted economics parameters determine the future energy demand in the residential sector. To capture the socio-economic characteristics and patterns of electricity demand, the household residing in the residential sector is classified into two

* ktoe-kilo ton of oil equivalent

regions: Bangkok metropolitan region and outside Bangkok metropolitan region. The Bangkok metropolitan region includes Bangkok, Nonthaburi and Samut Prakarn. The Metropolitan Electricity Authority (MEA) is responsible for electricity distribution in the Bangkok metropolitan region while the Provincial Electricity Authority (PEA) is responsible for the outside Bangkok metropolitan region.

The model for residential electricity demand forecasting is disaggregate model, divided into six income classes, five dwelling types and nine end-use devices. The nine end-use devices include fluorescent tube, rice cooker, air-conditioner, electric fan, refrigerator, freezer, washing machine, iron and television. The structure of the residential electricity consumption model is shown in Fig. 1.

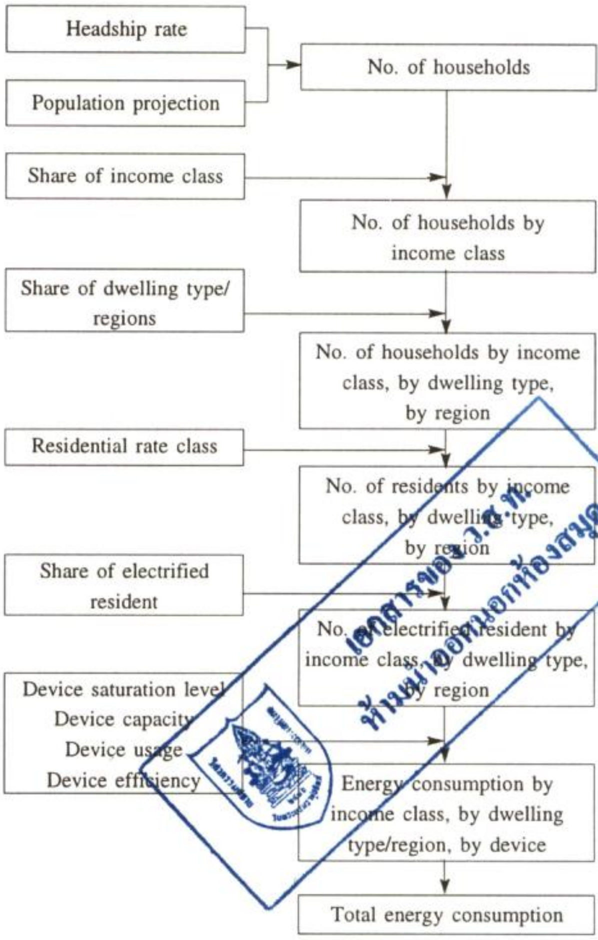

Fig. 1 Structure of residential energy consumption model

Household Projection

The population projection data from the World Bank [3] is adopted to determine the number of households by using the headship rate method [4]. The specific headship rate is estimated by using the following equation:

$$h(i,\ j,\ t) = \frac{H(i,\ j,\ t)}{P(i,\ j,\ t)} \qquad (1)$$

where

$h(i, j, t)$ = specific headship rate of sex i and age j in year t (no. of heads/no. of population)

$H(i, j, t)$ = number of household heads of sex i and age j in year t

$P(i, j, t)$ = population of sex i and age j in year t

The total number of households of the year following the base year is estimated by using the following equation:

$$\sum_i \sum_j H(i,j,t+x) = \sum_i \sum_j P(i,j,t+x) \times h(i,j,t+x) \qquad (2)$$

where x = the year following the base year

The specific headship rates always change over time depending on socio-economic factors such as rural-to-urban migration and increase in per capita income. The sex-age specific headship rates for this study are obtained from the population and housing censuses in 1980 and 1990 [5,6].

Household Classification

The household income level is a major determinant of electricity demand. Households in both MEA and PEA's areas are classified according to six income classes, shown in Table 1. The income categories should be interpreted in relative rather than in absolute terms, for instance, households earning less than 500 Baht per month in the PEA's area should be considered as households belonging to the lowest income level.

Table 1 Income classes in MEA and PEA's areas

Unit : Baht per month

Income class	
MEA's area	**PEA's area**
<5000	<500
5,001-7,000	501-1,500
7,001-15,000	1,501-3,000
15,001-25,000	3,001-7,000
25,001-50,000	7,001-15,000
>50,000	>15,000

Dwelling Type

Another major determinant of household electricity demand is the dwelling type. Households in the MEA's area are classified into five dwelling types; namely, detached house, row house, townhouse, apartment/condominium and flat. In the PEA's area, households are divided into four regions; namely north, northeast, central and south regions. The expansion of the middle class income size as well as increase in land price around the big city result in less residential space but more households living in townhouse, apartments and condominiums.

Residential Rate Class

Several households operate small home-based businesses such as food shops, shops, etc. are billed under different rates of electric tariffs applied to commercial customers. In order to determine the number of households billed under the residential rate of electric tariffs, the residential rate class is applied. It is assumed that the number of households of the residential rate class will increase in the future. Thus, after the year 2020, all of the households residing in the MEA's area will be billed under the residential rate class while some of the households in the PEA's area still operate the small home-based businesses.

Electrified Household

The number of electrified households is one factor affecting electricity demand. In 1996 the electrified household was accounted for 76.2 percent of the total household in Thailand. In this study, it is assumed that all of the households will be electrified after the year 2000.

Household Appliances

Appliance ownership is another factor affecting energy demand. It is expected that the ownership rates of appliances tend to be higher in higher income classes. The number of appliances per household also relates to the size of the dwelling units. Appliance ownership, however, reaches saturation levels as household moving up the income ladder. The differences in the number of appliances between the high- and middle-income households tend to be narrow. The appliance ownership rates are assumed to increase every year except for the fluorescent light and colour television due to the saturation of appliances.

Electricity Consumption

The electricity demand of the residential sector is estimated by using the following equation :

$$EC(t) = \sum_i \sum_j \sum_k \sum_l \begin{bmatrix} HH_i(t) \times INC_{i,j}(t) \times \\ DLT_{i,j,k}(t) \times RSC_{i,j,k}(t) \times \\ SHE_{i,j,k}(t) \times STL_{i,j,k,l}(t) \times \\ CPT_{i,j,k,l}(t) \times USG_{i,j,k,l}(t) \end{bmatrix} \quad (3)$$

where

$EC(t)$ = Energy consumption in year t, kWh.,

$HH_i(t)$ = Number of households in region i in year t,

$INC_{i,j}(t)$ = Fraction of income class j in region i in yera t,

$DLT_{i,j,k}(t)$ = Fraction of dwelling type k by income class j in region i in year t,

$RSC_{i,j,k}(t)$ = Fraction of residential rate class by dwelling type k and income class j in region i in year t,

$SHE_{i,j,k}(t)$ = Share of household with electricity by dwelling type k and income class j in region i in year t,

$STL_{i,j,k,l}(t)$ = Saturation level of device l by dwelling type k and income class j in region i in year t,

$CPT_{i,j,k,l}(t)$ = Capacity of device l by dwelling type k and income class j in region i in year t, kW,

$USG_{i,j,k,l}(t)$ = Usage of device l by dwelling type k and income class j in region i in year t, hour.

Demand-Side-Management (DSM) Alternative

In this study, the efficiency improvement of six appliances; namely, air-conditioner, refrigerator, electric fan, rice cooker, television and fluorescent tube are applied with the following assumptions:

1. The changes of fluorescent tubes from 20 W to 18 w and from 40 W to 36 W.
2. The efficiency rating labels of refrigerators and air-conditioners to encourage manufacturers to produce more efficient refrigerators and air-conditioner.
3. The efficiency improvement of rice cookers by adding more insulation.
4. The efficiency improvement of televisions by reducing the stand-by power.
5. The efficiency improvement of electric fan.

In order to urge the manufacturers to keep on improving efficiency of the appliances, especially the refrigerator and air-conditioner, the labels for efficiency rating should be revised after implementation for a period of times. In this study, an average efficiency improvement of 1 percent per year is assumed for each type of electric devices.

Electricity Supply Systems and Modeling

In order to supply the future electricity demand, the capacity expansion of the existing power system is needed. A least cost electricity expansion model, called the Wien Automatic System Planning Package (WASP), is used to find out the economically optimal expansion plan subjected to the specified constraints. The WASP utilizes probabilistic estimation of system production costs, unserved energy cost, reliability and the dynamic programming method for comparing the total cost of alternative system expansion plan. The installed capacity of the existing power system in 1997 is 17,501.5 MW. The candidate power plants used in the model are presented in Table 2.

Table 2 Candidate power plants used in the WASP model

Plant Name	Plant type	Capacity (MW)	Fuel type
CL10	Thermal	1,000	Coal
OL10	Thermal	1,000	Fuel Oil
CC06	Combined Cycle	600	Natural Gas
GT02	Gas Turbine	200	Diesel

Constraints and Assumptions used in modeling the Power System

1. The minimum and maximum reserve margins are 15 percent and 25 percent, respectively [7].
2. The natural gas supplied through pipeline from the neighboring countries is limited to 1,080-2,809 MMSCFD, which is enough for the generation of approximately 11,650 MW of combined cycle power plant or about 19 units of 600 MW capacity [7].
3. The number of peak-load power plants (hydro- and gas-turbine power plants) is approximately 20 percent of the total installed capacity.
4. The capacity of coal-fired power plants is not higher than 50 percent of the total capacity of the system.
5. The on-going projects of the hydropower plants are not considered in this study.

RESULTS

Electricity Consumption in the Residential Sector

Results of the analysis of electricity consumption per household by income class are shown in Table 3, revealing more electricity consumption for the higher income levels.

Results of electricity demand projection are shown in Tables 4 and 5. In 2015, the demand-side-management programs for the residential sector can save 8,097 GWh of electricity, accounted for 16 percent of the total electricity consumption in this sector.

The electricity consumption of residential sector is mainly used in air-conditioning systems, accounted for 43 percent of the total electricity demand of the sector. The efficiency improvement of air-conditioner and refrigerator can reduce electricity consumption by 25 percent and 20 percent, respectively, compared

Table 3 Electricity consumption by income level

Unit: GWh

Income level (Baht/month)	Reference scenario					Efficiency-oriented scenario				
	1998	2000	2005	2010	2015	1998	2000	2005	2010	2015
MEA's area										
<5000	1,001	1,205	1,469	1,832	1,941	950	1,102	1,291	1,541	1,614
5000-7000	765	998	1,222	1,472	1,667	727	920	1,102	1,302	1,458
7000-15000	2,314	2,836	3,756	4,773	5,554	2,211	2,636	3,386	4,195	4,800
15000-25000	1,015	1,230	1,435	1,704	1,887	965	1,142	1,312	1,528	1,672
25000-50000	1,878	2,348	3,041	3,712	4,278	1,769	2,151	2,725	3,248	3,691
>50000	1,910	2,352	2,877	3,460	3,858	1,719	2,030	2,368	2,742	2,972
Sub-total	8,883	10,968	13,799	16,952	19,184	8,341	9,980	12,183	14,556	16,206
PEA's area										
<500	125	166	189	212	238	125	157	173	189	214
500-1500	872	1,079	1,255	1,452	1,544	870	1,022	1,158	1,305	1,388
1500-3000	1,718	2,139	2,612	3,101	3,556	1,693	2,007	2,385	2,760	3,160
3000-7000	4,151	4,735	5,872	7,060	8,181	4,049	4,493	5,409	6,334	7,225
7000-15000	2,943	3,607	5,402	7,438	9,700	2,745	3,207	4,417	5,711	7,066
>15000	2,223	2,823	4,302	5,985	7,817	2,135	2,652	3,920	5,336	6,863
Sub-total	12,034	14,549	19,632	25,248	31,036	11,617	13,536	17,462	21,635	25,917
Total	20,917	25,517	33,431	42,200	50,220	19,958	23,517	29,645	36,191	42,123

Table 4 Electricity demand projection by end-use device

Unit: GWh

Year	Reference scenario					Efficiency-oriented scenario				
	1998	2000	2005	2010	2015	1998	2000	2005	2010	2015
Air-conditioner	6.300	8,122	12,086	16,619	21,413	5,699	7,050	9,872	12,994	16,147
Refrigerator	4,249	4,930	6,003	7,136	7,953	3,951	4,433	5,198	5,942	6,465
Cooking	3,146	3,711	4,476	5,279	5,848	3,146	3,501	4,097	4,682	5,187
Electric fan	1,495	1,861	2,508	3,242	3,963	1,495	1,855	2,492	3,213	3,924
Lighting	1,634	1,872	2,182	2,543	2,810	1,574	1,813	2,091	2,414	2,654
Television	1,411	1,744	2,072	2,419	2,699	1,411	1,587	1,792	1,984	2,213
Freezer	257	292	359	422	481	257	292	359	422	481
Washing	138	191	279	367	421	138	191	279	367	421
Ironing	159	195	243	285	312	159	195	243	285	312
Others	2,128	2,600	3,223	3,888	4,320	2,128	2,600	3,223	3,888	4,320
Total	20,917	25,517	33,431	42,200	50,220	19,958	23,517	29,645	36,191	42,123

with the reference scenario. Energy consumption of the air-conditioner and refrigerator is accounted for 53 percent of the total electricity consumption in the residential sector.

Power Generation Expansion and Environmental Implications

Table 6 shows the number and type of committed plants from the WASP model for both reference and efficiency-oriented scenarios. Fig. 2 shows the total power generation capacity for both scenarios. The efficiency-oriented scenario can postpone 2,000 MW of the additional capacity requirement in 2015 with lower electricity generation by 9,293 GWh and saving the fuel requirement by 2,010 ktoe, shown in Figs. 3 and 4, respectively.

The decrease in the additional capacity requirement reduces not only the fuel consumption but also the airborne emissions. Figs. 5 to 7 show the corresponding emissions for both scenarios. In 2015, the carbon dioxide, sulfur dioxide, and suspended particulate matter emissions of the efficiency-oriented scenario are lower than those of the reference scenario by 4.2, 8.1 and 4.4 percent, respectively. The global warming potential (GWP) of the greenhouse gases (GHGs), including carbon dioxide, methane, and nitrous oxide, is applied to estimate the carbon dioxide equivalent, presented in Fig. 8. Results show that in 2015 the efficiency-oriented scenario can reduce 8.24 million ton of GHGs or 4.2 percent, compared with the reference scenario.

Table 5 Final electricity demand

Unit: GWh

Sector	1998	2000	2005	2010	2015
Residential					
Reference scenario	20,917	25,517	33,431	42,200	50,220
Efficiency-oriented scenario	19,958	23,517	29,645	36,191	42,123
Agriculture/1	103	100	110	133	156
Commercial/1	28,274	32,937	50,941	78,269	109,570
Industrial/1	33,460	35,962	47,040	65,145	82,974
Transport/1	0	800	1,730	3,453	3,763
Total					
Reference scenario	82,755	95,317	133,252	189,199	246,683
Efficiency-oriented scenario	81,796	93,316	129,466	183,190	238,587

Source :/1 Thailand Environment Institute (1998).

Table 6 The number and type of committed plants from the WASP model

Year	Plants in commitment								Additional capacity (MW)	
	CL10		OL10		CC06		GT02			
	Reference	EOS	Reference	EOS	Reference	EOS	Reference	EOS	Reference	EOS
1998	-	-	-	-	1	1	-	-	600	600
1999	-	-	-	-	2	2	-	-	1200	1200
2000	-	-	-	-	2	2	-	-	1200	1200
2001	-	-	-	-	2	2	-	-	1200	1200
2002	-	-	-	-	2	2	1	-	1400	1200
2003	-	-	-	-	2	2	1	-	1400	1200
2004	-	-	-	-	2	2	2	1	1600	1400
2005	1	1	-	-	2	2	-	1	2200	2400
2006	1	1	-	-	2	2	1	1	2400	2400
2007	2	1	-	-	2	2	1	1	3400	2400
2008	3	2	-	-	-	-	1	1	3200	2200
2009	1	2	-	-	-	-	1	1	1200	2200
2010	2	2	-	-	-	-	1	1	2200	2200
2011	3	3	-	-	-	-	1	1	3200	3200
2012	3	3	-	-	-	-	2	1	3400	3200
2013	3	3	-	-	-	-	1	1	3200	3200
2014	3	3	1	1	-	-	2	3	4400	4600
2015	3	3	1	-	-	-	1	3	4200	3600
Total	25	24	2	1	19	19	16	16	41,600	39,600

Note : The EOS stands for the effciency-oriented scenario.

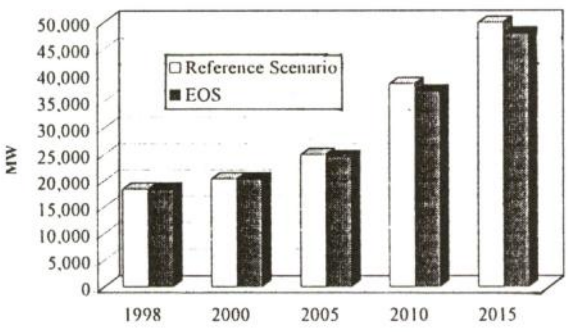

Fig. 2 Total power generation capacity

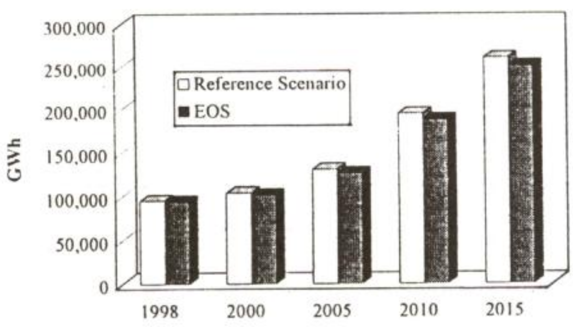

Fig. 3 Total electricity generation

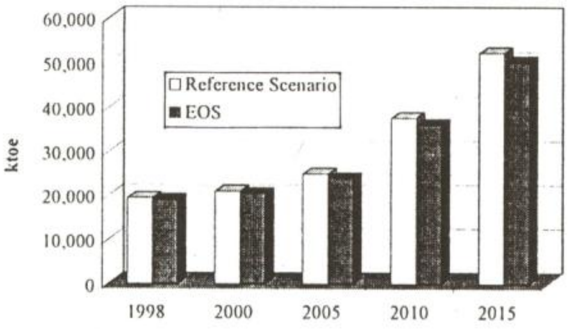

Fig. 4 Fuel requirement for electricity generation

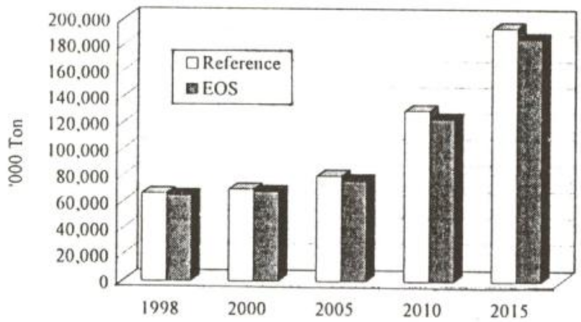

Fig. 5 Carbon dioxide emissions

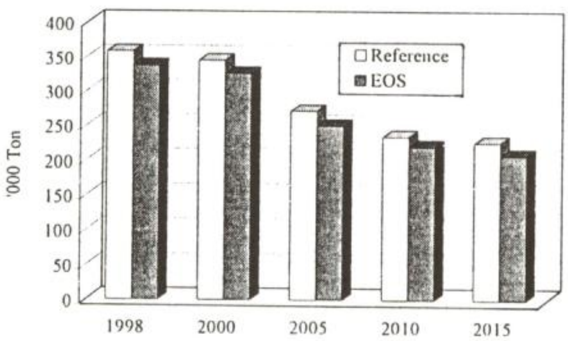

Fig. 6 Sulfur dioxide emissions

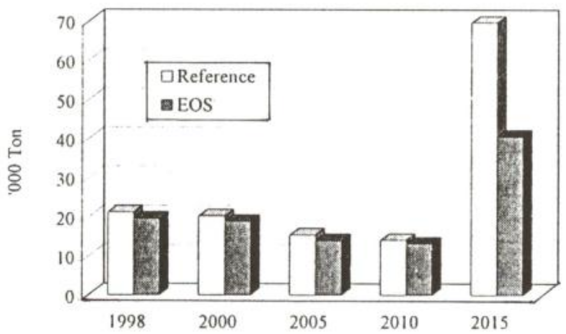

Fig. 7 Suspended particulate matter emissions

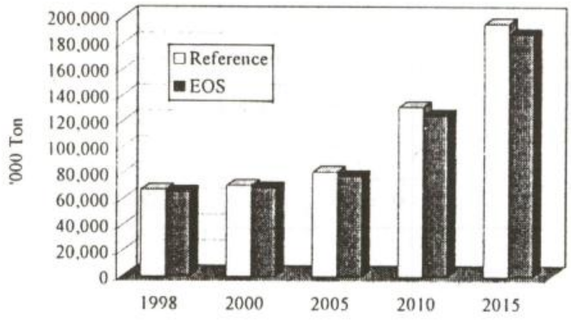

Fig. 8 Carbon dioxide equivalent emissions

CONCLUSION

The implementation of high efficiency devices in the residential sector plays a significant role in not only reducing electricity consumption but also deferring the capacity expansion schedule of the power plants and mitigating airborne emissions. In order to enhance the amount of electricity savings, the device efficiency should keep on improving. Further strategies on demand-side management should be developed and implemented at the same time. Finally, the methodology presented in this paper can be applied to other economic sectors for allocating the resources in electricity generation and reducing emissions in the country.

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