Reduction of Energy Consumption and Corresponding Emissions in Thai Residential Sector by Improved Cooking Stoves, Family Biogas Digesters and Improved Charcoal-making Kilns Options

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Abstract

The renewable energy used for reducing the final energy consumption and corresponding environmental emissions in the residential sector of Thailand are investigated in terms of energy saving, environmental emission reduction, and economic viability for a planning horizon of 33 years. Three renewable energy options in this study are improved cooking stoves, family biogas digesters, and improved charcoal-making kilns. To estimate the energy consumption and the emissions, a computer-based tool, called "Long-range Energy Alternative Planning (LEAP)" model, is used. Results show that each option is economically viable and has high potential to reduce the emissions in the residential sector.

Keywords: Residential energy consumption, GHGs emission, improved cooking stoves, family biogas digesters, and improved charcoal-making kilns.

Nomenclature

BAU	Business-as-usual
B/C ratio	The benefit/cost ratio
CDM	The clean development mechanism
CH_4	Methane
CMK	Improved charcoal-making kilns
CMK1	The CMK option at the charcoal price of 3.5 Baht per kg
CMK2	The CMK option at the charcoal price of 5.0 Baht per kg
CMK3	The CMK option at the charcoal price of 6.2 Baht per kg
CMK4	The CMK option at the charcoal price of 10.0 Baht per kg
CO_2	Carbon dioxide
DoAE	The Department of Agricultural Extension
ECS	The existing cooking stove
FBD	Family biogas digesters
FBD1	The FBD option is used as a wastewater treatment system in livestock farms
FBD2	The FBD option is used to produce biogas for replacing the use of LPG
GHGs	Greenhouse gases
ICS	Improved cooking stoves
JGSEE	The Joint Graduate School of Energy and Environment

KMUTT	The King Mongkut's University of Technology Thonburi
ktoe	Thousand tonne of oil equivalent
LEAP	Long-range Energy Alternative Planning model
LPG	Liquefied petroleum gas
NPV	The net present value
SEI	The Stockholm Environment Institute
UNFCCC	The United Nations Framework Convention on Climate Change

1. Introduction

Over the last 10 years, the Thai government has been introducing and implementing many strategies to reduce energy consumption in all economic sectors. The most successful strategy is to produce efficient electric appliances instead of inefficient electric appliances. The process of this strategy was to enforce manufacturers implementation together with end-users. However, many programs have failed such as the improved cooking stove program. The problems include a lack of available data, knowledge and skill of staff in charge and end-users. Consequently, the following three options: improved cooking stoves (ICS), family biogas digesters (FBD), and improved charcoal-making kilns (CMK), are introduced and investigated as options for reducing energy consumption, as well as the corresponding environmental emissions in the residential sector. However, in this study only CO_2 and CH_4 are considered as greenhouse gases (GHGs) and presented in CO_2 equivalent form. The energy and environmental analysis show the potential reduction of energy consumption and emissions through the three options. Likewise, results of economic analysis show economic viability for the three options. The study period is 1998-2030 and the base year is 1998. Even though Thailand has many resources of renewable energy, these three options are chosen because the residential sector is the third largest energy, consuming sector in Thailand and renewable energy is the largest source of energy used in this sector, mainly for cooking, heating, and lighting purposes in the rural area [1]. As a result, the standard of living of people in rural areas will be improved if these three options succeed. Therefore, it is believed that the results of this study are useful to use as one data source in order to implement these three options.

2. Assumptions

The study explores four different scenarios to project different trajectories of the final energy consumption and the GHGs emission. They are categorized as business-as-usual (BAU), improved cooking stoves (ICS), family biogas digesters (FBD), and improved charcoal-making kilns (CMK) scenarios. Details of the assumptions for each scenario are as follows:

Firstly, for the BAU scenario or the base case, the assumptions to project energy consumption and GHGs emission are based on the historical data in the period 1990-1998, government plans, as well as the on-going activities and committed activities of the government, in the future.

Secondly, concerning the ICS scenario, the study assumes that the penetration rate of the improved charcoal cooking stove (ICS) is the same as in the BAU scenario because the existing charcoal cooking stove (ECS) in the BAU scenario will be completely replaced by 2011 for Bangkok and the municipal areas [2]. Based on the existing trend, this study assumes that the ECS will be completely replaced by 2020 for the rural areas. Since in the past the government did not pay attention to the improved wood cooking stove, the assumption of its penetration rate is calculated based on the penetration rate of the improved charcoal cooking stove which was introduced by the Thai government [2]. Consequently, the penetration rates are 10% in 2005, 50% in 2010, and 100% in 2015 for Bangkok and the municipal areas. For the rural area, the penetration rates are 10% in 2005, 30% in 2010, 90% in 2020, and 100% in 2023. Hence, the difference between the BAU and the ICS scenarios is the penetration rate of the improved wood cooking stove.

Next, in the FBD scenario, the consumption of LPG will be replaced by biogas with a more progressive rate than in the BAU scenario, as shown in Table 1. The first year of the replacement is 2006 [3]. The projection of the replacement of LPG consumption by biogas from [2, 4] is used for the BAU scenario in this study. In addition, maximum potential to substitute the use of LPG by biogas is around 300 ktoe per year, calculated from [5, 6].

Table 1 The projection of the replacement of LPG consumption by biogas in the residential sector

Unit : ktoe

Scenario	Year				
	2000	2005	2010	2020	2030
The BAU scenario	1.5	12.0	28.2	58.1	88.3
The FBD scenario	1.5	12.0	34.9	97.2	274.7

Finally, regarding the CMK scenario, the replacement of the inefficient kiln with an efficient kiln is assumed. The inefficient kilns are earth or rice husk mounds and mud beehive kilns while efficient kilns are brick beehive kilns [7]. In this scenario, the assumption of the potential of the replacement is separated into 2 cases: the low case and the high case. For the low case, 25% of inefficient kilns are replaced with the figure being 50% for the high case. The proportion of using charcoal-making kilns from [8] is used as the baseline.

3. Methodology

The methodology in this study consists of 2 sections: 1) the energy and environmental analysis and 2) the economic analysis. The overall methodology of the study is shown in Figure 1.

3.1 The energy and environmental analysis

The historical data of number of households, electrified household penetration rates, and end-use device penetration rates by area in the residential sector of Thailand from 1990 to 1998[9, 10] are used to forecast the period 1999-2030. The data for the period 1990-1998 are used because of the limitation of available data. Related to [10], the area in Thailand is separated into 3 areas: Bangkok, the municipality, its and the rural areas. The end-use devices used in this study are fluorescent lamp, incandescent lamp, compact fluorescent lamp, electric pot, electric stove, refrigerator, television, video, radio, air conditioner, electric fan, electric iron, water heater, washing machine, gas stove, charcoal stove, and wood stove. In addition, the LEAP model developed by the Stockholm Environment Institute (SEI), which is based on end-use model [11], is used for obtaining the energy consumption pattern and the GHGs emission in the period 1998-2030. The LEAP model is a simulation model used to represent the current energy situation for a given area and to develop forecasts for the future under certain assumptions. Hence, at first an overview of the current situation is created by specifying data for the starting year. Then a basic scenario is developed assuming a continuation of current trends. After that, interventions can be evaluated by using scenarios. As LEAP model follows an end-use model, demand-driven approach, which means that the analysis starts from the end-use of energy. The demand program divides the society in a hierarchical tree structure of four levels: sectors, sub-sectors, end-uses, and devices [11]. In this study, therefore, the sector is the residential, and the sub-sectors are Bangkok, the municipality, its and the rural areas. The end-uses are; for example, lighting and cooking, and the devices are; for instance, fluorescent lamp, incandescent lamp, compact fluorescent lamp, electric stove, gas stove, charcoal stove, and wood stove.

3.2 The economic analysis

The economic analysis aims to state an economic viability of each option and the result is used for decision making. Usually, the methodology for analysis benefits and costs of the project is the net present value (NPV) and the benefit/cost ratio (B/C ratio). Therefore, these two methods are used in this study. Besides the benefit-cost analysis, sensitivity analysis is done to validate the results by investigating an effect of economic parameters; for instance, plant maintenance cost, raw material cost, labour cost, interest rate, and inflation rate.

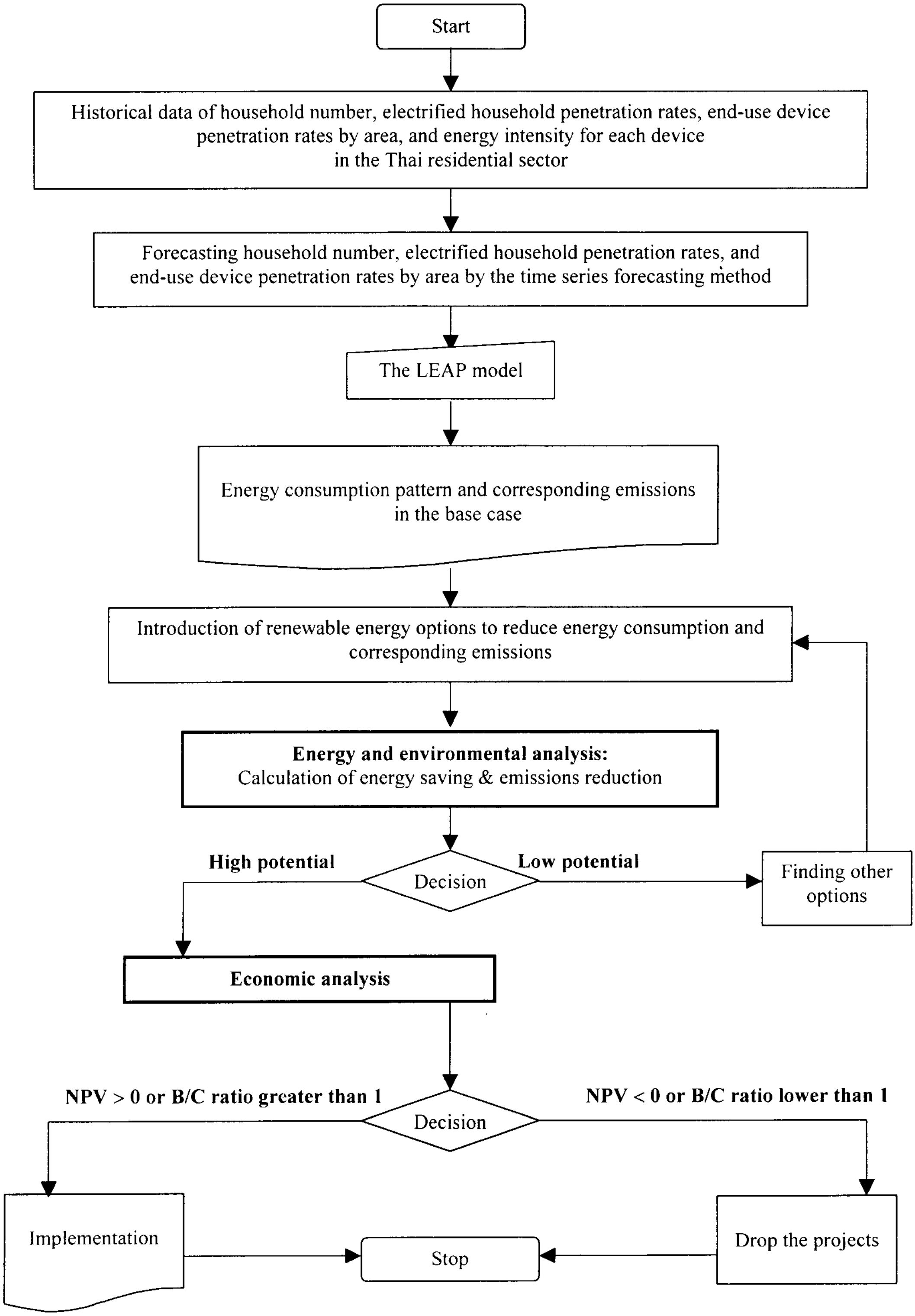

Figure 1. The overall methodology of the study

3.2.1 The ICS option

In the ICS option, the B/C ratio methodology is chosen as the criterion for the decision making due to the short time period of the life span of a stove. In the short time period, the time value of money does not affect the benefits and the costs [12]; therefore, it is easy to calculate for the NPV value. The benefits of this option are the sum of fuel saving and capital cost saving. In summary, to analyze the benefits and the costs of the ICS option, the following characteristics are considered for the base case.

- The stove price in 2001of the ECS is 75 Baht per unit, and 150 Baht per unit for the ICS [13],
- The efficiency of the ECS is 21% for both the wood and charcoal cooking stoves while the efficiency of the ICS is 29% for the wood cooking stove and 32% for the charcoal cooking stove [14],
- The capital cost saving is calculated from the money that the users have to spend, two times higher, for the ECS compared to the use of the ICS during 2 years. Thus, the capital cost saving is 150 Baht [= (4 stoves x 75 Baht per stove for the ECS) – (1 stove x 150 Baht per stove for the ICS)]. The life span of the improved cooking stove is 2 years while for the existing cooking stove is only half a year [13].

3.2.2The FBD option

In the FBD option, both the NPV and the B/C ratio methodologies are used because this option has a long time period with the life span of digester equal to 15 years [15, 16]. In addition, the benefits of the FBD are biogas and manure while the costs of the FBD are (i) capital investment, (ii) annual operation, (iii) stove replacement, (iv) labour and (v) waste and water feeding [17]. The benefit-cost analysis of the FBD option is categorized into 2 cases:

- The FBD option is used as a wastewater treatment system in livestock farms, called FBD1 case, and
- The FBD option is used to produce biogas for replacing the use of LPG, called FBD2 case.

Regarding the FBD1 case, the waste and water feeding cost are not included in the cost because the wastewater is produced from the farm. On the other hand, to use the family biogas digester in the FBD2 case, the cost of waste and water feeding are included in the cost because the investors have to buy waste and pay for water. Since the digester has a long time period, the nominal interest rate and the inflation rate affect the costs and the benefits of the family biogas digester investment. Therefore, for the base case, the nominal interest rate in 2002 is equal to 7.36% per year [18] and the inflation rate of 0.96% per year [19, 20] are used in this study.

3.2.3 The CMK option

In the CMK option, the B/C ratio methodology is chosen as the criterion for the decision making because of the short time period of the life span of kiln which is equal to 5 years [21]. The benefit of the CMK option is from the sale of charcoal while the costs consist of (i) the construction cost, (ii) the cost of operating time, (iii) the labour cost, and (iv) the raw-material wood cost [21]. Unfortunately, there are no available data with the same size for each type of kiln; therefore, the data of the earth or rice husk mound under the size of 2.1 m^3, the data of the mud beehive kiln under the size of 2.2 m^3, and the data of the brick beehive kiln under the size of 2.0 m^3 are used in this study. Since the size of each type of kiln is close to each other, it is believed that the results can be realizable. Furthermore, the average price of charcoal cannot be used for the analysis because this price gives the B/C ratio less than 1 for all types of kiln. Thus, the economic analysis for this option is categorized into 4 cases depended on the charcoal price as the following:

- CMK1 case: the charcoal price is 3.5 Baht per kg [22],
- CMK2 case: the charcoal price is 5.0 Baht per kg [23],
- CMK3 case: the average price of charcoal is 6.2 Baht per kg, and
- CMK4 case: the charcoal price is 10.0 Baht per kg [24].

4. Results and Discussions

The results in Table 2 show that, in the BAU case, the final energy consumption increased from 7,307.6 ktoe per year in the base year to 11,030.8 ktoe per year in 2030. It shows that the final energy consumption increased by 50.95% in 2030 compared to the base year, accounting for an average growth rate of 1.54% annually. The GHGs emission is around 22,250 thousand tonnes of CO_2 equivalent per year during the study period. The emissions remain nearly constant while there is an increase in the final energy consumption increase because the Thai government has been continuing to introduce and implement many strategies to reduce the emissions.

In the ICS option, the results in Table 2 show that the final energy consumption is reduced from 74.2 ktoe per year in 2005 to 674.3 ktoe per year in 2030. The GHGs emission is reduced from 319.1 to 2,897 thousand tonnes of CO_2 equivalent per year in 2005 and 2030, respectively. The emissions reduction costs in 2001 were 49.17 Baht and 16.97 Baht per tonne of CO_2 equivalent per stove for the wood and the charcoal cooking stoves, respectively. Moreover, the B/C ratios from the replacement of the ECS with the ICS are 2.62 and 11.45 for the wood and the charcoal cooking stoves, respectively. Therefore, the improved cooking stove is competitive to the existing cooking stove. To succeed in this option a training program for stove makers is needed because the lack of skill of stove makers caused the failure of this option in the past. The awareness of the use of inefficient cooking stoves, in terms of environmental concerns, should be considered and strongly presented to users during the implementation program as well.

In the FBD option, the results in Table 3 show that the LPG consumption is reduced by 1.4 ktoe per year in 2006 and by 182.1 ktoe per year in 2030. The GHGs emission is reduced by 3.8 thousand tonnes of CO_2 equivalent per year in 2006 and by 499.1 thousand tonnes of CO_2 equivalent per year in 2030. As a result, Thailand could save exported currency for the imported LPG totalling 17.6 million Baht and 2,299 million Baht per year in 2006 and 2030, respectively at the LPG price in 2002 equal to 13.6 Baht per kg [25]. Not only can the LPG consumption be reduced, but also the imported chemical fertilizer. According to [6], the quality of the manure from the digester is the same as the quality of the imported chemical fertilizer in the formula of 16-20-0 (percentages by mass of nitrogen, phosphorus and potassium, respectively) which had a price in 2002 equal to 5,821.80 Baht per tonne [26]. The potential of the fertilizer produced from the biogas digester in the residential sector is around 400 million tonnes per year. Therefore, all small farmers in the residential sector of Thailand will earn from selling the fertilizer from biogas digester at a maximum potential of 199,800 million Baht per year at the price of the fertilizer from biogas digester in 2001 equal to 0.5 Baht per kg [27]. According to [26], the price of the imported chemical fertilizer in the formula of 16-20-0 in 2002 was 5,821.80 Baht per tonne, therefore, Thailand's potential of saved exported currency from imported chemical fertilizer is approximately 2,330,000 million Baht per year if all manure in the residential sector are used for biogas digesters. For economic viability, results clearly show that the FBD option is viable to use only when the FBD is used as the wastewater treatment system in the animal farms (FBD1 case) because the NPV is positive and the B/C ratio is greater than 1 for all sizes of digesters. Otherwise, the NPV is negative and the B/C ratio is lower than 1 for all sizes of digesters for FBD2 case.

In the CMK option, the results in Table 4 show that the use of raw-material wood is reduced by around 100 and 200 ktoe per year for the low case and the high case, respectively during the study period. Furthermore, the results show that the greatest value of the B/C ratio comes from the case that the charcoal is produced from the brick beehive kiln, followed by the mud beehive kiln and the earth or rice husk mound. Most importantly, the values of B/C ratio are greater than 1 in the CMK4 case only. Therefore, in terms of economics the charcoal makers cannot earn income under the situations of CMK1, CMK2, and CMK3 cases. Thus, the breakeven point of the price of charcoal is calculated to know how much one kg of charcoal produced from each type of kiln should be sold to recover the investment. Results show that the charcoal production by the earth or rice husk mound, the mud beehive kiln, and the brick beehive kiln should be sold at prices above 8.5, 7.0, and 6.8 Baht per kg, respectively. Obviously, the charcoal produced from the brick beehive kiln has the lowest investment cost because the charcoal producers will recover their investment when they sell the charcoal at 6.8 Baht per kg.

Table 2 Final energy consumption and GHGs emission in the residential sector

Item	Unit	Year				
		1998	2005	2010	2020	2030
Energy consumption	ktoe					
The base case		7,307.6	8,705.3	9,529.9	10,413.5	11,030.8
The ICS option		7,307.6	8,631.1	9,297.6	9,741.0	10,356.5
The FBD option		7,307.6	8,705.3	9,529.9	10,413.5	11,030.8
The GHGs emission	Thousand tonnes of CO_2 equivalent					
The base case		21,039.7	23,043.2	22,865.5	22,083.5	21,305.2
The ICS option		21,039.7	22,724.1	21,867.5	19,194.0	18,408.2
The FBD option		21,039.7	23,043.2	22,843.6	21,969.8	20,806.1

Table 3 LPG consumption and GHGs emission in the residential sector for the base case and the FBD option

Item	Unit	Year				
		1998	2006	2010	2020	2030
LPG consumption	ktoe					
The base case		763.7	1,083.7	1,222.5	1,560.9	1,886.3
The FBD option		763.7	1,082.3	1,214.5	1,519.4	1,704.2
The GHGs emission	Thousand tonnes of CO_2 equivalent					
The base case		21,039.7	23,148.0	22,865.5	22,083.5	21,305.2
The FBD option		21,039.7	23,144.2	22,843.6	21,969.8	20,806.1

Table 4 Raw-material wood used in the charcoal process in the CMK option

Case study	The use of raw-material wood (ktoe)				
	1998	2005	2010	2020	2030
The base line	6,271.5	6,518.4	6,290.1	5,732.2	5,142.1
The low case	6,160.2	6,402.6	6,178.4	5,630.4	5,050.8
The high case	6,048.7	6,286.8	6,066.6	5,528.5	4,959.4

5. Conclusions and Recommendations

This study has aimed to introduce three renewable energy options and proved their economic viability. Results have shown that the three options are economically viable. Energy consumption and GHGs emission have been shown to be reduced through the replacement of the existing cooking stove with the improved cooking stove in the ICS option. In the FBD option, the LPG consumption and the GHGs emission can be reduced by replacing the use of LPG with biogas. It has been shown to be economically viable when the FBD is used as the wastewater treatment system. In addition, lowering LPG consumption could reduce imported LPG. In the CMK option, use of raw-material wood is reduced through charcoal production by the use of efficient kilns instead of inefficient kiln. Concerning ICS option, it not only reduces energy consumption and the emissions, but also human health will be better by replacing using the existing cooking stove because the improved cooking stove produces less emissions and particles. Regarding FBD option, the production of the FBD option is methane. Therefore, it is dangerous if this gas leaks. Hence, the safety of the system is important for this option.

As a result, it is believed that this study gives useful results. For example, it might be used as a guideline to ask for financial aid before implementation under the clean development mechanism (CDM) as set up under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). The technical and financial aid also should not be ignored during the implementation. Finally, by the above strategies it is believed that the success of the three options would be achieved in the near future.

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7. References

[1] Department of Energy Development and Promotion (DEDP), Thailand Energy Situation 1999, 2000.

[2] National Energy Policy Office (NEPO), Additional Data for the Assumption and the Calculation of the Energy Conservation Potential, 2001.

[3] National Energy Policy Office (NEPO), The Strategy Plan for the Energy Conservation of Thailand, 2001.

[4] National Energy Policy Office (NEPO), Energy Conservation Strategy in Thailand, 2001.

[5] Nation Statistical Office (NSO), 1993 Agricultural Census Whole Kingdom, 1993.

[6] Department of Agricultural Extension (DoAE), The Calculation for Construction of Fix-Dome Type Biogas Digester Manual.

[7] United States Environmental Protection Agency (EPA), Greenhouse Gases from Small-scale Combustion Devices in Developing Countries: Charcoal-making Kilns in Thailand, 1999.

[8] Department of Energy Development and Promotion (DEDP), The Study of the Direction of Energy Used in Rural Area in Thailand in 1991, 1992.

[9] Department of Local Administration Ministry of Interior (DoLA), The Report of Household Number, 2001.

[10] Nation Statistical Office (NSO), The Report of Household Energy Consumption Survey, 1998.

[11] www.seib.org/leap, LEAP2000 Model Version 2000.0058.

[12] Juan S. B. Heredia, Integrated Development and Economics of Energy Projects, Asian Institute of Technology, Bangkok Thailand, 1996.

[13] King Mongkut's University of Technology Thonburi, KMUTT NEWS, Vol. 19, May-June 2001.

[14] Forest Products Research Division, Royal Forest Department, Thailand, High Efficiency Stove.

[15] Appropriate Technology Association (ATA), Renewable Energy Technology of Thailand, 2001.

[16] www.chmai.loxinf.co.th/~bau/project, BAU Biogas Advisory Unit.

[17] Department of Agricultural Extension (DoAE), The Estimation of the Potential of the Energy Conservation Project, 1998.

[18] Bangkok Bank and Others, The Announcement of the Loan Interest Rate, 2002.

[19] www.moc.go.th/thai/abe/index, The Situation of the Living Cost and the Inflation Rate from 1994 to 2001.

[20] www.bot.or.th/BOIhomepage/Library, The Inflation Rate in 2002 from February to July.

[21] Forest Products Research Division, Royal Forest Department, Ministry of Agriculture and Cooperative, Charcoal Production Improvement for Rural Development in Thailand, 1984.

[22] Chareanpaisan Sombun-Katewal Road, Tumbol Thaladloung, Amphur Maung, Aoungthong Province, 14000, 2002.
[23] REX Newsletter, Issue No.4. Special Issue, October 2001.
[24] Survey at Khlong Luang Market Pathum Thani Province, September 2002.
[25] www.nepo.go.th/retail_LPG_prices.html, Retail LPG Price, August 18, 2002.
[26] www.oae.go.th/research/fertilizer, The Situation of the Chemical Fertilizer in June, 2001 Compared to the Amount of the Fertilizer and the Imported Price (CIF).
[27] www.nepo.go.th/encon/coop/biogas, The Project of the Implementation of the Biogas Digester in the Livestock Farm.