MODELING FUTURE DEMAND FOR ENERGY RESOURCES: A STUDY OF RESIDENTIAL ELECTRICITY USAGE IN THAILAND

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ABSTRACT

Modeling Future Demand for Energy Resources:
A Study of Residential Electricity Usage in Thailand

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Thailand has a critical need for effective long-term energy planning because of the country's rapidly increasing energy consumption. In this study, the demand for electricity by the residential sector is modeled using a framework that provides detailed estimates of the timing and spatial distribution of changes in energy demand. A population model was developed based on the Cohort-Component method to provide estimates of population by age, sex and urban/non-urban residency in each province. A residential electricity end user model was developed to estimate future electricity usage in urban and non-urban households of the seventy-six provinces in Thailand during the period 1999-2019. Key variables in this model include population, the number of households, family household size, and characteristics of eleven types of electric household appliance such as usage intensity, input power, and saturation rate. The methodology employed in this study is a trending method which utilizes expert opinion to estimate future variables based on a percentage change from the most current value.

This study shows that from 1994 to 2019 Thailand will experience an increase in population from 55.4 to 83.6 million. Large percentage population increases will take place in Bangkok, Nonthaburi, Samut Prakarn, Nakhon Pathom and Chonburi. At a national level, the residential electricity consumption will increase from approximately 19,000 to 81,000 GWh annually. Consumption in non-urban households will be larger than in urban households, with respective annual increases of 8.0% and 6.2% in 2019. The percent increase of the average annual electricity consumption will be four times the average annual percent population increase. Increased electricity demand is largely a function of increased population and increased demand for high-energy appliances such as air conditioners. In 1994, air conditioning was responsible for xx% of total residential electricity demand. This study estimates that in 2019, air conditioning will account for yy% of the total demand. Low, base, and high scenarios were modeled to provide estimates of the potential range of electricity demand that could be expected. The low scenario assumes the adoption of energy efficient appliances and reduced usage through conservation measures. Total demand in 2019 under the low scenario is xx, yy% of the demand under the base scenario. Through policy, education, and technology options, the potential exists for Thailand to reduce the future demand for energy. This study identifies key factors related to residential electricity demand that should facilitate planners in the development of these options.

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LIST OF ABBREVIATIONS

ADB .... Asian Development

CDR .... Crude Death Rate

DSM .... Demand Side management

EGAT .... Electric Generation Authority of Thailand

FGD .... Flue Gas Desulfurisaton

GIS .... Geographic Information System

Gwh .... Gigawatts-hour

HOMES .... Household Model for Economic and Social Studies

IEA .... International Energy Agency

IIEC .... Institute for Energy Conservation

Kwh .... Kilowatts-hour

MEA .... Metropolitan Electric Authority

NESD .... National Economic and Social Development

NESDB .... National Economic and Social Development Board

NIE .... Newly Industrialized Economies

NRD2C .... The National Rural Development Committee

NSO .... National Statistical Office

OECD .... Organization of European Community Development

PEA ....Provincial Electric Authority

PTT ....Petroleum Authority of Thailand

TEI ....Thailand Environment Institute

TDR ....Total Death Rate

TFR ....Total Fertility Rate

TDRI..Thailand Development Research Institute

UN .... United Nations

CHAPTER I

INTRODUCTION AND OVERVIEW OF THE STUDY

1.1 Introduction

Problems of increasing energy consumption persist in Thailand. Energy planners must plan in the long term to meet future energy consumption levels, taking into account the country's limited resource base and social, economic, and technological dynamics of energy. Conventional long term planning in Thailand, using a macro approach, does not provide detailed estimates of the *timing* or *spatial distribution* of changes in energy consumption within the country. Such detailed estimates are critical to planners and decision-makers in Thailand who are responsible for long range development in the energy sector. Detailed estimates of the timing and spatial change in future energy consumption allow planners to proactively manage resources such as, allocating budgets to build necessary infrastructures for provinces with high future energy consumption or provinces with dramatic increase in future consumption.

Long term planning for the entire energy sector includes conducting detailed studies for all users and resources of the energy sector which include users in industrial, commercial, transport, and residential sectors and energy resources such as petroleum, electricity, coal, and natural gas. This study performed detailed estimations of future energy consumption for one energy resource by one sector. That is, this study estimates future electricity usage of households in urban and non-urban[1] areas of Thailand at the provincial level for the period between 1999 to 2019. The estimates at the provincial level, which never before were available in Thailand, are important information for utility planners to assess timely and costly investment in expansion or new transmission and distribution of electricity systems to households in each province. Additionally, the end user approach, which estimates electricity usage from appliances owned and used in households, utilized in this study, allows energy planners to assess the impact of technological improvement of electric appliances on total electricity usage in households of Thailand. The residential electricity model developed in this study can also be used as a framework for energy planning in other sectors.

Modeling of residential electricity consumption in this study also included estimation of households, which was performed based on detailed population information and population modeling. In Thailand, as in many countries, electricity usage and population levels are positively related. An increasing population translates into more households and more demand for electricity. Estimation of population was performed at the

[1] The word non-urban used in this study does not necessarily mean rural. This study classifies urban and non-urban population based on land use classification of Thailand, Department of Land Development. Urban class refers to urban and built up land. Land that does not belong to urban class such as, agricultural land, forest land, and miscellaneous, therefore, falls into non-urban class.

provincial level based on age, sex, and residency (urban or non-urban areas). Estimates of future population at this detailed level are beneficial not only for energy planning, but for other resource management and planning in the residential sector; because population is a driving force of resource utilization. Future population estimates can be used to project future consumption for resources such as; schools, hospitals, and garbage disposal services within a province.

The development and use of detailed models of population and residential electricity in this study should provide a better understanding of the dynamic of demographic processes and linkages between population and household electricity consumption. The estimates of future electricity consumption should lead us to better our ability to manage, in the long range, our limited natural resource base.

1.2 Overview of Thailand

General information about the geography, politics, social and economic variables of Thailand are useful for understanding this study. Geographically, the Kingdom of Thailand occupies a land area of 513,115 square kilometers (approximately the size of France). Thailand is in the Indochinese Peninsula, located in Southeast Asia on the Gulf of Thailand and the Andaman Sea. Thailand shares boundaries with the Union of Myanmar (formerly Burma) and Laos People's Democratic Republic on the North to form the "Golden Triangle", Cambodia (Kumpuchea) and Laos People's Democratic

Republic on the East, Malaysia on the South, and the Union of Myanmar and the India Ocean on the West (see Figure 1).

Figure 1: Political Boundaries of Thailand and Neighboring Countries
(Source: The Perry-Castañeda Library Map Collection, The University of Texas at Austin: South East Asia. Map Produced by U.S. Central Intelligent Agency. [Online Image] Available http://www.lib.utexas.edu/Libs/PLC/Map_collection/middle_east_and_asia/Southeast Asia_pol197.jpg, December 23, 1998

Politically, Thailand has been a unified monarchy since 1350. Presently, Thailand's government is a constitutional monarchy with an elected parliament. There are three levels of government created for administrative purposes: the central (based in Bangkok Metropolis) the provincial, and the local levels. For statistical purposes, Thailand is usually divided into five geographic regions: the mountainous and ridges in the **North**; the rolling and semi-arid plateau (the Khorat plateau) in the **Northeast**, the valleys of Chao Phraya and several smaller rivers in the **Central area**; the plains and hilly area in the **East**; and the peninsular in the **South**.

Bangkok is generally treated separately from the five regions because of its unique characteristics and importance as the center of politics and economics. Adjacent to Bangkok is an area known as Bangkok Metropolitan Region (BMR). The BMR includes provinces of Nonthaburi, Prathum Thani, Samut Prakarn, and Samut Sakorn. Being close to Bangkok, the BMR has access to the largest market of the country (Bangkok), access to the central government services, and superior infrastructures compared to remaining provinces in the country. The BMR is the area where the majority of Thailand's industries are located and it is also close to ports. For these reasons, the BMR plays an important role in economic development of Thailand and is one of the most populated areas of the country with a high percentage of migrants. The other area which has shown increasing number of new industries and rapid population change due to the Thai government policy to promote export led and labor intensive industries in this region is the area known as Extended Bangkok Metropolitan Region (EBMR). The EBMR includes provinces of Chonburi, Rayoung, Chachoengsao, Saraburi, and Pranakorn Sri

Ayudhaya. Each region includes one or more provinces that are the center of a region as far as social, economic, and political aspects are concerned. These provinces have high population and superior infrastructures compared to other provinces within the region. The centers of the regions include Chiangmai in the North region, Nonthaburi and Bangkok in the Central region, Khon Kean, Ubon Ratchathani, and Nakhon Ratchasima in the Northeast region, and Songkla and Nakhon Sritammarat in the South (See Figure 2).

For administrative purposes, Thailand is further subdivided into 76 provinces. Each province is governed by a centrally appointed governor. Each province is divided into districts (amphoe) governed by centrally appointed district chiefs. Currently, there are 699 districts in the nation. Each district is further subdivided into subdistricts (tambons), and villages governed by locally elected subdistrict chiefs and village headmen. There were 6,905 subdistricts, and 62,994 villages and 132 municipal areas in Thailand in 1997. In terms of urban and rural areas in Thailand, the latest Population and Housing Census (1990) indicates that 27.1% of Thai population live in urban areas and 72.9% live in rural areas[2].

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[2] Definitions of urban and rural areas in this case are the administrative definition. Urban areas include municipal areas and urban sanitary districts. Rural areas refer to rural sanitary districts and non-municipal areas and outside sanitary districts. For detailed definition of municipal areas and sanitary districts see Summary Report of Population and Urbanization in Thailand from the Population and Housing Census, 1990. Office of National Statistics

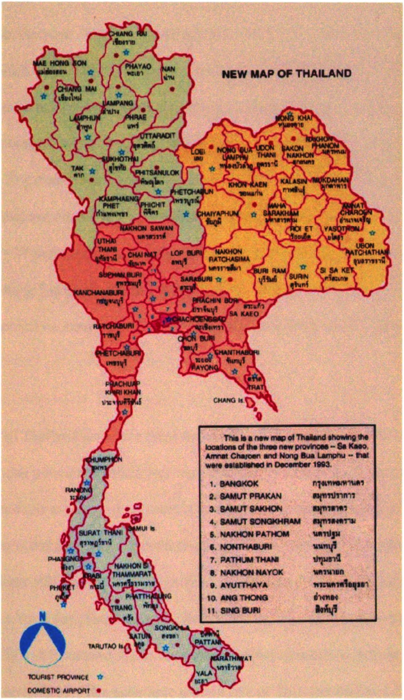

Figure 2: The Seventy-Six Administrative Provinces of Thailand (Source: Map With Only County Boundary. [Online Image] Available http://www.ee.surrey.ac.uk/Personal/R.Apiwatwaja/Map/tmap1.html, December 23, 1993)

Thailand is located in a tropical zone. The temperature and humidity of the country is high throughout the year. The average temperature of the country ranges from 77 to 82 degrees fahrenheit. Typically, the temperature increases during the day, peaking during afternoon hours. Thailand experiences high solar radiation throughout the year. The solar radiation ranges from 370 to 390 cal/cm^2- day. The relative humidity of the country is higher than 70 percent year round. Climate has a large impact on the types and usage of appliances that are unique in Thai households and different from western countries. Approximately 37 percent of total electricity consumption in Thai households in 1997 is from space cooling (using air conditioners and fans) while more than half of total residential electricity consumption in western countries is from space cooling and heating.

The economy of Thailand grew at a rate ranging from 5.5 to 11.3 percent during 1961 to 1990. During this period the nation was regarded internationally as a success. Thailand has changed from an exporter of agricultural products to an economically progressive state with exports dominated by manufactured goods and services. Nevertheless, the agricultural sector still employs the majority of the Thai people, approximately 60-65 percent of the labor force (Siamwalla, A., Setboonsarng, S., and Patamasiriwat, D., 1994). Recently, the Southeast Asian countries have experienced an economic down turn that started in early 1997. The economic growth rate of Thailand declined from approximately 9 percent and reached zero in 1997. Economists believe that the economic situation of Thailand will not improve in the next few years (Thailand Development Research Institute, TDRI in Susankarn, 1998).

1.3 Background of The Electricity Situations and Problems

During the period 1975 to 1990, total electric consumption of Thailand increased approximately 5.2 fold, from 7,782 to 40,130 gigawatt-hrs. (Gwh)[2] (IEA, 1995). According to the Electricity Generation Authority Thailand (EGAT, 1997), the consumption of electricity is currently growing at more than 14 percent per year. Last year, EGAT invested more than 1 billion US$ in additional power generation and transmission systems to meet the growing consumption for electricity in Thailand. It is likely that the consumption will continue to increase in the future.

The growing consumption for electricity in most developing countries, including Thailand, is underpinned by the growth in economic activity, per capita income, and population (IEA, 1995, CEC, 1993, Warr, 1993, and Ross and Thadaniti, 1993). The growth in economic outputs underlined by rapid expansion in industrial activities is reflected in the share of the industrial sector in electricity consumption. IEA (1995) reported that the electricity consumption of the industrial sector in Thailand increased from 4,765 gwh in 1975 to 17,687 gwh in 1990. In this period, the residential sector accounted for a lesser, although still substantial, share of Thailand electricity consumption. The consumption in this sector increased from 1,490 gwh to 8,088 gwh,

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[3] According to IEA (1995), calculations of electricity production and final consumption use the energy content of the electricity. Production of hydo-electricity uses the energy content at a rate of 1 gwh = 0.086 thousand ton. Calculation of production of electricity from oil, gas, and coal (lignite) uses the net calorific values). Net calorific value of oil is 7.31 barrels/ton. Net calorific value of lignite is 0.092 ton of oil equivalent per ton of lignite.

however, its contribution to the total consumption in the nation was fairly constant and varied from 19 to 25 percent throughout this period (Figure 3).

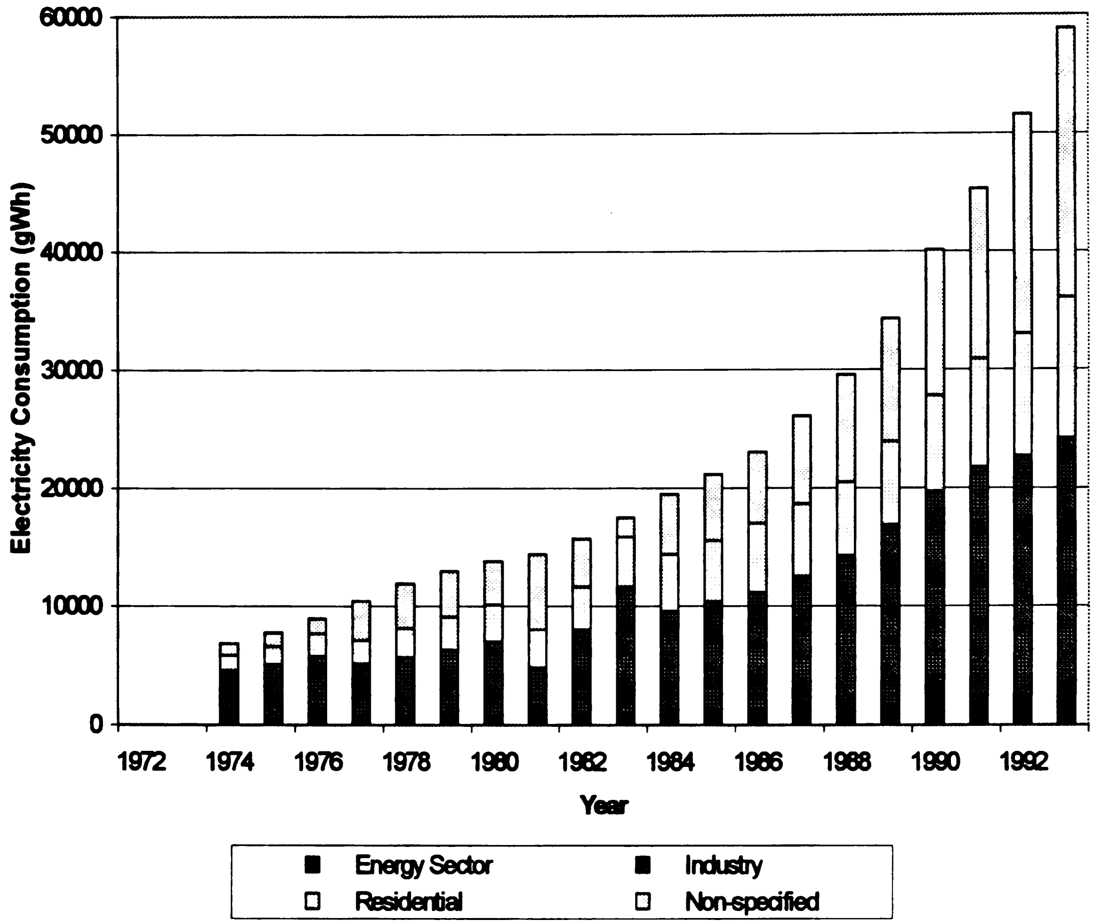

Figure 3: Contribution of Each End User to Total Electricity Consumption in Thailand (Source: International Energy Agency, 1995)

Note: Energy Sector: Electricity used by the energy producing industries, e.g. for heating, lighting and operation of all equipment used in the extraction process.

Industry: Include non-ferrous metals, iron and steel industry, and non-specified industries.

Residential: All consumption by households.

Non-Specified: All other consumption

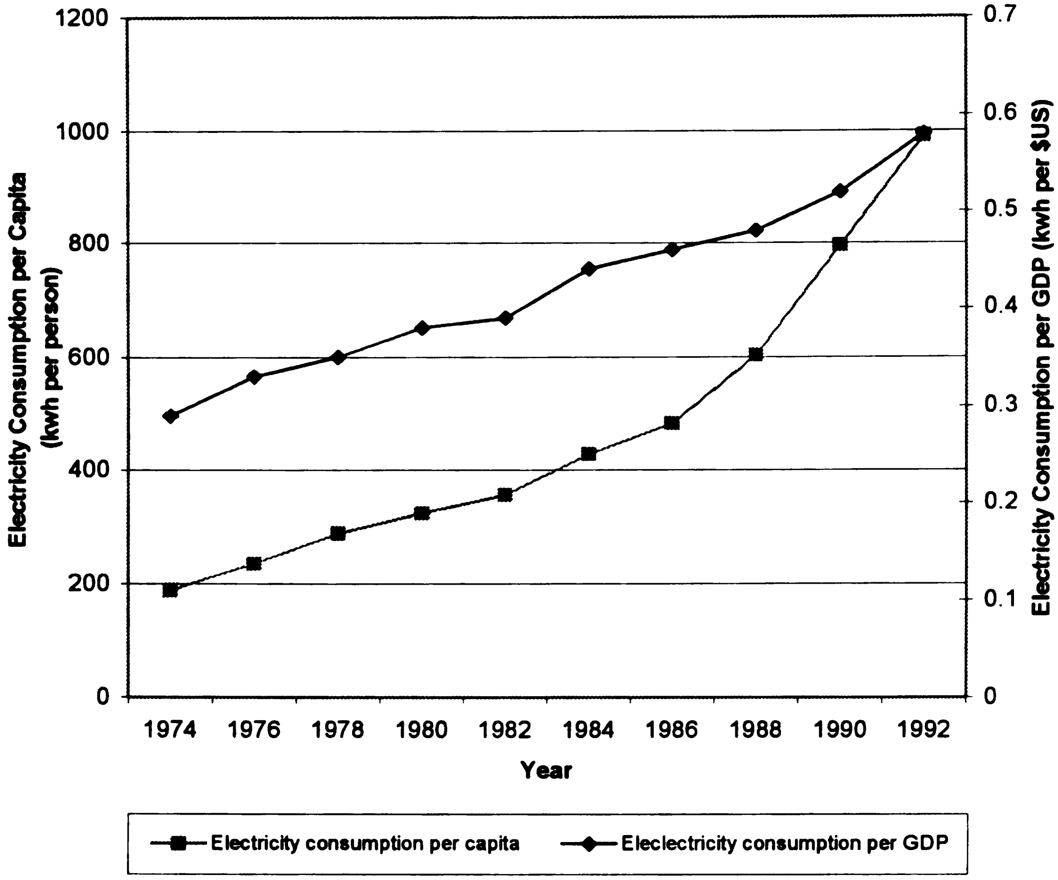

Figure 4: Electricity Consumption per Capita and GDP at Constant 1992 US$
(Source: Asian Development Bank (1992), p 501)

A specific explanation of the increase is not simple because the level and characteristic of electricity consumption in each household varies within the country, especially between urban and non-urban areas. Higher electricity consumption by households and utilization of electricity beyond subsistence and the use of electric appliances are related to the growth in per capita income and increasing urbanization. These two factors are highly correlated (OECD, 1994). According to the Asian Development Bank, ADB (1994), the per capita GDP of Thailand increased from $US 360 in 1975 to $US 1,527 in 1990. The electricity consumption increased in accordance with the rise of per capita income. IEA (1995) reported that Thailand electric consumption per GDP increased steadily from 0.31 kilowatt-hour (kwh) per $US in 1975 to 0.52 kwh per $US in 1990 (see Figure 4). The electricity consumption per capita also showed a similar increasing trend in those years. The consumption increased from 208 to 796 kwh per capita in both years respectively.

Changes in residential electricity consumption are also reflected in electricity sales. According to OECD/IEA (1997), the level of total residential sector sales per capita depends upon both the level of urbanization and the level of electrification. For countries whose electrification rates begin to approach saturation, growth in residential electricity use will mirror the growth in the saturation rates for appliances. The saturation rate for an appliance is calculated as the percentage of total households that own one or more of the appliance. These rates depend upon the rate of economic growth and per capita income. An increase in electricity consumption has also resulted from a rural electrification program in Thailand implemented between 1986-90. As a result of this program, 93 percent of villages in Thailand had access to electricity compared to 66 percent in 1985 and 34 percent in 1980 by the end of 1993 (ADB, 1993). The electrification program is accompanied by increased use of electric lighting and appliances. It is likely that electric appliance ownership rate for households in Thailand will increase in the future since these appliances could become available at lower cost and urbanization is expected to increase.

The growth in economic development in Thailand has been accompanied by an increased percentage of the population living in urban areas. According to the United Nations (1993), the percent urbanization in Thailand grew from 15.1 to 22.2 percent from 1970 to 1990 (Figure 4). The projection of the United Nations for percent urbanization in Thailand is as high as 48.6 percent by the year 2025, assuming that there will be no inverse trend. A study conducted by OECD (1994) on energy in developing countries concluded that electricity consumption in urban areas was higher than for rural areas in most developing countries. This also applies in the case of Thailand.

The growth in electricity consumption in the Thailand residential sector has also been encouraged by energy pricing policies that have kept the electricity price below its economically efficient level. The average residential price of electricity based on constant 1992 prices was approximately 0.072 US dollars per watt-hour in 1975 and increased to 0.08 US dollar per watt-hour in 1992 (Asian Development Bank, ADB, 1994).

The last and very important factor that contributes to the growth of electricity consumption in the residential sector in Thailand is the rise of population. Like other resources, the consumption of electricity increases as the population increases. Although the population in Thailand increased by 16.4 million people or 39.5 percent from year 1975 to 1992 (ADB, 1994), the residential electricity consumption increased by approximately 588 percent during the same period (IEA, 1995) (see Figure 5). Currently, the population in Thailand is 60 million and is projected to be 72 million by the year

2025 (National Economic and Social Development Board, NESDB, 1997). The average population growth rate of Thailand decreased from 3.08 percent during 1965-1970 to 1.32 percent during 1985-1990. The recent rate is relatively low compared to neighboring countries. The average population growth rate for these countries during 1985-1990 was 2.58 percent for Laos People's Democratic Republic, 2.63 percent for Malaysia, and 3.12 percent for Cambodia. While Thailand successfully decreased the population growth rate, the Thai government still viewed the total fertility rate and crude death rates to be too high and unacceptable (The United Nations, 1995). The decrease of population growth rate (see Figure 6) is due to the success of the National Family Planning Program that reduced the population growth rate from 3.0 percent in 1970 to 1.3 percent in 1990.

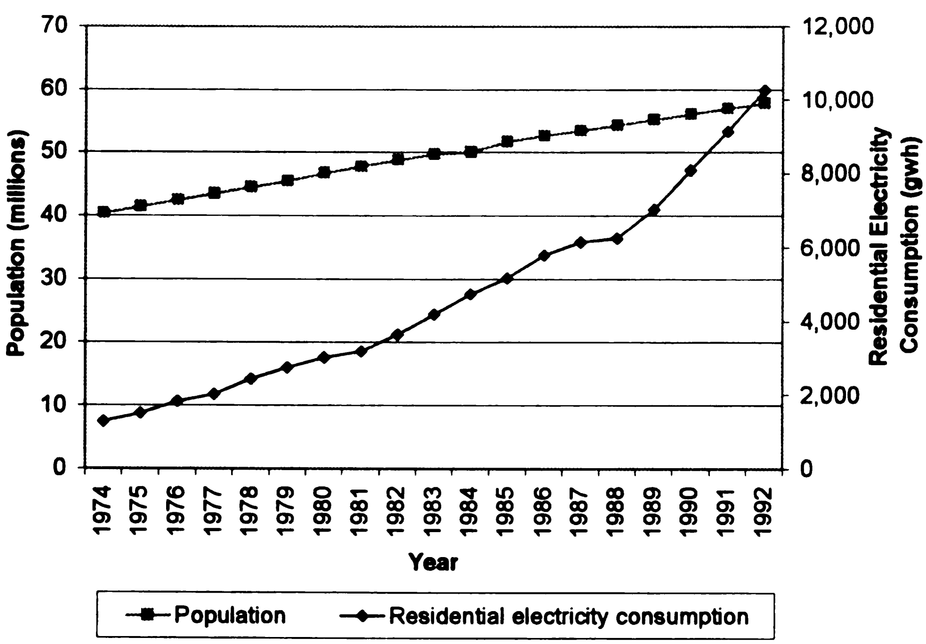

Figure 5: Thailand Population and Residential Electricity Consumption: 1974-1992

(Source: Asian Development Bank, 1994 and The United Nations, 1993)

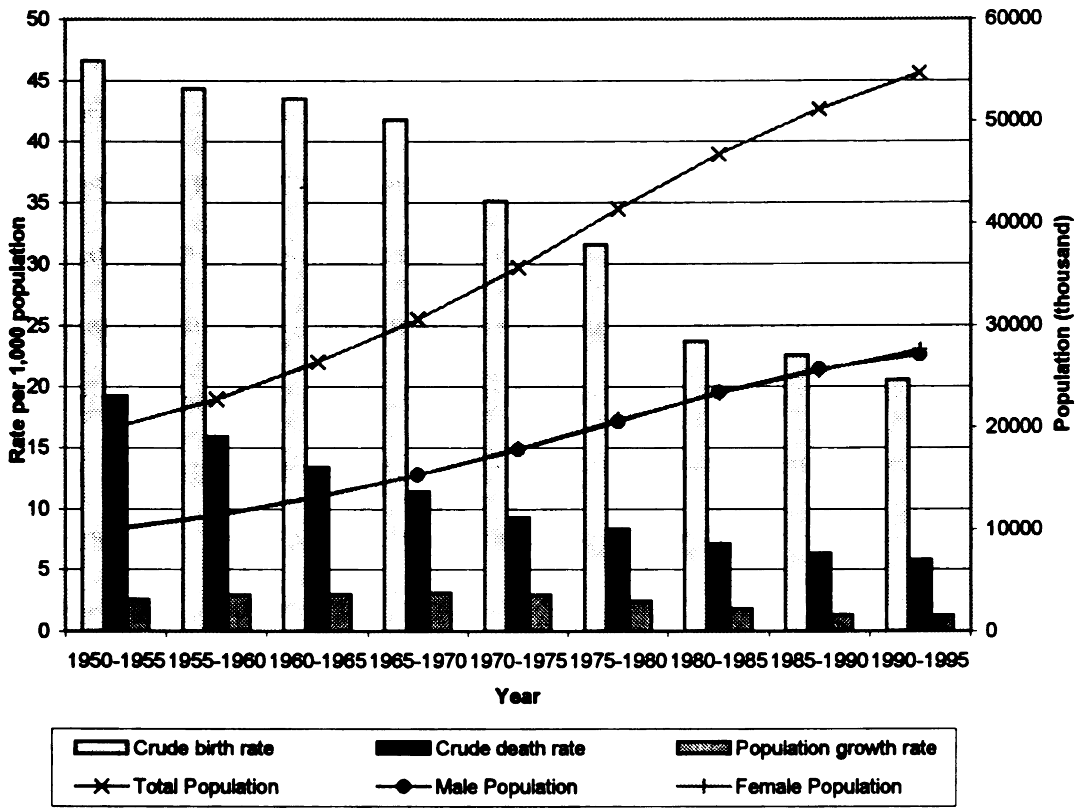

Figure 6: Thailand Growth, Birth, and Death Rates, 1950-1995
(Source: World Population Prospects: The 1992 Revision, The United Nations, p.624)

According to the 1985 population estimates by Mason, Phananiramai, and Poapongsakorn (1993) the structure of population in Thailand was composed of a large number of young people (age from birth to 14) and a small number of older people. The age composition of Thai population in that year had a triangle shape. Since the population growth rate has decreased, it is very likely that the future population pyramids of Thailand will have a narrower base because of a decreasing number of young population and an increasing number of adults and middle-aged population.

The last population component that is more important at the local or provincial level is the composition of population in urban and non-urban areas. In Thailand, this composition has changed over time. According to the most current Population and Housing Census (1990), 81 percent of the population in Thailand live in rural areas. Historical migration trends indicated an increasing number of people moving from rural areas to urban areas and a decreasing number of people moving from urban areas to rural. However, migration from rural to rural areas still dominates other streams. The stream that effects electricity consumption the most is the urban designation migration stream because urban migrants have the potential to earn more income and to purchase and use electric appliances. The census (1990) on ownership of household appliances also indicated the growing ownership of electric appliances in urban households.

1.4 Problem Statement and Justification of the Study

As electricity consumption in Thailand continues to increase, energy planners need an analysis tool to facilitate long-range planning to prepare for the increasing consumption. A tool such as modeling is especially beneficial for a country with limited resources such as Thailand because a model allows us to better understand variables and their linkages in the model. It also provides estimates of key variables based on our best information and assumptions formulated in the model. For planners to benefit the most from the model developed in this study, there are four important characteristics of the model that need to be taken into consideration: 1) level of detail, 2) flexibility, 3) incorporation of opinions of planners or experts, and 4) range of outputs

Firstly, determination of the level of detail of a model is one of the most critical decisions. Long-term energy planning requires a thorough, detailed understanding of energy consumption dynamics, at a detailed level of sectors, sub-sectors or end uses. This study pertains to only one sub-component of the entire energy planning process. This study estimated the consumption for one resource (electricity) by one sector (residential) of one country (Thailand). Thailand is chosen as the study area because of the affiliation of the author with the country and because of the country's critical need for prudent energy planning in the future.

The conventional approach to energy planning in Thailand is a macro-level approach. The projections performed by this approach are usually performed by extrapolation of the historical trend. At the macro level, energy consumption can correspond to the amount of energy required in a country or to the amount of energy supplied to the consumers. While macro-level studies allow us to understand the general long-term trend in terms of energy consumption, this approach does not provide detailed estimates of the *timing* or *spatial distribution* of changes in energy consumption within the country.

Rather than using the aforementioned macro-level approach, this study focuses on the detailed modeling of the residential electricity usage in Thailand at the provincial level. The model developed in this study looks at the role of technology, that is, unit consumption of electrical household appliances. The model also tries to identify the technical improvements incorporated in new equipment from the effects of energy savings measures in the existing equipment. The economic role incorporated into the model is the change of consumer consumption behaviors in terms of acquiring electric household appliances (appliance saturation rate) and the appliance usage. The model also considers the social factor by including the impact of population change in different geographical areas of the country into the model.

Electricity consumption is directly related to number of households and appliances owned and used in households. Estimation of electricity consumption at the provincial level based on future trends of changes in family size and appliance ownership in urban and non-urban areas specific to each province should give us better estimates of total household electricity consumption in each province. Estimates at the provincial level from this study will allow electric planners to foresee the change of the consumption pattern at a level that was not possible in the past. The information at this level is very important for long-term planning for electricity distribution and transmission systems. This is because expansion or establishment of new substation or transmission line into an area with high future consumption or an area with high potential increase of the consumption is a time consuming and costly process. This is especially true when new systems are required in a remote area where other infrastructures such as roads are not adequate. The electricity consumption estimates can also be used as an indication of expansion or urbanization of a province.

Secondly, flexibility of a model refers to the ability for the model to handle special circumstances or exceptions that apply to some provinces. This means that the model has to be developed in a manner to handle these cases without difficulty. There were circumstances that criteria formulated in the population and residential electricity models did not apply to all provinces. An example is the calculation of net migrants from within province migration stream. Because of the lack of data on net migration at the provincial level, the national net migration rate was supposed to be used in the calculation of the net migrants for all provinces. The national rate could not be applied to all provinces because this may result in negative population of non-urban areas in provinces with low non-urban population. Therefore, three criteria were established to handle this situation (see the detail of the criteria in Chapter III under Migration).

Thirdly, involvement of planner or expert opinion in the model is a critical step for any model to be accepted by decision-makers and planners. They are the ones who have authority in making final decisions. Expert opinions referred to judgements of demographers and energy planners who know the past and can assess the future trends of population and electricity variables in the model developed in this study. Expert opinions utilized in this study were judgements of the author based on discussions or reading materials related to population and energy trends in Thailand. In this study, experts assessed future trends of each variable in the models. Trending method was used to assess future estimates of the variables based on percent change of these variables from the current estimate. A trending method is a reasonable method to communicate with experts or planners about future changes because planners are more likely to foresee future changes in terms of percent rather than complex mathematical function. With the ability to incorporate expert opinions and be mathematically flexible, this model can be used to make informed decisions that are responsive to the rapid changes taking place in Thailand

Fourthly, a single estimate of residential electricity consumption is not as meaningful as a range of the consumption estimates (low and high consumption which were calculated as fraction of base consumption). The electricity consumption model was designed to run under different "scenarios", with a scenario defined as a particular set of assumptions or input parameters of the model. A low (conservative) scenario was defined to estimate the lower level of electricity consumption. This scenario includes, for example, low usage and power input of electric household appliances. Alternatively, a high-end scenario was defined and run using the upper ranges of the input variables and assumptions. The low and high estimates provide the potential range of electricity consumption that could be expected. Ultimately, policy makers can then assess this range of potential consumption and determine acceptable response levels and the criteria necessary to achieve such levels. By defining different scenarios, the model can be used to assess the impact of various policy options (such as family planning, and consumption side management) on the projected consumption for electricity.

In summary, the development and use of detailed models of sub-components, such as developed in this study, should provide a better understanding of each component, and consequently, a better understanding and management of the entire energy planning process. This model can be used as a framework for energy planning in other sectors. Moreover, the underlying detailed population model can be used as a basis for modeling other resources used in the residential sector. Better understanding and modeling capabilities should lead to pro-active management, not reactive management. Ultimately, this is the basis and the justification for this research; better understanding leading to more effective management of resources.

1.5 Objective of the Study

There are two objectives in this study. The first objective, which is a global objective or a broader goal of this study, is to build a framework for modeling and projecting consumption of energy resources in a manner that is both dynamically and spatially detailed and mathematically flexible. The residential electricity model in this study was developed such that it can be used as a framework for estimating consumption of other energy resources in other sectors.

The second objective, which is a specific objective of this study, is to estimate electricity usage by the residential sector in Thailand from 1999 to 2019. Based on the estimates of potential range of the future household electricity consumption, policy recommendations were made for energy planners on supply and consumption of energy resources. Recommendations on options for energy fuel resources were made for the supply side. For the consumption side, also known as the demand side management (DSM), policy options to manage the increasing future electricity consumption in the residential sector by seeking reduction of electricity consumption through the use of more efficient appliances were made.

1.6 Overview of the Study

Residential electricity consumption is largely a function of the number of households and the saturation rate of electrical appliances within the household. It follows, therefore, that the modeler must be able to estimate the future number of households in Thailand. Since household numbers are a function of total population, a detailed population model is necessary. Note that because average household size has decreased over time, there is not a 1:1 correlation between household numbers and population. Population at the country level is largely a function of the age-specific and gender-specific birth and death rates. Because this study is done at the provincial level, however, migration between provinces must also be considered in the population model.

Because of the differences in electrical appliance saturation rates by urban and rural households, it is also necessary to categorize and model the population and households as either "urban" or "non-urban". Migration must also explicitly consider migration patterns in four streams: rural-rural, rural-urban, urban-rural, and urban-urban.

The modeling technique employed in this study is based on the hypothesis that historical trends combined with expert opinion of future changes in these trends can be used to accurately assess the future. The general situation is to start with the most current estimate of some variable, (for example, age-specific birth rate) and then "trend" this variable into the future based on expert opinion, results of other studies, local knowledge, or educated assumptions. Note that the trend need not be linear or even conform to any mathematical formula. This methodology allows for the use of expert opinion and judgement in a simulation modeling setting; an important point as we consider the potential for use of this model by planners.

CHAPTER II

POPULATION MODELING: GENERAL DISCUSSION AND LITERATURE REVIEW

Chapter 2 consists of two sections: a review and discussion of population characteristics and trends of the Thai population and a discussion of population projections and modeling. The first section provides historical and current information on five characteristics of the Thai population: fertility, mortality, migration, population growth, and population distribution and density. The second section is divided into 2 subsections. Population projection and modeling in general is discussed in the first subsection and a discussion specific to Thailand is in the second subsection.

I. GENERAL DISCUSSION ON POPULATION MEASURES, CHARACTERISTICS AND TRENDS OF POPULATION IN THAILAND

2.1 Fertility

Fertility can be measured in many ways as summarized by Davis (1995) and Saunders (1988). This subsection describes three fertility measures that were used in this study. The first measure is the most widely used and most easily understood measure: the Crude

Birth Rate (CBR). CBR is the number of live births in a year divided by the total population in the same year multiplied by 1,000 to eliminate decimals. The second measure, called age-specific birth rate, is a rate of birth calculated for women in a particular five-year age group. Age-specific birth rate is calculated as the number of live births by women in an age group divided by the number of women in the same age group multiplied by 1,000. An aggregation of age-specific birth rates is called Total Fertility Rate (TFR). TFR is the number of children an average woman can be expected to have during her reproductive years. The formula for the TFR calculation is:

$$TFR = 5\ [\sum_{i=15-19}^{i=45-49}(b_i\ /\ Pf_i)]\ /\ 1000$$

Where:

5 is number of years in age interval

b_i is number of births born during the year to women in age group i

Pf_i is number of women in age group i

The fertility rate in Thailand declined rapidly in the 1980s and declined more slowly in the 1990s (Figure 7). More recently in 1997, the CFR was 15.6 per 1,000 population (Institute for Population and Social Research, Mahidol University, 1997). There are three explanations for the declining fertility trend in this country.

The first explanation, which probably has made the greatest contribution to the declining CFR, is related to population policy in Thailand. The Thai government developed the National Family Policy in 1968 and implemented family planning programs in 1970. The goal of the policy was to reduce the rate of population growth from 3.0 to 2.5 percent from 1972-1976, 2.5 to 2.1 percent from 1977-1981, and to 1.5 percent from 1882-1986 (United Nation, 1980). As a consequence of the success of the programs, the CFR declined rapidly.

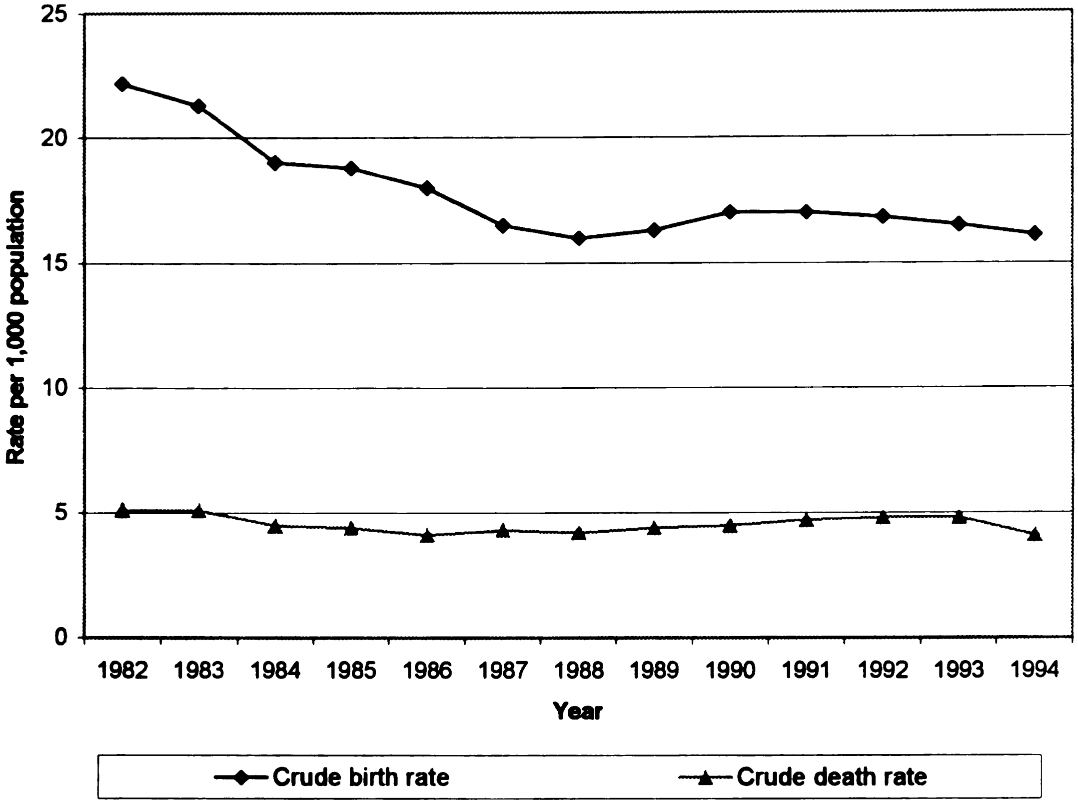

Figure 7: Thailand Crude Birth and Death Rates: 1982 – 1994
(Source Public Health Statistics, Ministry of Public Health)

The second explanation involves land availability and the change in the demand for children. Thailand has undergone profound socioeconomic change during the last 30 years. Changes taking place tend to interact with and reinforce one another. Rural agrarian lifestyle in the country has gradually been replaced by a modern urban lifestyle. The proportion of household members engaged in agriculture has decreased. Consequently, the size of land holdings has not changed, averaging about 3.5 hectares per person in both 1963 and 1983 (Chamratrithirong and Debavalya, 1987). The rate of expansion of agricultural holdings has also slowed because most of the usable new agricultural land in Thailand was occupied by the end of 1980, except in parts of the south (Whitaker, 1981). Since activities in the agricultural sector have been reduced, the demand for farm labor and correspondingly children has been reduced as well. The desired family size decreased from 3.8 in 1970 to 3 in 1984 at the national level, 3.8 to 3 for rural families and 3.6 to 2.7 for urban families in the same years (Chamratrithirong and Debavalya, 1987). The results of group discussions conducted by Chamratrithirong and Debavalya (1987) also indicated that large families are now increasingly perceived as an economic burden.

The third explanation concerns education and the role of women in the social context. Generally speaking, the role of Thai women during the past thirty years has changed from housewife to working woman. Fertility studies have demonstrated that in most developing countries reproductive behavior is related to female education levels and the employment of women in the formal sector (United Nations, 1992). This seems to apply to the case of Thailand, however, in lesser extent. In the past, Thai women did not have a chance to acquire education because females were prohibited by culture to go to schools that were generally run by monks. Universal compulsory education in Thailand was enacted into law in 1921. However, it was not until 1980 that compulsory education was implemented and all females had to attend schools. Education opens doors for work opportunities in the formal sector for women. Work and education tends to delay marriage. Age at first marriage of Thai women has traditionally been moderately late compared to other developing countries (Chamratrithirong and Debavalya, 1987). Chamratrithirong and Debavalya (1987) stated that the contribution of age at marriage to the reduction of fertility in Thailand was modest although the age at marriage of Thai people has increased somewhat over the last few decades. The later study conducted by Guest and Chamratrithirong (1992) concluded that a woman's level of education has been shown to be strongly and inversely related to fertility in Thailand. They cited the study conducted by Retherford et al (1979) and reported the TFR during the period 1965-69 for women with some primary school education to be 6.5 births per woman and for women with some secondary school to be 2.7 births per woman. The 1980 and 1990 census also showed that differentials continue to exist but the differentials were much smaller.

The analysis of fertility or reproductive behavior can be done in greater detail when the age-specific fertility rate is available. According to Guest and Chamratrithirong (1992), changes in fertility from the period 1965-69 to 1975-79 occurred for women of all ages. They discovered that in the period 1965-1969 the highest fertility rates occurred in women aged 25-29 followed by women aged 30-34. In the period 1975-1979 this phenomenon shifted to women aged 20-24. Public health statistics (1994) showed that women aged 20-24, followed by women aged 25-29 in the period 1990-1994 had the highest fertility rate (Figure 8). The absolute fertility rate declined from 1965-69 to 1975-79 in women aged 30-34. Guest and Chamratrithirong (1992) discovered that women aged 25-34 were responsible for close to 90 percent of the total change in fertility during that period. This age group should be the focus group for family planners.

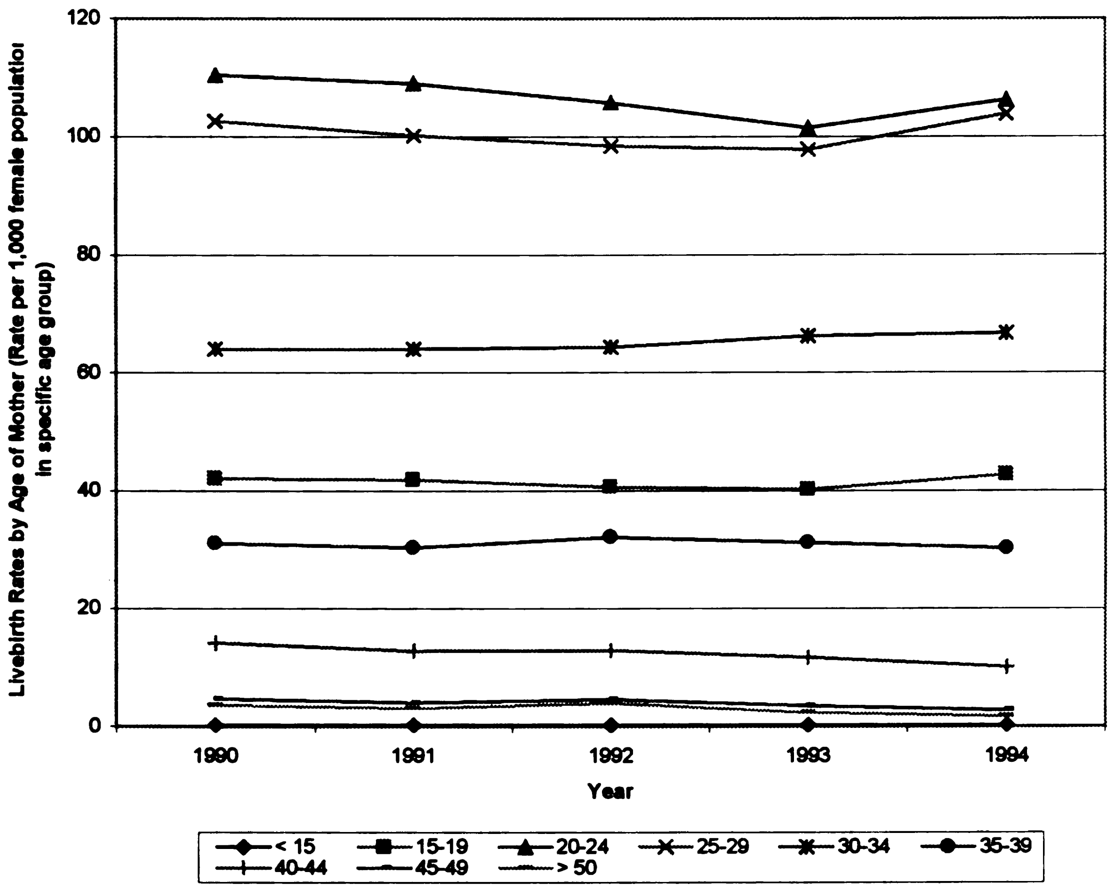

Figure 8: Thailand Age Specific Birth Rates: 1990 - 1994
(Source Public Health Statistics, Ministry of Public Health)

In terms of the fertility rate for urban and rural women, not many studies have been conducted. According to Knodel and Prachuabmoh (1973), the fertility rate difference between rural women and those from the provincial urban areas were noticeable for women in all childbearing age groups between 1965-1979. The greatest difference was found in women aged 30-34 in this period. The more current study conducted by Guest and Chamratrithirong (1992) concluded that the fertility differentials across urban/rural place of residence as well as socio-economic groups have been reduced or have almost disappeared.

2.2 Mortality

The number of deaths can be described in various ways. A first measure is the Crude Death Rate (CDR). It is the number of deaths occurring in a population during a year divided by the number of persons in the population and multiplied by 1,000. A second measure is the age-specific death rate. This is a measure of the number of deaths during the year of persons in a five-year age interval divided by the number of people in the same age interval.

In Thailand the CDR declined from 5.1 to 4.9 deaths per 1,000 population in 1982 and 1993 respectively. This change was relatively small compared to the decline from 19.2 per 1,000 population in 1950-55 to 6.3 per 1,000 population in 1985-90 (United Nations, 1992, see Figure 6 in Chapter 1). The high CDR in the past could result from inadequate health care services and lack of health education. Theoretically, the improved economy of a country should increase the quality of life of people in the country. In other words, increased individual income should result in better health status and prolonged life.

According to NESDB (1985), The Thai government expenditure on health services per capita increased by 151 percent during the period 1976-1984. NESDB also found that individual consumption expenditure per capita on personal health during the same period had increased. The more current statistics on environmental sanitation from the Public Health Department (1994) reveals a better quality of life as there were increased numbers of safe drinking water sanitary wells, households with pest control, and households with improved food sanitation. With the improved quality of life and more government spending on public health programs, it is likely that the death rate in Thailand will continue to decline gradually.

Differences in death rate were found between Thai males and females in all age groups in the period 1990-94 (see Figure 9) with males having higher death rates in all age groups. The difference was more than 50 percent in age groups from 15-19 to 45-49. The difference was highest in age groups 20-24 and 25-29 (80 percent). The death rate difference of males and females was down to 18 percent in the population age group 70 years and older. A possible cause of death rate differences between males and females in this period can be attributed partly to life styles. In Thailand, males have a higher tendency to be involved in high-risk activities that could lead to death, such as smoking, drinking and violence.

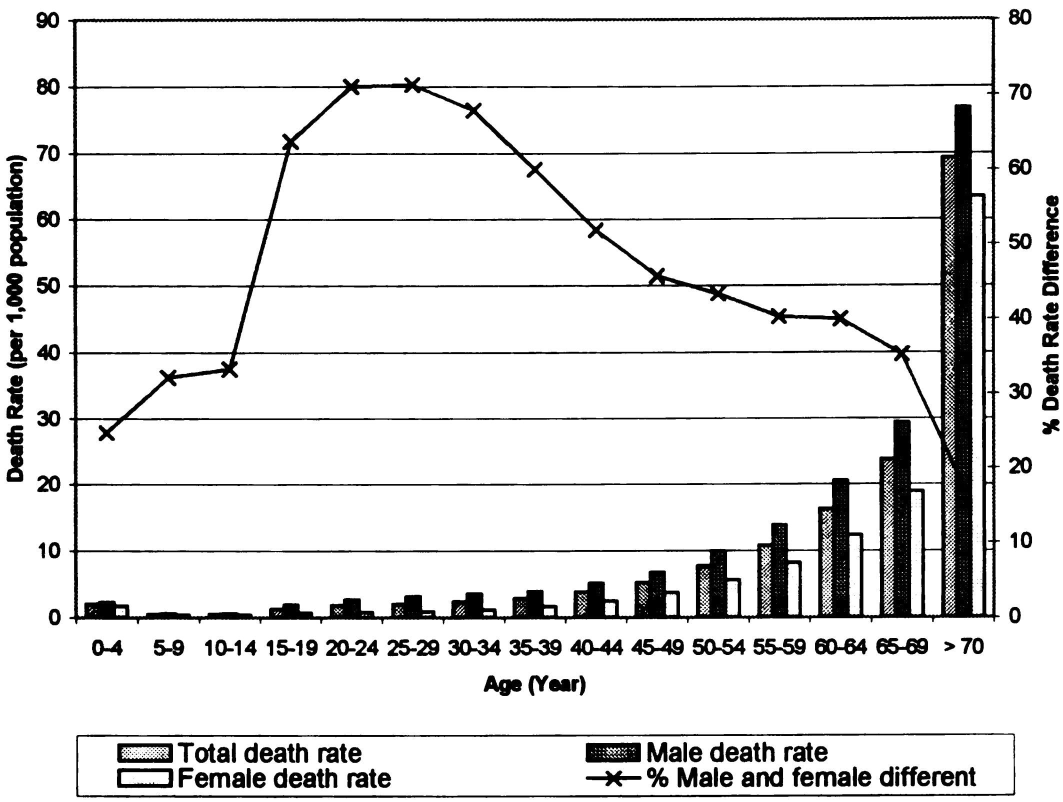

Figure 9: Thailand Death Rate by Sex and Age: 1994
(Source Public Health Statistics, Ministry of Public Health)

Regarding death rate by residence, studies in this area in Thailand are very limited and not up to date. However, the relationship between death rate and residency established in the past can be utilized to project future trend. Porapakkham (1986) studied differences in death rates between urban and rural Thai from the pattern of utilization of health resources and accessibility to health care service in terms of travelling time and cost to visit health services. She conducted a survey in 1979 and concluded that the population in urban areas, where modern health facilities were available and accessible, was three times as likely to use private clinics, hospitals and government hospitals as those in rural areas. She also discovered that rural people are often more likely to use drug stores for self-treatment. The smaller proportion of the rural population utilizing hospitals reflects the unavailability and inaccessibility of these facilities in the past. In the future, it is likely that the death rate of the Thai population both in urban and non-urban areas will continue to decrease gradually because of the government efforts to improve education and living standards, increase spending in health care programs, and support technological advancement of the country.

2.3 Migration

This section describes migration streams by regions, sex and age group, and urban and non-urban status of migrants. In Thailand, migration streams by region refer to a change of residency of persons to the current province of residence from other provinces within or outside the region since the time of the last census. Figure 10 illustrates the overall picture of migration at the regional level between 1980 to 1990 in Thailand. According to the most current census (1985-90), regions ranked by net migrant rate from highest to lowest were the Bangkok, Central, Northeast, North, and South. Only Bangkok and the Central region experienced a net gain in this period. The net migration rates were 6.7 and 2.6 per 100 population for Bangkok and the Central region respectively. The net migration rates for regions that experienced net loss were 3.2, 9.2, and 0.2 per population for the Northeast, North, and South region respectively.

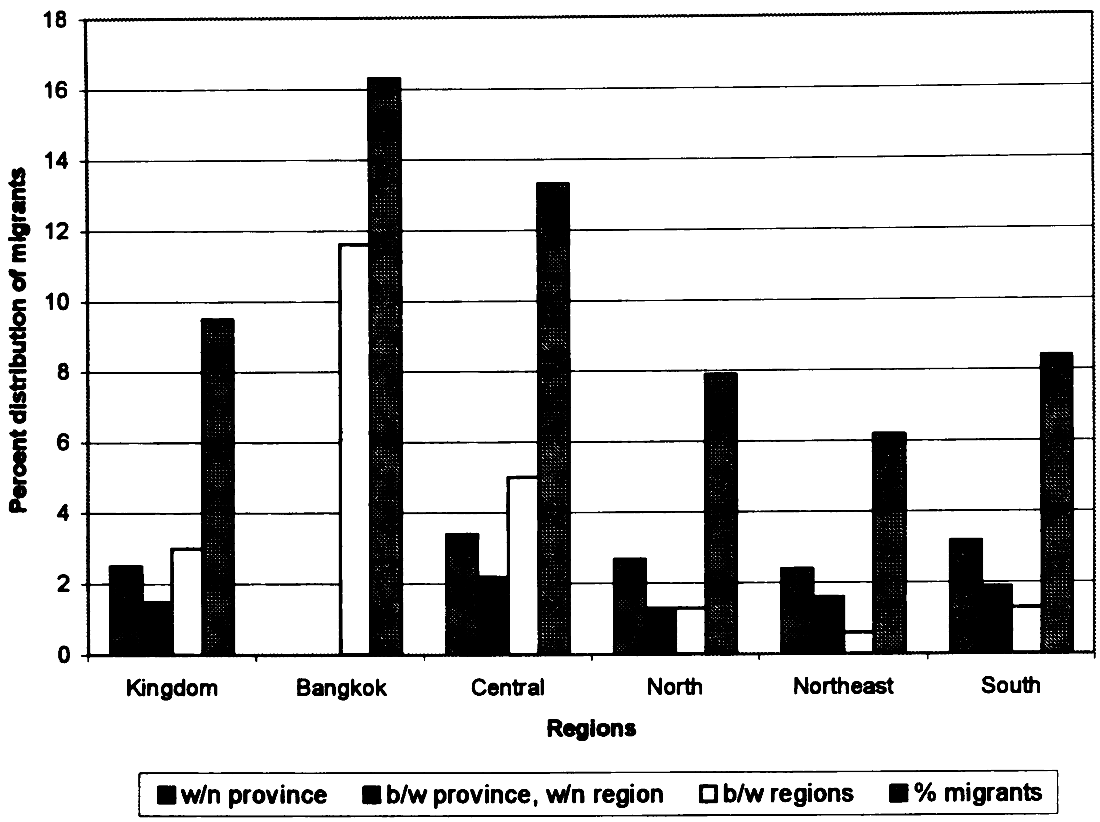

Figure 10: Thailand Migration Distribution by Regions: 1990
(Source: National Statistical Office)

The Northeast region experienced a net loss in population during the last 40 years. The net loss was due to the high number of people migrating out of this region. The Northeast has the largest population in the country. A lack of income and employment opportunities in much of this region contributes to the high migration in this region. The North region experienced a net gain between 1955 to 1970. This period was the peak time for logging in the country, particularly in the North region. Job opportunities in this region in that period also included farming. After logging was banned 1975, the North region lost its importance and experienced a net migration loss for the first time to

Bangkok and the central region between 1985-1990. In this period, the number of total migrants from the North and the Northeast region decreased. The explanation for this was the decline in the economy due to the oil crisis in 1979. Because of the slow economy during the oil crisis, job opportunities in the industry sector, located in the central region and Bangkok, were also diminished.

Bangkok has always experienced a net gain of in-migrants. Bangkok experienced a net gain of 67,045 and 372,200 net migrants in 1955-60 and 1985-90 respectively. The increased migration to Bangkok illustrates the economic and political dominance of Bangkok. As argued by Pejaranoda, Samipaporn and Guest (1995), the Thai government which have favored the urban dwellers, particularly those living in Bangkok, is believed to contribute to the increase of Bangkok attraction to migrants.

After experiencing a large net loss from 1955 to 1975, the central region has benefited from the economic growth of Bangkok and has experienced a net gain after 1975. This region now absorbs some of the migration stream that would otherwise be directed to Bangkok. As a result, the central region experienced the six-fold increase of the net gain compared to Bangkok in 1985-1990.

The South region has experienced the lowest net migration rate compared to other regions. Being geographically isolated from other regions, this region has the least migrants since the level of migration tends to decrease as travelling distance increases. However, this region experiences a high proportion of movement occurring within the region. Few people migrate out of the region because the job opportunities in this region are rather high (from fisheries and aquatic farming, mining, and rubber plantation and industry). The income level of the population in this region is also relatively higher than income levels in other regions.

The migration level in Thailand seems to be the higher within region than between regions. In some regions, half or more of the migrated population moved within or between provinces located in the same region. This is normal, because migration for shorter distances involves less resource in terms of time and cost.

Economic reasons and employment opportunities are not the only reasons for the Thai population to migrate. There also are social reasons contributing to migration such as education and marriage. Marriage-associated migration is influenced by the Thai cultural norm that men move into their wife's parent's household upon marriage. However, no study has been carried out to determine the contribution of the marriage-associated migration to the overall migration rate in Thailand. Married women (and children in some families) also have to accompany husbands to new locations in the case of a job relocation.

The other way to observe migration is to look at the urban and non-urban residency status of migrants. This way, migration streams are classified into urban-urban, urban-rural, rural-rural, and rural-urban. The dominant stream in Thailand has always been the rural-rural one. Nevertheless, the percent of migrants in this stream declined -- from 62.6 to

40.9 percent in the period 1965-1990. Rural-urban is ranked the second highest in terms of percent migrants. The trend of percent migrants in this stream increased from 10.5 to 18.4 percent in the same period. Percent urban-urban stream increased from 8.9 percent between 1965-70 to the peak of 17.2 percent between 1975-80 and declined to 13.5 percent in the period 1985-90. The migration in the urban to rural stream also increased from 9 to 10.5 percent between 1965-70 and 1985-90 accordingly (Table 1).

Table 1: Migration Streams of Migrants: 1965-1970, 1975-1980, 1985-1990

Migration stream	Percent Migration		
	1965-1970	1975-1980	1985-1990
Population age 5 and over	100.0	100.0	100.0
Non-migrants	88.4	92.4	92.0
Migrants	11.6	7.6	8.0
Migration Streams			
Urban-Urban	8.9	17.2	13.5
Rural-Urban	**10.5**	**14.3**	**18.4**
Unknown-Urban	3.6	3.3	4.1
Total migrants with urban destination	23.0	34.8	36.0
Rural-Rural	62.6	52.0	40.9
Urban-Rural	**5.4**	**9.4**	**12.6**
Unknown-Rural	9.0	3.8	10.5
Total migrants with rural destination	77.0	65.2	64.0

(Source: National Statistical Office, 1993 in Pejaranonda, Santipaporn, and Guest, 1995)

Explanations for changes in each migration stream over time in Thailand vary depending on the type of stream. Pejaranonda, Santipaporn, and Guest (1995) provided four reasons for migration in the rural-urban stream. The first reason is related to new employment opportunities that are centered in urban-based service and manufacturing industries. Since the fifth National Economic and Social Development plan, the Thai government utilized the urban-based development strategy to promote their economic development. This created job opportunities and increased migration to urban areas. The second reason cited was the reduction of suitable land for agriculture. The traditional means of increasing agricultural land by extending the areas under cultivation was no longer an option. Therefore, the opportunities for employment in the agricultural sector declined. This problem took place about the same period that mechanization in agriculture became more common. The third reason is that the increased level of education of the population has made aspirations for employment in non-agricultural sectors greater. Moreover, the income in sectors other than the agricultural sector (urban areas) has risen faster than agriculture (non-urban areas). Lastly, expansion of urban boundaries increases the number of places categorized as urban. The expansion of urban[4] boundaries increased the number of municipalities, which were generally designated by government agencies as urban areas, from 707 municipalities in 1980, to 843 municipalities in 1990.

In the urban-rural migration stream, Pejaranonda, Santipaporn, and Guest (1995) also provided three explanations for the change of residency from urban to rural areas. The first explanation is that some of the migrants in this stream are the return migrants from

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[4] There is no official definition of urban or rural in Thailand. Thai government usually designates municipality as urban and non-municipal as rural. There are three types of municipality: muang, nakorn, and tambon municipalities. A muang municipality refers to a town that has population at least 10,000 persons and an average density of 3,000 or more per square kilometer and revenue base sufficient to carry out municipal functions. A nakorn municipality requires a population of 50,000 persons and an average density of 3,000 or more per kilometer and sufficient revenue base. There are no specific criteria for desingation of a tambon municipality. They are established by decree (Pejaranonda, C., Santipaporn, S., and Guest, P., 1995)

rural to urban areas. These migrants are those who leave the rural areas to work in urban areas and then return to the original place of residence after the work is finished. The second explanation contributes to the increased cost of urban land. This forces people to relocate to the rural periphery of urban places and commute to work. The third explanation involves rural development policies of the Thai government. These policies promote the transfer of government employees to work in rural areas.

In terms of sex and age group of migrants, the probability of migration for both males and females in Thailand has not changed during the period 1955-1990 (Figure 11). The highest migration in Thailand in this period was for young adults. The percent migration of the population aged 20-24 and 25-30 were more than any other age group. This applied to both males and females. The concentration of migrants was greatest in both sexes aged 20-24 and gradually declined except for males in the period 1985-90. About one third of total male migrants in this period were in the 20-24 age group. The percent male migrants in the next age group reduced drastically to 15 percent of the total male migrants. After this age group percent male migrants declined gradually as the age group increased.

The migration differential based on sex could also be observed from the sex ratio of migrants in each migration stream. According to the 1965-70 census, the migrant population of males dominated the migrant population of females in all streams. This pattern changed in 1980 and 1990 (Figure 12) when the number of female migrants was more than the number of male migrants in the urban designation areas (urban-urban and rural-urban). This pattern also continued in 1990. However, the ratio of female to male migrants in urban-urban stream declined by 2.45 percent. The sex ratio of female to male migrants increased in the rural-urban stream by 3 percent. The increase in female urban directed migration streams was evident for migration to Bangkok. Of every 100 female migrants to Bangkok there were 87 male migrants between 1985-90. The high proportion of young adult female migrants in Bangkok suggested a high demand for young females and high job opportunities in a sector that was selective of females. This sector included the service sector. Types of jobs in the service sector are housekeeping jobs, restaurant work, and jobs in the entertainment business. The demand for female labor was also high in some industrial sectors such as garment and textile industries, which were one of the fastest growing industries in the country. Some other industries where the nature of work does not require special sex related skills, such as electronics and computer industries also prefer women to men for various reasons (dependability and responsibility).

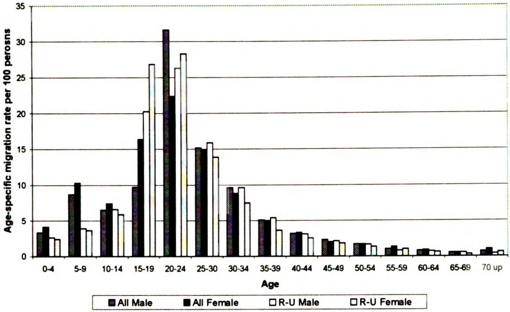

Figure11: Thailand Age and Sex Specific Migration Rate, 1990
(Source: National Statistical Office, 1990)

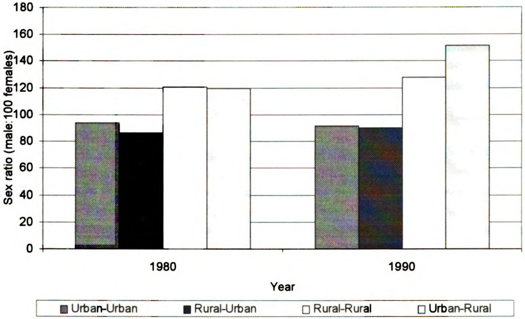

Figure12: Number of Male Migrants Per 100 Female Migrants by Migration Streams

(Source: National Statistical Office, 1990)

The proportion of male to female migrants was very high in the urban directed stream to the Central and Northeast regions. This is obvious between 1985-90 when the sex ratio in the urban-rural stream increased by 26.7 percent from the period between 1975-80. The increase of the sex ratio in the rural-rural stream was 5.7 percent during the same period. Migration to the Central and Northeast regions was dominated by males interested in work in agriculture in that period.

The age and sex structure of migrants in the past suggests that the young adult age group will continue to be the major migrant group. Previous trends based on the age and sex structure of migrants also suggest that the difference between percent male and female migrants will become smaller. Currently the sex ratio in all migration streams is female dominated (117.1 percent). It seems that this trend will continue, especially in the urban directed streams because the demand for female labor will continue to grow due to a policy to promote the tourism industry in the next decade of the Thai government. It is expected that tourism will bring 2-4 billion baht to the country (Siam Post, December 15, 1996). The rural directed streams will continue to be dominated by males because the nature of this work requires labor skills specific to men. Moreover, it is very likely that job opportunities in the urban areas will decrease due to the current economic crisis. There is high potential that a large number of migrants (rural-urban) will return to rural areas and migration to urban areas will decrease in the next few years during the recovery of the economy of the country.

2.4 Population and Growth Rates

The population growth rate refers to the change in the volume of population from natural increase (birth and death) and net migration when compared to population in a given a year. This number is usually expressed as the rate per 1,000 population per year or a percentage.

The population growth rates in Thailand declined steadily from 32.2 to 1.98 per 1,000 population in 1960 and 1990 accordingly. In the future, it is expected to continue to decrease more slowly because of lower fertility and mortality rates in the country.

2.5 Population Distribution and Density

According to the Institute for Population and Social Research, Mahidol University (1998), the population of Thailand in January 1997 was approximately 60 million persons with 18,981,000 urban population and 41,122,000 rural population. By region, there were 20 million people in the Northeast, 12 million people in the North, 13 million people in the Central region, 7.5 million people in the South, and 7.9 million people in Bangkok.

The overall population density in Thailand was about 106 persons per square kilometer as of 1997. The region that had the highest population density was the Central Plains with

118 persons per square kilometer. This was followed by the Northeast, the South, and the North with a population density of 113, 99, and 62 persons per square kilometer respectively. The population density of Bangkok Metropolitan was 3,758 persons per square kilometer.

II POPULATION PROJECTIONS

This section provides an overview of population projections and the modeling framework in general as well as the framework specific to Thailand. Projections for the population components are also discussed.

2.6 A Framework for Population Projection and Modeling

In this subsection, population, fertility, mortality, and migration projection methods utilized in the population modeling are described. This subsection focuses on the methods that can potentially be used and serve the purpose of this study.

Projection of population can be performed at different levels of detail using various methods. In general the base period population and projections of fertility, mortality, and migration are required to estimate future population. There are many techniques that have been used in population projection studies (Newell, 1988; United Nations 1992; and

Dave 1995). The most common ones are (1) mathematical extrapolation, (2) ratio, and (3) Cohort component.

2.6.1 Mathematical Extrapolation and Regression

This method is a rough approximation of future population by extension of a historical population trend into the future. The major assumption of this method is that the current rate of growth will continue in the future. This assumption can lead to unreasonable projections, especially if the projections will be carried far into the future and/or done for non-homogeneous areas. The extrapolation method involves extrapolation along mathematical curves such as straight lines and geometric and logistic curves. A least squares technique is often used to fit a curve through the known data points of the past. When regression is applied as a mean of extrapolating a trend, the future of unknown behavior variables related to population change can be integrated into a single expression.

Mathematical extrapolation in projection models is often used as submodel of the model, such as survival rates (equals to 1 – death rates) and fertility rates that may need to be projected into the future. The projection can be simply performed by the extension of the historical rate of change of the survival rate or fertility rate. More sophisticated regression methods can also be used for projecting these submodels.

The mathematical extrapolation method is useful when historical data is available and rough approximation is required, without detail, by age and sex. The model in this study performs projections of population by age and sex in urban versus non-urban areas for the 76 provinces of Thailand. Using this method for the fertility, mortality, and migration submodel at the provincial level is not possible because historical data of these parameters by age, sex, and urban versus non-urban areas in each province is not available. The non-linearity of components such as migration trend over time could not be dealt with insufficient accuracy using extrapolation or regression techniques.

2.6.2 Ratio Method

In this method the ratios or shares of a larger population for which a projection already exists are calculated to express the data. The past trends of the ratios is determined, projected, and multiplied by the projection for the parent population.

For the ratio method to be utilized in this study, it would require acquiring projection of population by age, sex, and urban and non-urban area at the regional or national level. The projected population would then be allocated to provinces based on the projection of the provincial, regional/national population ratios into the future. Although this approach seems straightforward and flexible, it is not the best approach to perform population projections for this study for two reasons. First, population projections at the regional or national level by age, sex, and urban versus non-urban do not exist in Thailand. Second, projection of national or regional population as well as the provincial ratio would have to be performed.

There is a possibility to use the ratio concept in this study for of the fertility and mortality submodel. Age and sex fertility and mortality rates specific to urban and non-urban populations are not projected for each province. The most recent historical data could be used to calculate the ratio of the age specific fertility/mortality rate for the province to the nation. The provincial age and sex specific fertility rate could then be calculated by multiplying this ratio by the projected national age and sex specific fertility rate. However, the statistical trending method is more appropriate to project births and deaths in this study because of the flexibility of the method and the ability to incorporate expert opinions into the model (This is discussed more in Chapter III).

2.6.3 Cohort-Component Method

The cohort-component method, also known as cohort-survival, deals explicitly with the fertility and mortality components of population change. The Cohort-component method takes into account the process of aging. It desegregates population into cohorts (i.e., population segments) of uniform age and sex. The projection is carried out based on the surviving members in each age group over time into the succeeding age group. The cohort-component model yields projections of future population size and its composition.

Changing population over time in relation to fertility, mortality, and migration is generally represented as the equation below:

$$P_1 - P_0 = F - M + NM$$

Where:

P_1, P_0 = the populations at times 1 and 0, respectively;

F = births during the period 0 – 1;

M = deaths during the period 0 – 1; and

NM = net migration during the period 0 –1

Davis (1995) summarized the cohort component model mathematically as will be described below and made the following assumptions. The population is divided into n male and n female cohorts. All cohorts other than the last of each sex consist of the specific population of an age group of m years. The 2n population cohorts projected m years into the future can be described algebraically. The cohorts projected m years into the future are calculated as:

$$M_1 = PM * \sum_{i=1}^{n} F_i * BR_i$$

$$F_1 = (1 - PM) * \sum_{i=1}^{n} F_i * BR_i$$

$$M_2 = M_1 * MS_1$$

$$F_2 = F_1 * FS_1$$

$$\vdots \qquad \vdots$$

$$M_{n-1} = M_{n-2} * MS_{n-2}$$

$$M_{n-1} = M_{n-2} * MS_{n-2}$$

$$F_{n-1} = F_{n-2} * FS_{n-2}$$

$$M_n = \sum_{i=n-1}^{n} M_i * MS_i$$

$$F_n = \sum_{i=n-1}^{n} F_i * FS_i$$

where:

PM = Proportion of male births.

$M_i F_i$ = Male cohort $_i$ and Female cohort $_i$, respectively;

MS_i, FS_i = Survival rates for male cohort $_i$ and female cohort $_i$, and

BR_i = Birth rate for female cohort $_i$

The Cohort component method relies heavily on assumptions made in the projection of various components. Projections of age specific fertility, mortality and migration rates for females and males in the area of study are required. This means that this method demands detail and a great amount of data. However, this method should provide more accurate projections since each component will be projected and evaluated separately. Additional variables related to each component can be included in the projection process.

The Cohort component method is often used as the main approach to performing population projections when age and sex are the major concern (Newell, 1988, and Davis, 1995). This technique is also often used with other techniques such as mathematical extrapolation and ratio techniques to calculate future births, deaths, and migration. This approach has been used by the U.S. Department of Commerce, Bureau of the Census and many local governments for population projections by sex, age, and race in local areas (Bureau of the Census, 1977). This study also considers the Cohort component method as the most appropriate method for projection since it handles population data by age and sex.

2.7 Population Projection in Thailand

The National Economic and Social Development Board (NESDB) is the central planning agency within the Office of the Prime Minister. The main function of the NESDB is to prepare the government's official statement on the direction of development for five-year periods. As part of the preparation of the national development plan the NESDB is responsible for projection of population of the country. The results from the projection are utilized in other development planning such as infrastructure, health services, and education.

During the course of preparing the population projections, the NESDB obtains population data from various agencies, but mainly from the National Statistical Office (NSO). The NSO is also a central agency within the Office of the Prime Minister and is responsible for conducting the population and household census survey every 10 years.

The NESDB utilizes the cohort component method to prepare a population projection at two levels: national and regional. Projection of urban and rural populations is also done, but only at the national level. The section below describes three population projections summarized from the study on integrating development and population planning in Thailand, conducted by the United Nations (1992). The projection results are not included in this section. Some of the results are presented and discussed in Chapter III in section 3.6 Discussion and Comparison of Projection Results.

2.7.1 National Population Projection

The NESDB prepared national population projections for the period 1980-2015 as part of the Seventh National Economic and Social Development Plan. The age and sex structure of the population was derived from the 1980 population and housing census data, adjusted for under-enumeration and age-misreporting. The NESDB prepared national population projections under three scenarios based on different assumptions regarding fertility and mortality change. These three scenarios were formed based on three fertility assumptions: high, medium, and low, and one mortality assumption that applied to all three fertility assumptions.

The NESDB used the time trend functions to fit the historical national age-specific fertility rate data obtained from the survey of population change, the longitudinal study, and the contraceptive prevalence survey. The resulting functions were utilized to project future age-specific fertility rates. After the age-specific fertility rates were obtained, total fertility rates were calculated. These rates were utilized in the population projection based on the medium fertility scenario.

The low and high fertility assumptions were formulated around the medium fertility assumption. The low and high fertility assumptions stated that it would take less time for the low fertility assumption and longer time for the high fertility assumption to achieve replacement fertility than the medium fertility assumption.

In terms of mortality assumptions, The NESDB formulated a single mortality assumption from the life expectation at birth by sex. It was assumed that the life expectation of males increased faster than that of females. This brought about the progressive reduction in the excess of female over male expectation of life. The life expectancy for both sexes was postulated to increase at a falling rate. The NESDB utilized life tables for the total population of Thailand to derive the survivor ratios. These age and sex specific survival ratios were used during the course of the projection.

The basic procedure to project population using the cohort component method is to project births, deaths, and migration independently. Thailand utilized this method and projected births using total fertility rate and deaths using survival rates calculated from a life table, however, it was not clear what migration projection method was used to prepare future migration rates for population projections. The common way to project migration, when the cohort component is used as a mean to perform population projections, is to calculate residual net migration by the forward survival method, assuming that the migration rate observed will continue (United Nations1992; US Department of Commerce, Bureau of The Census, 1972). In the NESDB case, the residual net migration was the difference between the 1990 census population and the 1990 expected population that was calculated from 1980 census population multiplied by survival rates.

It is possible that a migration component was not taken into account when Thailand's population projections were carried out at the national level. Projection of migration within the country is not necessary because changing places of residence from one place to the other within the country does not effect the change of the number of people in the country. Immigration has a negligible impact on Thailand's national population, so it was unnecessary to take into account this component during the course of population projections.

The cohort-component method seems to be the appropriate method for Thailand to project population at the national level for several reasons. First, the method is straightforward, simple to use, and is logical if base data (population, births, deaths, and migration) is available and correct assumptions are made. Thailand has a good set of historical population and fertility data at the national level. Thailand Population and Housing Censuses provide information with great detail on population (broken down by age and sex) and fertility (broken down by age) that could be traced back to the year 1911. Because of the relatively reliable historical fertility data, using the mathematical curve fitting function was appropriate to project future births. Projections of population based on the assumptions of three levels of fertility provided good information in terms of the range of population and the uncertain future behavior of fertility.

As far as the approach used for mortality projection is concerned, the calculation of age and sex specific survival rates from the appropriate life table is a common approach. The population and Housing Census before 1990 did not provide information on the expectation of life by sex and age groups. Age-sex-specific survival ratios were computed using the West family of the Coale-Demeny model life tables (Ministry of

Public Health, 1994). Because of less reliable information on life expectancy at birth, it is arguable whether the postulation of life expectancy is appropriate to obtain future death rates. In Thailand's case, this method seems to be acceptable because the life expectancy data was the best reliable information available in the county as far as mortality is concerned. Although stated in the assumption regarding mortality that the life expectation of males increased faster than of females, this assumption did not agree with historical statistics. The expectation of life by sex and age groups from 1969-1991 illustrated the faster rate of increased expectation of life of females in young age groups and equal rates in the young adult age groups (Public Health Statistics, 1994).

2.7.2 Regional Population Projection

The NESDB prepared two sets of regional population projections for the seven regions of Thailand based on two internal migration assumptions. The internal migration assumptions were formulated from five-year interregional migration information in censuses of 1960, 1970 and 1980. From the size and patterns of the migration in those periods, the first assumption postulated a constant age-sex structure of migrants and the constant regional distribution of migrants that were consistent with a historical rate on internal mobility. The second assumption postulated a fixed age-sex structure of migrants with a changing regional distribution of migrants. This change was compatible with a declining overall rate of internal mobility over time.

Regarding preparation of the regional fertility rate, the age-specific fertility rates were obtained from adjusted registration data on births and the number of females in each region in the period 1972-82 for the projection of future fertility rates. The time trend functions were fitted to these age-specific regional time series. These functions were used subsequently for the projection of future age-specific fertility rates of women in each region. Adjustment was made so that these age-specific fertility rates after being weighted by regional numbers of women in the child-bearing age would add up to the national age-specific fertility rates under the medium fertility assumption.

In the case of mortality, assumptions were made by postulating initial assumptions on regional-level mortality by sex using expectations of life at birth. Adjustment was also made for the regional expectations of life at birth after being weighted by regional populations by sex so that they would add up to the national-level expectations of life by sex.

The preferred migration data for the migration projection for a large area such as a region is gross migration rather than net migration because gross migration reflects the closer relationship to the real migration process. During the course of migration projection, Thailand obtained gross migration data from the census from five-year migration data. The first assumptions that postulated the constant age and sex structure of migrants along with the constant regional distribution of migrants were unrealistic. Historical migration data based on the age and sex structure of migrants showed insignificant change in age and sex structure of migrants. It is also arguable whether changes in regional distribution of migrants were constant. Previous migration patterns showed variations in the number of migrants in each region in different census years. However, whether the changes were constant is still in question. The second migration assumptions regarding unchanged age and sex structure of migrants and the changing distribution of migrants were more compatible with historical migration trends.

The projection of fertility was prepared in the same manner as for the national projection except that the base data was from difference sources. Adjusted Household Registration data at the regional level was used instead of the Population and Housing Census Data. By using the registration data, there could be problems associated with the proper allocation of births to the place of residence of the mother. This becomes more problematic in areas with high migration. Recent migrants in Thailand do not usually change residency. If a migrant had a child, the migrant has to notify the local registrar office to obtain a birth certificate. In this case, the birth cannot be correctly allocated to the place of the residence of the mother. When age-specific fertility rates were obtained, the denominator, which is the number of women in the childbearing age group, did not represent the true number of childbearing age population of the region. Although there is a disadvantage associated with utilizing registration data to project fertility, one advantage regarding utilizing registration data is that the data on births is accurate and much more updated than the census data.

Regional mortality assumptions were formulated using the same procedure as the national assumption except that they had to be applied specific to the regions. It was not clear how Thailand coped with the problems of limited regional mortality information. Problems arise when a life table that relates strictly to the population of each region is not available. If age specific death rates are similar through out the country, national rates could be used instead of the survival rates specific to age and region. In the case of Thailand, national age-specific survival rates could be applied to the regional area because the mortality difference between regions is not too large and has decreased over time.

Although a migration component was built into the regional projection based on the analysis of migration patterns from census 1980, there was still no attempt to prepare a projection of population in urban and rural areas for each region.

2.7.3 Urban and Rural Population Projection

Projections of urban and rural populations were carried out at the national level using the United Nations modified ratio method. The United Nations (1984) population projection method was carried out based on the assumption that urbanization would follow a logistic curve. The only requirement for this method was estimates of the rates of growth of the urban and rural populations. Once an assumption about the urban-rural growth rate difference was made, the level of urbanization can be determined independently of the rate of total population growth. The 1980 population and housing census and the medium fertility variant of the national population projections were used to project the urban and rural population for the period 1980-2015.

CHAPTER III

POPULATION MODELING: METHODOLOGY AND RESULTS

There are two main sections in this chapter: methodology and results. The methodology section is divided into three subsections. The first subsection discusses the input data and sources. The second subsection describes the preparation of baseline data. The third subsection discusses the development of the population model. The result sections is divided into three subsections. The first subsection presents projection results at three levels: national, regional, and provincial. The second subsection presents and discusses the sensitivity analysis of the population model. The last section compares projection results of this study with other studies.

I MODEL AND METHODOLOGY

3.1 Data Input and Sources

Two types of data for population modeling were used in this study: population data and the spatial data in Geographic Information System (GIS) Format, which was used to reclassify population data and to generate map results.

3.1.1 Population Data

Population data used in this study were data of fertility, mortality, and migration. These data were obtained from three sources:

- Central Office for Civil Registration, Bureau of Registration Administration, Department of Local Administration, Ministry of Interior: Base Population Data for 1994

- Ministry of Public Health: National age and sex specific fertility and mortality rates for 1994

- The National Census of Population and Housing: Five-year regional migration data (Recent migration data) from the 1990 survey.

3.1.2 Geographic Information System (GIS) Data

The GIS data used in this study was obtained from the Thailand National digital database called Thailand on a Disc, 1996, assembled by the Thailand Institute of Environment (TEI). Thailand on a disc is a GIS database developed for use with PC ARC/INFO and ArcView. The scale of this digital database is 1:250,000. The datasets are organized into five regions: Central, East, Northeast, North and South. Each region contains nine layers that include administrative, agricultural, rural socioeconomic, environmental, forestry, geology, infrastructure, topography and water. The first three (administrative, agricultural, rural socioeconomic) were the main layers used in the model. Three layers were the base layers used to classify the base population into urban and non-urban populations at the district level.

- Socioeconomic Layer: This layer has a coverage called *Human* and an associated lookup table[5] that contains rural population data at subdistrict level. There are 7113 subdistrict polygons in this coverage. Each polygon has associated 1992 population data and a unique id based on the National Rural Development Committee (NRD2C) registration coding scheme.

- Administrative Layer: A coverage of political boundary in this layer has polygons of boundaries of subdistricts with associated ids of subdistricts, districts, and provinces based on the NRD2C registration coding scheme.

- Agricultural Layer: This layer has a land use coverage that contains polygons classified based on seven types of land use. This coverage was used as a source to generate urban and non-urban coverage.

3.2 Baseline Data Preparation

Baseline data in the population model in this study were population, fertility, mortality, and migration data. Only base data of population and migration were processed and are discussed in detail below. Base data of fertility and mortality are described in the modeling section and under fertility and mortality, accordingly.

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[5] A Look up table is a separate data table associated with a coverage that is linked to a feature attribute table (polygon attribute table in this case) of a coverage by unique ids.

3.2.1 Population Baseline Data

Baseline population data in this study was obtained from the Central Office for Civil Registration. The data was the 1994 population data at the district level, classified by sex with 104 age groups from new born to age group 103 years and older. This data had to be reclassified into 5 year intervals of 16 age groups by sex and urban versus non-urban areas.

Each district was given a new id based on the NRC2D coding scheme because this coding scheme would be used as a common key to join the population data to the GIS data. Building this relational database required processing of the aforementioned GIS data and the population datasets. The process of preparation is summarized in Figure 13 and explained below.

Processing of GIS Data

The purpose of processing the GIS data was to build coverages of urban and non-urban population at provincial level. The human, political boundary, and land use coverages were used in this process. Steps involved in the processing can be summarized as follows:

Verifying Original Data

The human and political boundary coverages were verified for missing data or duplicate id[6]. Each polygon must have a unique id for tables to be joined or a relational database to be created. Polygon attribute tables of both coverages were exported and stored in MS Access. Data verification was performed using query statements in MS Access.

Generation of New Coverages

The urban and non-urban human coverages were created with the following steps:

1) Generate national coverages of human, political boundary, and land use.

Original GIS data was organized by regions. The national coverages were generated in ARC/INFO using the *union* command to join the regional data into the national coverage. All coverages were converted into shapefiles so that the files could be easily used in ArcView as themes.

2) Generate district population theme

The district population theme was generated by joining the subdistrict population data in the lookup table of the human coverage with the polygon attribute table of the national political boundary generated in 1). The joined table was processed in ArcView using the *mergetheme* operation to dissolve boundaries of polygons of subdistricts, which share the same district id, to form new district polygons.

[6] It is necessary that each polygon (in this case represent each tambon or subdistrict) has a unique identification. A unique id is used to differentiate each polygon and is important when operations such as merging and intersecting polygons are performed.

3) Generate urban and non-urban land use themes

These new coverages were created through *Query* operations in Arcview. The national land use file generated in 1) was reclassified from 7 to 2 classes of land use type: urban and non-urban. A query statement was built to separate urban land use type from the rest and this became urban land use theme. A query statement was built to combine all except urban land use types together to form a non-urban land use theme.

4) Generate urban and non-urban district political boundary coverages

These coverages were created using the Arc/Info *intersect* operation. Intersecting coverages created in 2) and 3) yielded a coverage that shows polygons of district based on urban and non-urban land use type (See Figure 13). The polygon attribute table of this coverage was later joined with the processed population data from the Central Office of Civil Registration.

5) Generate provincial political boundary theme.

This theme was generated in ArcView using a *merge* operation to dissolve boundaries of district polygons that share the same provincial id and form provincial polygons. This theme was used to display the results of population and electricity projections.

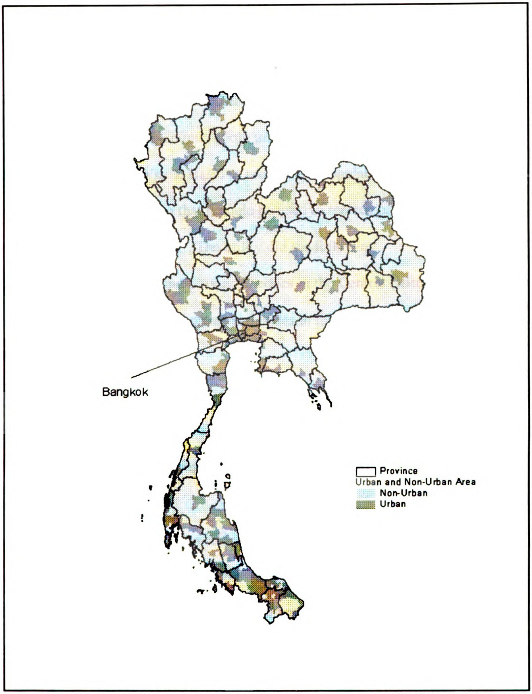


Figure 13: Political Boundary of Provinces in Thailand by Urban and Non-Urban Land

The population data from the lookup table of the human layer was replaced by the population dataset from the Central Office of Civil Registration. The main reason for this was that the human layer did not include population data for urban areas. The Central Office of Civil Registration, on the other hand, has more current, detailed, and complete population data of the entire country (both urban and non-urban population data). A utility was written in MS Visual Basic to process the population dataset from the Central Office of Civil Registration so that it could be used to replace population data in the lookup table of the human layer. The utility did the following:

1) Replaced the subdistrict and provincial codes in the Central Office of Registration with the NCR2D subdistrict and provincial codes in the Human lookup table.

2) Classified Data by Age Group

A five-year interval of ages was use to classify population data from the Central Office of Civil Registration were reclassified using a five-year age interval. The resulting data was the baseline population data grouped by sex and divided into 16 five-year span age groups.

3) Assigned urban and non-urban codes

Urban and non-urban codes were assigned to processed data in 2) by joining this data with the urban and non-urban district political boundary coverages created previously. The resulting data was used as the baseline population data for the population modeling in this study

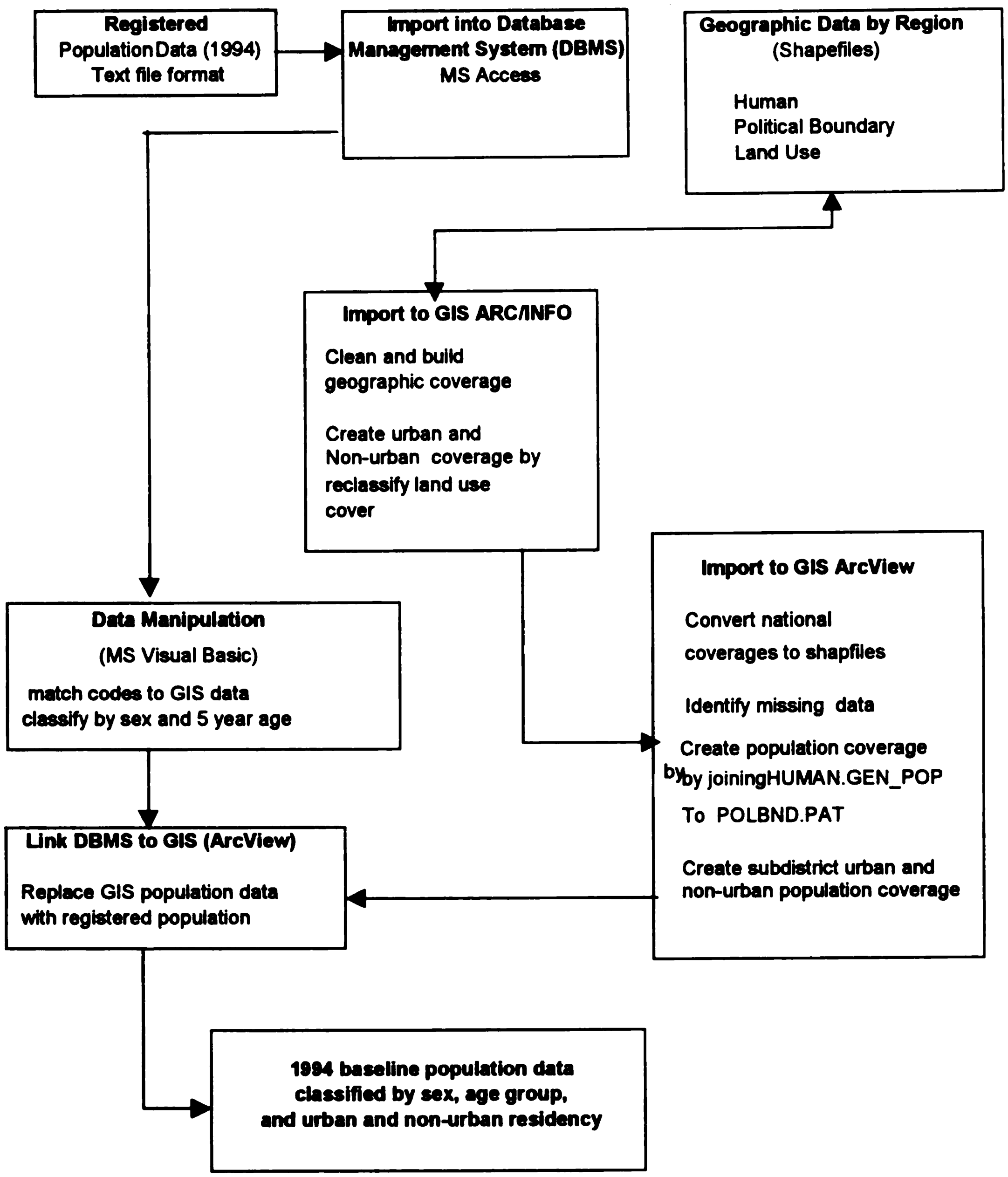


Figure 14: Flow Chart of Baseline Population Preparation

3.2.2 Migration Baseline Data

Regional five-year migration data from the Regional Population and Housing Census 1990 was utilized as the base migration data. Some characteristics of the 1990 census in terms of administrative political boundary can be described as follows. In 1990 Thailand had 73 provinces[7] (76 provinces in 1994) and the regions, according to the census, were classified into four regions: the Central, North, Northeast, and South. The East region did not exist at that time and provinces, which now belong to the East region, was included in the Central region. As a result, there was no interregional migration data or data of migrants from other provinces moving into the East region. Furthermore, the census treated Bangkok as an individual region, excluding it from the Central region.

The regional five-year migration baseline data used were available in a tabular format, which can be described as follows. There was a total of five tables -- one for each region. The row listed provinces (within the region) of residence at census, 1990. The column listed previous regions of residence before 1985. The columns were consisted of the Central, North, Northeast, and South regions, and Bangkok. Each regional tabular data provided the number of male and female migrants from each region moving into each province listed within a region. For each province, data on migrants moving within province was also available.

[7] As a result of administrative adjustment in 1992, there are three new provinces.

Notice that migration data were given at the regional and provincial level and classified by sex. No data concerning age and urban and non-urban status of migrants were available. In order to determine age of migrants in each province, national age distribution of migrants for male and female was applied to all migrants in each province. The number of male or female migrants in each age group was determine by multiplying a probability of male or female in each age group to migrate to number of male or female in each age group. Determination of urban and non-urban status of migrants was based on percent urban and non-urban population in each province.

From the given data, three types of migration rates for male and female were calculated. At the provincial level, percent migrant of a province and percent migrant moving within province were calculated. Migration rate of a province was calculated from the number of migrants in a province divided by the total population in a province. Within province migration rate was calculated from the number of migrants moving within a province divided by the total population of a province. At the regional level, percent migrant from other regions was calculated from the number of migrants from each region divided by the total population of a province. For each province, there were into province migration rates from Bangkok, the Central, North, East, Northeast, and South region. The calculated rates were used as based migration data in the population model. Calculation of the rates was performed using MS Excel and the rates were stored in MS Access.

The processing of the migration data included assigning the NRC2D provincial codes to all provinces for each table. This step was essential because population projections were performed at the provincial level. All provincial codes of the migration data had to conform to the provincial codes of other data tables or GIS data for the model to recognize the migration data. The three new provinces with no migration data used the migration data from the parent provinces before the change of the political boundary. The baseline migration database was built and stored in MS Access.

3.3 Population Model

This subsection explains the population model developed in this study. Assumptions and calculations involved in the model are discussed. This subsection is divided into four parts. The first part describes the overall population model in terms of methodology used. The remaining parts discuss the fertility, mortality, and migration component in detail. Examples of calculations are also included.

3.3.1 Overview of the Population Model

Population projections were performed at provincial level by age, sex, and residency. It is necessary to perform the projections at this level of detail. Age structure of population plays important roles in terms of births and deaths. Age structure of female population in childbearing age group determines number of newborns. Population in different age group also has different probability or risk to die. Since the projection was performed at provincial level, migration plays crucial role in determination of provincial population. It is necessary to be able to determine residency of population and migrants.

The projections of population in this study were performed using the most current estimate of age and sex specific birth and death rates, migration rates combined with trends of these variables based on expert opinion, results of other studies, local knowledge, or intuition of future changes in these trends.

The Cohort-component technique was used to perform population projections (Figure 15). The base population was categorized into 5-year age groups by sex and area of residency (urban and non-urban) in order to perform 5-year period projections from 1999 to 2019. Based on the birth trends, Births were estimated from the summation of newborns to women in the childbearing age group. Deaths by age and sex were also projected, based on the trend of death rates. At the end of every five years, the total population was calculated by adding the number of newborns and subtracting deaths, within five years, from the base population. The projected number of migrants was performed after this adjustment since migration data excludes all persons, both migrants and non-migrants that die during the projection interval. Since the cohort-component model has run in five-year time interval, migration estimates must also be done in five-year interval.

Notice that the model involved the projection of each population component separately. Multiple regression, a common approach to perform projections, is not suitable for this study because it requires the modeler to identify causal factors of each population component and use these to build models. A good example is the case of the migration model. Construction of a regression model of migration would require estimation for causal factors of the 76 provinces in Thailand. Regression models such as this are typically linear or follow some continuous (increasing or decreasing) function, which is not always the case when considering the trend of certain variables. Construction of a regression model of migration would also require time-series data of provincial migration in order to define the model (not available for this study). Because of the complexity of modeling provincial migration, the lack of adequate time-series data on inter-provincial migration, and the likely inability of the resulting model to explain a high proportion of the variance in migration, it was decided that regression modeling would not be used to project future migration amounts and patterns.

Rather than regression modeling, the trending method was used for modeling provincial-level migration (see detailed discussion under migration). This method was also used for modeling provincial level fertility and mortality for similar reasons as migration.

Discussion of population modeling is divided into three subsections: fertility, mortality, and migration. Each subsection discusses base data, assumptions, trending, and calculations in the model. Migration is discussed in great detail because of the complexity of the model, assumptions formulated, and the direct impact on urban and non-urban populations.

The overall population model was developed as an integrated application. MS Access, and MS Excel were used to create necessary tables and store data and projection results. The Visual Basic programming language was used to define and run the model. The projection results were also mapped using ArcView. The summary of the process involved in developing the population model is illustrated as a flow chart (Figure 15).

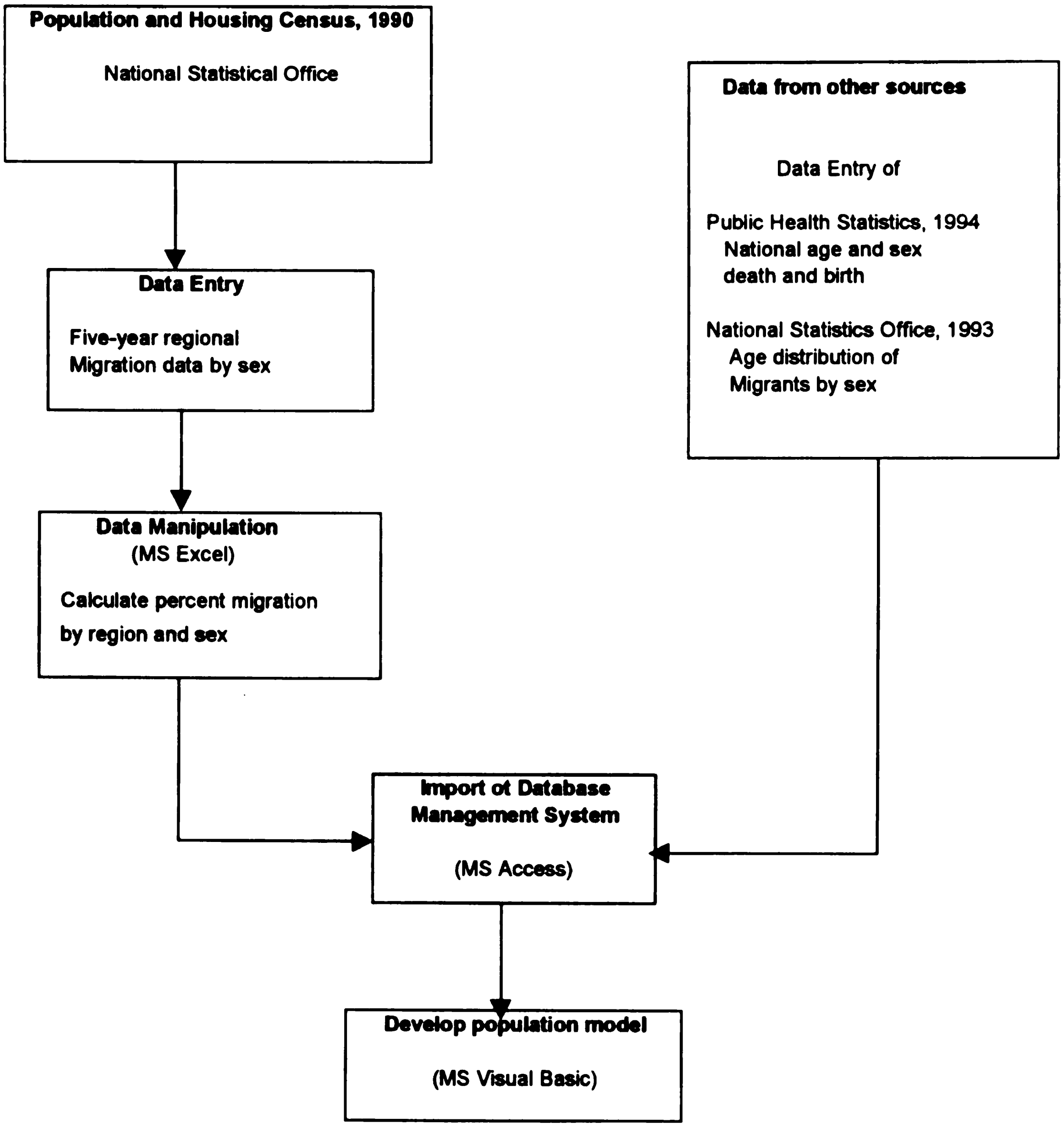


Figure 15: Flow Chart of Processes in Developing the Population Model

3.3.2 Fertility Modeling

Base Data

The national age-specific birth rates of child bearing women age group 15-49 yeas old in 1994 were used because of the unavailability of this data at the subdistrict, provincial, or regional level. The data was obtained from the Public Health Statistics, Ministry of Public Health.

Assumptions

1) *There is no significant difference in the fertility rate specific to age group nationally, regionally, or locally (provincial level).*
2) *There is no significant difference in the spatial pattern of age-specific fertility rates for urban and non-urban women in the childbearing age groups.*

In the absence of historical trends of age specific fertility rates of women in urban and non-urban areas, historical total fertility rates (TFR) were used to observe the fertility patterns between women in both areas. The TFR of non-urban women had always been slightly higher than the rates of urban women. For example, in the period 1974-1976, the TFRs of non-urban and urban women were 4.98 and 4.49 births per 1,000 women respectively. Because of the small difference in the past and the tendency for lesser difference in the future, this study assumed that urban and non-urban women in the same age group have the same fertility rate.

3) *The probability of a newborn female is 0.5 and the probability of a newborn male is 0.5.*

This assumption was necessary because the calculated number of newborns (births) had to be broken down by sex in order to calculate the number of males and females born to a particular female age group in the projection year.

4) *The age of childbearing women is between 15 to 49.*

Selection of the childbearing age group in this study was based on population literature that usually indicates the age group to fall within this range. Statistically very few births occur to women aged below 15 and older than 49.

Trending of Birth Rates

The over all age specific birth rate in Thailand has not changed significantly the last five years (1990-1994). There was a slight decline of the rate in most age group, however, especially the high fertility age group: women aged 20-24, and 25-29 years old (see Figure 8 in Chapter II). Based on current (1994) age specific birth rate, the rate was trended, using expert opinion, to decline by 1 percent per year in the period 1994 to 2019.

Calculations

The national age specific fertility rates were applied to childbearing women in urban and non-urban areas in every province. Calculations of the number of births were performed at the end of each projection year (every five years). For every new projection year, the trended rate – a five percent decrease from previous projection year – was used in the calculation. The equations for the calculations are listed below.

$$Births = \sum_{i=4}^{10} (b_i w_i * 5) / 1000$$

Where:

$Births_i$	=	*Number of newborns to all women in child bearing age group*
b_i	=	*birth rate of women age group i (births per 1,000 women age group i),*
w_i	=	*Number of women age group i,*
i	=	*Age group (group 4 is age 15-19 years old, and age group 10 is age 45-49 years old, and*

5 is the number of year during one projection period

Births were calculated only for women in childbearing age groups (group 4 to 10). After births were calculated, the next step was to determine the number of newborn males and females. This number later becomes the base population for age group 0-4 years old for the next projection year. The equation used to calculate the number of males and females in age group 0-4 years old in the following projection year includes:

$$F_{new} = Births * (1-Pct_m)$$

$$M_{new} = Births * (Pct_m)$$

Where:

F_{new}	=	*Number of newborn females,*
M_{new}	=	*number of newborn males, and*
Pct_m	=	*Probability of newborns being males = 0.5*

3.3.3 Mortality Modeling

Base Data

The national age and sex specific death rates for the year 1994 was used as the base death rates because of the unavailability of this data at the subdistrict, provincial, or regional level. The data were obtained from the Public Health Statistics, Ministry of Public Health.

Assumptions

1) *The difference between the death rate specific to age group and sex is not significant at the national, region, and local levels.*
2) *Mortality rates were not significantly different between urban and non-urban population within the same sex and age group.*

This assumption was formulated based on indirect social measures associated with health and death. Improved living standards and government spending in heath care programs should lessen the difference in death rate between the urban and non-urban population.

3) *There will not be a catastrophe or major events, such as a war or new disease, that will significantly reduce the population in the next 20 years.*

Trending of Death Rates

In the absence of the historical age specific mortality data, the recent trend of CRD was observed and applied to the age specific death rate. CRD in the last five years (1990-1994) showed a much more gradual decrease compared to the rapid decrease between 1950 and 1990 (see Figure 6 in Chapter I). Based on expert opinion, future death rate was determined using current (1994) national age and sex specific death rate, which was trended to decrease 0.05% per year or 2.5% in the period 1994-2019. Notice that the death rate was trended to decrease at a much slower rate than the birth rate (1% per year) because it generally takes a much long period of time to change life expectancy (used to determine age specific death rate). Therefore, there will not be a large change in the life expectancy within 25 years.

Calculations

Calculations of deaths were performed every five years and conducted separately based on area of residence (urban and non-urban) for males and females in each province. The death rate specific to each age group and sex was applied to the base population of the projection year. Trended age and sex specific to death rate, a decreased by 0.05 percent of the previous projection year, were used for the next projection period. The equation used to determine the number of deaths in each age group is as follows:

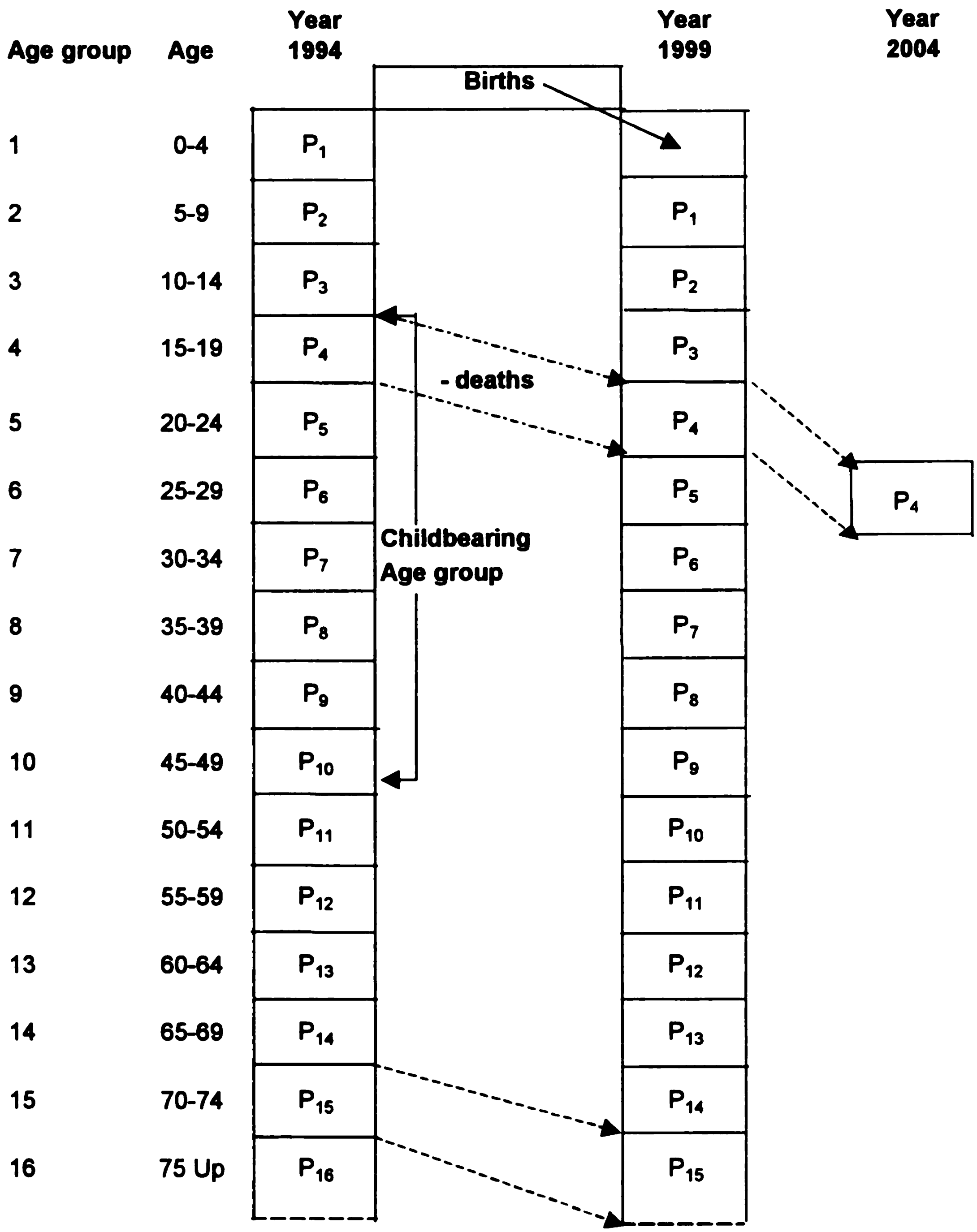


Figure16: Flow of Population under Cohort-Component Method

$$Deaths = \sum_{i=1}^{16} (d_i \, p_i * 5) / 1000$$

Where:

Deaths = *Total deaths of population in all age group,*

d_i = *Death rate of population age group i , (deaths per 1,000 persons in age group i),*

P_i = *Population age group i, and*

i = *Age group = i = 1 to 16 (group1 is 0-4 years old and age group 16 is 75 years old and up), and 5 is the number of year during one projection period*

When births and deaths by sex, age group and urban versus non-urban areas were calculated, the total population before migration was calculated by adding projected births and subtracting projected deaths from the current population. Figure 16 shows the flow of population between projection period 1 and 2. An example of the calculations of births, deaths and population of urban males and females in each age group, using the Cohort Component approach, is given below.

Table 2: An Example of Baseline Population Data in Urban Area by Age Group

Baseline population: Time 0

Age group	Age	Number of urban male	Number of urban female	Male death rate	Female death rate	Birth rate
1	0-4	98	100	2.3	1.7	0
2	5-9	103	81	0.6	0.4	0
3	10-14	118	98	0.7	0.4	0
4	15-19	146	130	2.3	0.7	42.8
5	20-24	186	152	3.4	0.9	106.4
6	25-29	179	171	4.3	1	103.9
7	30-34	175	178	4.5	1.2	66.8
8	35-39	155	184	4.8	1.6	30.2
9	40-44	117	166	5.4	2.3	10.1
10	45-49	112	126	6.7	3.3	2.7
11	50-54	89	99	9	4.9	0
12	55-59	87	96	11.9	7.1	0
13	60-64	73	91	18.1	11.2	0
14	56-69	60	61	27.7	18.6	0
15	70-74	37	45	63.3	54.5	0
16	75 up	44	78	63.3	54.5	0
Total		1779	1856			

Proportion of male and proportion of female birth = 0.5

Table 3: Calculation of Number of Births, Deaths by Sex and Age Group of Urban Population Using Cohort Component Method (An Example)

Projected birth and deaths: Time 1

Age group	Age	Number of death urban male		Number of death urban female		Number of urban births	
1	0-4	0.23	(98 x 2.3) / 1000	0.17	(100 x 1.7) / 1000	0.00	
2	5-9	0.06	(103 x 0.6) / 1000	0.03	(81 x 0.4) / 1000	0.00	
3	10-14	0.08	(118 x 0.7) / 1000	0.04	(98 x 0.4) / 1000	0.00	
4	15-19	0.34	(146 x 2.3) / 1000	0.09	(130 x 0.7) / 1000	55.64	(130 x 42.8/1000)
5	20-24	0.63	(186 x 3.4) / 1000	0.14	(152 x 0.9) / 1000	161.73	(152 x 106.4/1000)
6	25-29	0.77	(179 x 4.3) / 1000	0.17	(171 x 1.0) / 1000	177.67	(171 x 103.9/1000)
7	30-34	0.79	(175 x 4.5) / 1000	0.21	(178 x 1.2) / 1000	118.90	(178 x 66.8/1000)
8	35-39	0.74	(155 x 4.8) / 1000	0.29	(184 x 1.6) / 1000	55.57	(184 x 30.2/1000)
9	40-44	0.63	(117 x 5.4) / 1000	0.38	(166 x 2.3) / 1000	16.77	(166 x 10.1/1000)
10	45-49	0.75	(112 x 6.7) / 1000	0.42	(126 x 3.3) / 1000	3.40	(126 x 2.7/1000)
11	50-54	0.80	(89 x 9.0) / 1000	0.49	(99 x 4.9) / 1000	0.00	
12	55-59	1.04	(87 x 11.9) / 1000	0.68	(96 x 7.1) / 1000	0.00	
13	60-64	1.32	(73 x 18.1) / 1000	1.02	(91 x 11.2) / 1000	0.00	
14	56-69	1.66	(60 x 27.7) / 1000	1.13	(61 x 18.6) / 1000	0.00	
15	70-74	2.34	(37 x 63.3) / 1000	2.45	(45 x 54.5) / 1000	0.00	
16	75 up	2.79	(44 x 63.3) / 1000	4.25	(78 x 54.5) / 1000	0.00	
Total		15		12		59	

Table 4: Calculated Total Urban Population by Sex and Age Group, Time 1

Projected population: Time 1

Age group	Age	Number urban male		Number of urban female	
1	0-4	29 a		29 a	
2	5-9	97.77	(98 – 0.23)	99.83	(100 –0.17)
3	10-14	102.94	(103 – 0.06)	80.97	(81 – 0.03)
4	15-19	117.92	(118 – 0.08)	97.96	(98 – 0.04)
5	20-24	148.45	(146 + 2.78 –0.34)	132.32	(130 + 2.78 – 0.09)
6	25-29	193.45	(186 + 8.09 – 0.63)	159.95	(152 + 8.09 – 0.14)
7	30-34	187.11	(179 + 8.88 – 0.77)	179.71	(171 + 8.88 – 0.17)
8	35-39	180.16	(175 + 5.95 – 0.79)	183.73	(178 + 5.95 – 0.21)
9	40-44	157031	(155 + 2.78 – 0.74)	186.48	(184 + 2.78 – 0.29)
10	45-49	117.21	(117 + 0.84 – 0.63)	166.46	(166+ 0.84 – 0.38)
11	50-54	111.42	(112 + 0.17 – 0.75)	125.75	(126 + 0.17 – 0.42)
12	55-59	88.42	(89 - .80)	98.51	(99 – 0.49)
13	60-64	85.96	(87 - .1.04)	95.32	(96 – 0.68)
14	56-69	71.68	(73 –1.32)	89.98	(91 – 1.02)
15	70-74	58.34	(60 – 1.66)	59.87	(61 – 1.13)
16	75 up	75.87	(37 – 2.34) + (44 –2.79)]	116.3	(45 – 2.45) + (78 – 4.25)
Total		1823		1903	

a = Number of new born male = number of new born female = [(130 x 42.8/1000) + (152 x 106.4/1000) + (171 x 103.9/1000) + (178 x 66.8/1000) + (184 x 30.2/1000) + (166 x 10.1/1000) + (126 x 2.7/1000)] x 0.5 = 29

In this example, the total number of urban males increases from 1779 to 1823 persons and the total number of females increases from 1856 to 1903 persons from projection Time 0 to 1 respectively.

The population model performed the same calculations as the above example of births, deaths, and total population for each sex in 16 age groups in urban and non-urban areas for each of the 76 provinces of Thailand.

3.3.4 Migration Modeling

Base Data

For each province, the following migration rates for male and female were calculated from the regional five-year migration data and used in this study: total migration rate, within province migration rate, rates of migration from other provinces. These migration rates were assumed to remain constant for the next 25 years. The migration rates were not broken down by age and residency (urban or non-urban). Some assumptions or exceptions were applied to estimate migrants of each province by age, sex, and area of residence and are listed below.

Assumptions

1) *Net migration rates from within province migration were equal to 0.03, 0.06, and 0.06 for a province with rural population greater than or equal to 10 percent, 15 percent, and 20 percent respectively.*

The within province net migration rate referred to the difference between migration rate of the urban to rural stream and rural to urban stream. The net migration rate of 0.06 was the average number of the net gain of rural to urban migration within a province at the national level during the period 1965-1990 (see Table 1 in Chapter 2). This study assumed that population of provinces with higher proportion of non-urban population was more likely to migrate within a province from non-urban to urban area. Therefore, the national net migration rate (6%) was used for provinces with 15% non-urban population. The rate of 5% and 3% was used for provinces with non-urban population equal or greater than 20% and 10% respectively.

2) *The probability of migrants to settle down in urban and non-urban areas of each province was equal to a proportion of urban and non-urban population in each province. Provinces in the BMR and EBMR were treated as special. The probability for migrants to settle down in non-urban areas of these provinces was 0.35 while the probability for migrants to settle down in urban areas was equal to the proportion of the population of in urban areas in each province.*

These probability values were applied to the total number of migrants in a province to determine the number of migrants that settled down in urban and non-urban areas. Because of the nonexistence of urban and non-urban migration data at the provincial level, this study assumed that the probability for migrants from other provinces to settle down in urban and non-urban areas in a province is the same of the proportion of urban and non-urban population in the province respectively. Provinces in BMR and EBMR are fast growing provinces with a high potential for jobs and housing. As a result, it was assumed that the probability for migrants to settle down in non-urban areas in these provinces is lower than the proportion of non-urban population. However, the probability for migrants to settle down in urban areas of provinces in the BMR and EMR is the same as proportion of urban population in these provinces.

3) Number of migrants taken out of a province origin was a proportion of percent province population to total migrants of each region.

Base migration data provided only migrant data from each region moved into each province. In this case, the designation province was known, but the origin province of migrants could not be determined. In the normal case when both data were available, after adding migrants into designation province, the same migrants could be subtracted out of origin province. In this study, the model could not perform this task simultaneously. The model had to add migrants into province one at a time until completed the calculation of 76 provinces. When performing this task, the model accumulated migrants which had to be subtracted out from origin provinces by regions. At this point the model had total number of migrants from each region which had to be broken by province. Determination of migrants to be subtracted out of origin province was then determined based on fraction of province population to total population of each region.

4) *There was no significant difference between the age distribution of male and female migrants at the national and provincial level. The age distribution was also the same for urban and non-urban migrants across the nation.*

The data at the national level on age distribution of migrants by sex was obtained from a migration survey conducted by The National Statistical Office (United Nations, 1993). The table of this distribution is shown in Appendix A. The probability for males and females in each age group to migrate was applied to urban and non-urban migrants to determine the urban and non-urban population in each age group. The assumption regarding no difference in age distribution of migrants between province was in part supported by the regional summary on census migration data, 1990 (National Statistic Office, 1993). The results demonstrated that the percent migration of females and males in the same age group in each region were very similar.

Calculations

The calculations for migration modeling involved determining four main types of migrants: total migrants in a province, within province migrants, in-migrants from other provinces, and out-migrants from a province. A diagram illustrating the calculation of the first three migrants is shown in Figure 17 and a diagram illustrating the calculation of out of province migration is shown in Figure 18. Calculation of migration in the population model in this study was done in similar manner for both males and females in urban and non-urban areas. When the word "population" is used in the calculation, it refers to males or females and the word "each area" refers to urban or non-urban areas in each province. The calculation in each step is described below.

1) Total migrants in province *i*

Calculation of migration in the model started by determining total migrants. Total migrants were calculated from multiply percent migrants in a province with population in the province.

$$M_i = W_i * P_m$$

Where:

M_i = *Total migrants in province i,*

W_i = *Population in province i, and*

P_m = *Percent migration of population in province i,* Migrants in province *i* were consisted of migrants for other province and migrants that moved within province *i*. Therefore, calculated total migrants in province *i* was later used to estimate within and between province migrants.

2) Within Province Migration

Based on the calculated total migrants in province *i* and the assumption made regarding percent migration within a province ($P_{w/n}$), the migrants moving within province *i* was calculated using the equation below:

$$X_i = M_i * P_{w/n}$$

Where:

X_i = *Migrants from within province i,*

M_i = *Total migrants in province i, and*

$P_{w/n}$ = *Percent within a province migration*

The calculated within province migrant of province *i* was the migrants from the four migration streams (rural-rural, urban-rural, rural-urban, and urban-urban). The migration stream that determines population in each area of a province was the migrant in the streams of the rural-urban and urban-rural stream. In the case of Thailand, the net migrant resulting from within province migration was always a net gain in rural-urban stream. The other two streams did not effect the net population in each area. From the calculated within province migrants, migrants resulting from net migration between the rural-urban and urban-rural stream were determined using the formula below.

$$Y_i = X_i * P_{net}$$

Where:

Y_i = *Net migrants within province i,*

X_i = *Migrants from within province i, and*

P_{net} = *Percent within a province net migration*

The next step was to extract calculated net migrant based on migration designation (urban or non-urban areas). The calculation was performed based on the proportion of urban population within province *i* for non-urban to urban migration and the proportion of non-urban population within each province for urban to non-urban migration. Since the net migrant was the result of the net gain to urban areas, therefore, only migrant in urban areas was calculated.

$$\text{Urban Pop} = (Y_i)(P_u)$$

Where:

Urban Pop = *Within province net migrants settled down in urban areas,*

P_u = *Proportion of urban population within province i, and*

The next step was to determine the net migrants in urban areas by age group. It was estimated by applying the age distribution (P_j) of migrants to the net urban migrant. The calculation used the formulas below:

$$Z_{iju} = (Urban\ Pop)\ (P_j)$$

Where:

$Z_{i,ju}$ = *Number of urban migrants from within province i in age group j,*

P_j = *Probability of migrants to be in age group j, j = 1 to 16*

At this point the model had the number of within province female and male migrants by age group, and urban and non-urban areas. The next step was to calculate the number of migrants from other provinces.

3). In-Migration from Other Provinces

For province *i*, migrants from other provinces was calculated by subtracting the migrants from within province *i* from the total migrants in province *i*. The calculation is shown below:

$$IN_i = M_i - X_i$$

Where:

IN_i = *In-migrants in province i from other provinces,*

M_i = *Total migrants in province i, and*

X_i = *Migrants from within a province i*

The next step was to extract the calculated in-province migrants (IN_i) in order to determine the migrants that settled down in urban and non-urban of province *i*. The calculation was performed based on percent urban and non-urban of population in province *i*. This can be written as:

$$I_u = N_j * P_u$$

$$I_{nu} = N_j * P_{nu}$$

Where:

I_u	=	*Migrants from other provinces settled in urban areas of province i,*
I_{nu}	=	*Migrants from other provinces settled in non-urban areas of province i,*
N_j	=	*Migrants in province i from other provinces,*
P_u	=	*Percent urban population in province i, and*
P_{nu}	=	*Percent non-urban population in province i*

After the in- province migrants in urban and non-urban areas in province *i* were calculated, the model had to determine these numbers based on age group of the migrants. The calculation was done by applying age distribution of migrations to the urban and non-urban migrants from other provinces. Equations used to perform the calculations were as follows:

$$O_{u,i} = I_u * P_j$$

$$O_{nu,i} = I_{nu} * P_j$$

Where:

$O_{u,i}$	=	*Migrants from other provinces age group j settled in urban areas of province i,*
$O_{nu,i}$	=	*Migrants from other provinces age group j settled in non-urban areas of province i,*
P_j	=	*Probability of migrants to be in age group j, j = 1 to 16*

At this point, the model calculated within province and from other province migrants of all provinces broken down by age, sex, and residency. The next step was to calculate population in urban and non-urban of each province adjusted by migrants. The calculations were performed using equations below.

Non-urban Population

Non-urban population of province i adjusted by migration was determined from adding migrants from other provinces that settled down in non-urban areas in the province and subtracted by the population of the province that moved out of non-urban areas of the province. The equation used to perform the calculation is listed as follows.

$$\text{Adjusted } Pop_{nuj} = Pop_{nuj} + O_{nuj} - Z_{nuj}$$

Where:

Pop_{nuj} = *Current non-urban population in province i, age group j,*

O_{nuj} = *Migrants from other provinces age group j settled in non-urban areas of province i,*

$Z_{nuj} = Z_{uj}$ = *Migrants within province i in age group j moved out from non-urban areas of province i.*

Urban Population

The current urban population (before migration) for province *i* had to be subtracted by the number of migrants moving out from this area (urban to rural within province *i*), added by the number of migrants from other provinces, that settled in the urban areas. The calculation can be represented in the equation below:

$$\textit{Adjusted } Pop_{uj} = Pop_{uj} + O_{uj} - Z_{uj}$$

Where:

Pop_{uj}	=	*Current urban population in province i, age group j,*
O_{uj}	=	*Migrants from other provinces age group j settled in urban areas of province i, and*
$Z_{uj} = Z_{uj}$	=	*Migrants within province i in age group j moved out from urban areas of province i.*

Notice that at this point the model estimated within province migrants and in-migrants for province *i* and adjusted them to the current population. Since the province origin of migrants added into province *i* (desingation province) were not available, migrants added into province *i* could not be subtracted out from the origin province. This meant that the model had to perform the calculation of within province and in-migrants for all 76 provinces, at the same time accumulate migrants, by regions, that had to be subtracted out from the origin provinces. Therefore, the next step was to determine migrants to be taken out of origin provinces.

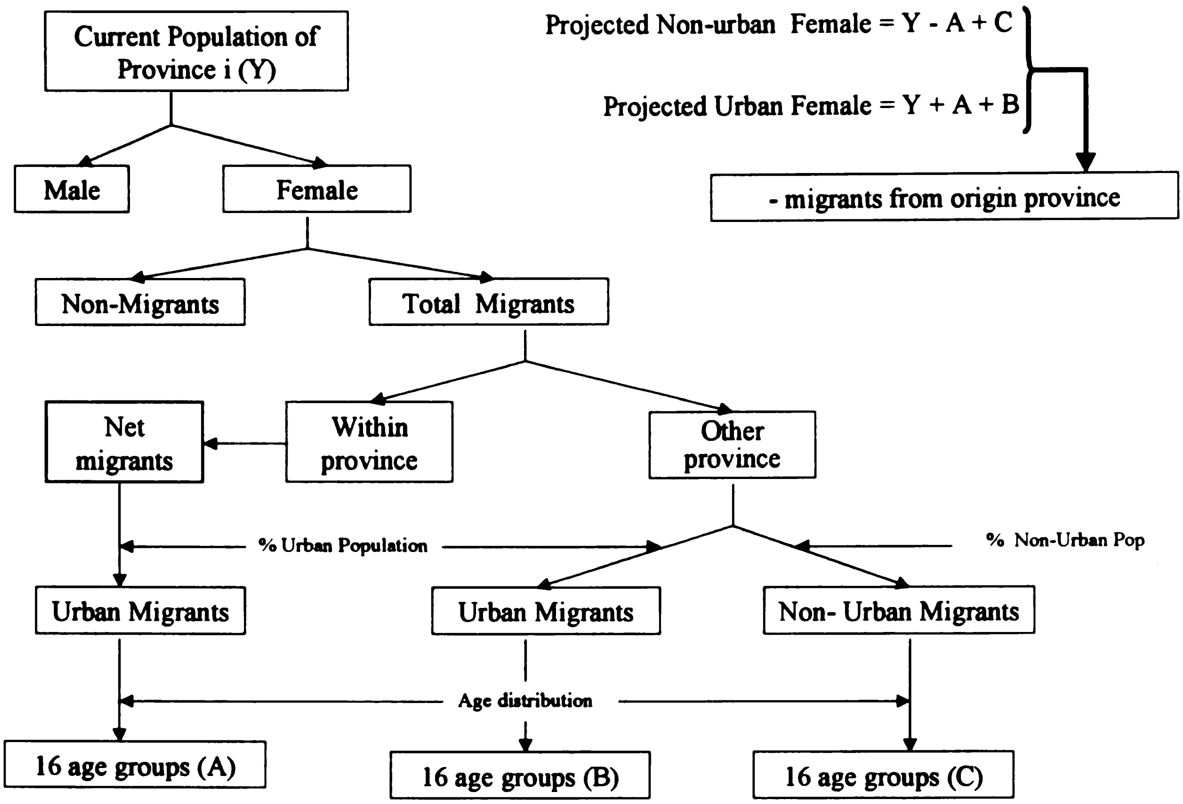


Figure 17: Diagram of Calculation of Female Within and From Other Province Migrants

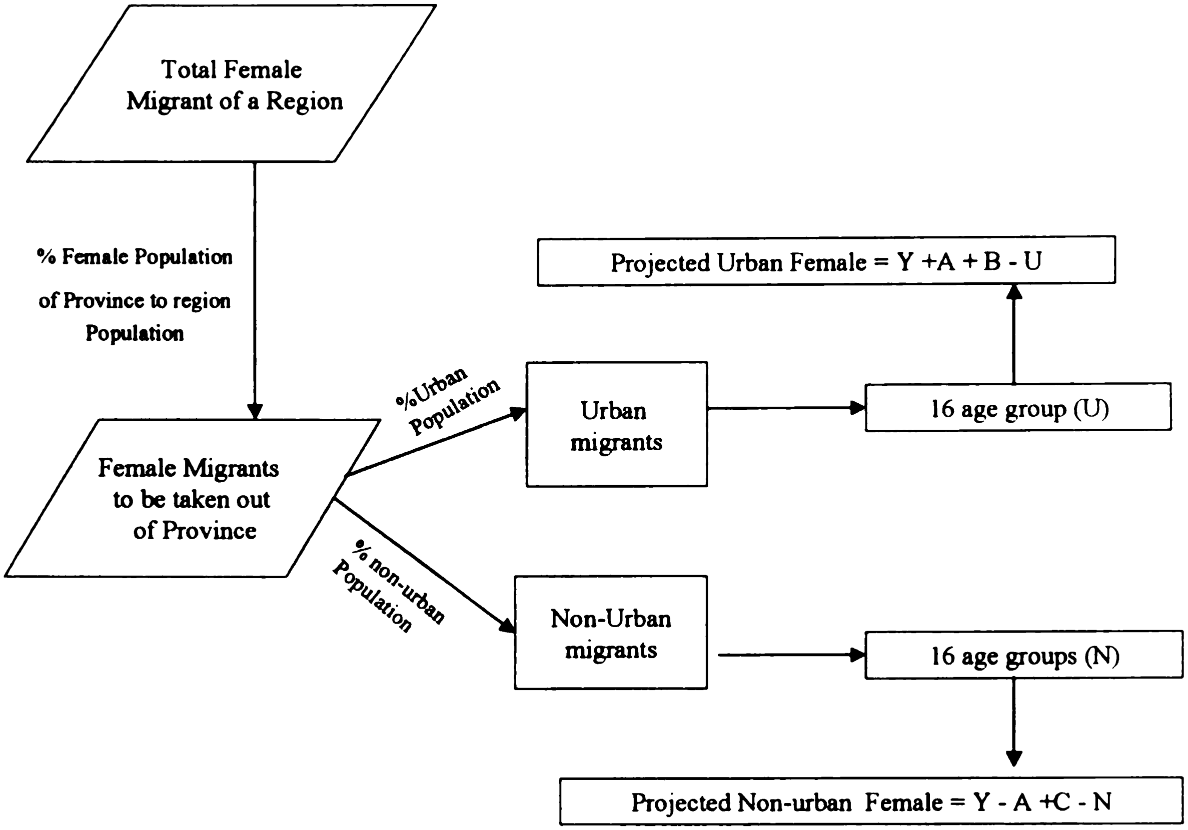


Figure 18: Diagram Illustrated Calculation of Origin Province Female Migrants

4) Out of Province Migrants

Determination of migrants to be taken out from origin province was based on the fraction of provincial population to total population in each region. The fraction of provincial population was assumed to be proportional to total migrants of the region. These migrants had to be extracted based on urban and non-urban residency and age group like other types of migrants. The calculations were performed in 4 steps as explained below.

4.1 Percent Population of Province *i* in Region *r*

The first step was to determine percent population of origin province or province I to each region population. The percents of population in province *i* to population of the Central, North, Northeast, South region, and Bangkok were calculated.

$$\% P_{i,r} = N_{i,r} / N_r$$

where:

$\% P_{i,r}$ = *% population of province i in region r,*

$N_{i,r}$ = *Population of province i in region r, and,*

N_r = *Total population in region r when r refers to Bangkok, Central, North, Northeast, East, and South region)*

4.2 Migrants To Be Taken Out From Origin Province *i*

It was assumed that migrants to be taken out of the origin province was equal to the percent of population of the origin province multiplied by total migrants of the region.

$$M_{out} = M_r * \ \% P_{i,r}$$

Where:

M_{out}	=	*Migrants taken out from province i,*
M_r	=	*Total migrants from region r to province i, and*
$\% P_{i,r}$	=	*% population of province i in region r*

4.3 Migrants To Be Taken Out of Origin Province *i* by Urban And Non-Urban Areas

Migrants taken out of origin province had to be extracted by area of residency. The calculation was performed based on proportion of urban and non-urban population in the origin province multiplied by total migrants to be taken out of origin province.

$$M_{out,nu} = M_{out} * P_u$$

$$M_{out,u} = M_{out} * P_{nu}$$

where:

$M_{out,nu}$	=	*Migrants to be taken out from non-urban areas of province i,*
$M_{out,u}$	=	*Migrants to be taken out from urban areas of province i,*
P_u	=	*Percent urban population in province i, and*
P_{nu}	=	*Percent non-urban population in province i*

4.4 Migrants To Be Taken Out of province Urban and Non-urban Areas of Origin Province *i* by Age Group.

$$M_{out,nu,j} = M_{out,nu,i} * P_j$$

$$M_{out,u,,i} = M_{out,u,i} * P_j$$

where:

$M_{out,nu,j}$ = *Number of non-urban population moved out of province i age group i,*

$M_{out,u,j}$ = *Number of urban population moved out of province i age group i, and*

P_j = *Probability migrants in age group j to migrate, j = 1 to 16*

The assumption of age distribution of migrants was applied to out of province urban and non-urban migrants to extract the migrants based on their age group.

The final step was to subtract migrants taken out of province *i* from the current population of province *i* adjusted by within province and from other province migrants. In the case of the non-urban population, the adjusted current non-urban population for province *i* had to be subtracted by calculated migrants to be taken out of non-urban areas of province *i*, based on age group. The calculation can be represented in the equation below:

$$\text{Projected non-urban population of province } i = \text{Adjusted } Pop_{nuj}\ldots - M_{out,nu,j}$$

Where:

Adjusted Pop_{nuj} = *Adjusted current non-urban population in province i, age group j, and*

$M_{out,nu,j}$ = *Non-urban population to be taken from non-urban area of province i, age group i*

In the case of urban areas, the adjusted current urban population for province *i* had to be subtracted by calculated migrants to be taken out of urban areas of province *i*, based on age group. The calculation can be represented in the equation below:

$$\textit{Projected urban population of province I} = \textit{Adjusted Pop}_{uj} - M_{out,u,j}$$

Where:

Adjusted Pop_{uj} = *Adjusted current urban population in province i, age group j, and*

$M_{out,u,j}$ = *Urban population to be taken out from province i age group i*

In summary, Births and Deaths of each province were calculated and adjusted to the current province population before the calculation of migration was performed at the end of year five. Using necessary assumptions, all population (births, deaths, migrants) in the population model were extracted in to units of population by sex, age, and urban and non-urban residency at the provincial level. The population model in this study had a hierarchical structure.

The calculations of births, deaths, and migrants were carried out according to the hierarchical order of each component in the mode and were performed in loops. The orders from the first to the last were year, region, province, and area respectively (See Figure 19). The model started the projection for year 1, region 1, province *i* in region 1, and area 1. The model calculated births and deaths for non-urban areas in province *i*, then calculated births and deaths for urban areas of the same province. Migrants within and from other provinces were calculated and added to the base population that was adjusted by births and deaths. This completed a loop for the projection of population for province i. The model performed the same calculations for the rest of the provinces in region 1 then moved to region 2 and repeated the same calculations until the calculations for the rest of the regions were completed. At this point the model adjusted current population with migrants within and from other provinces. Next, the model calculated migrants to be taken out from each province and subtracted this number from the adjusted current population. The model completed the circle of a projection of year 1 at this point and repeated the same calculations for year 2 until year 5. The results of the projections were the total number of population in 76 provinces of Thailand broken down by sex, age group, and urban and non-urban area from 1999 to 2019.

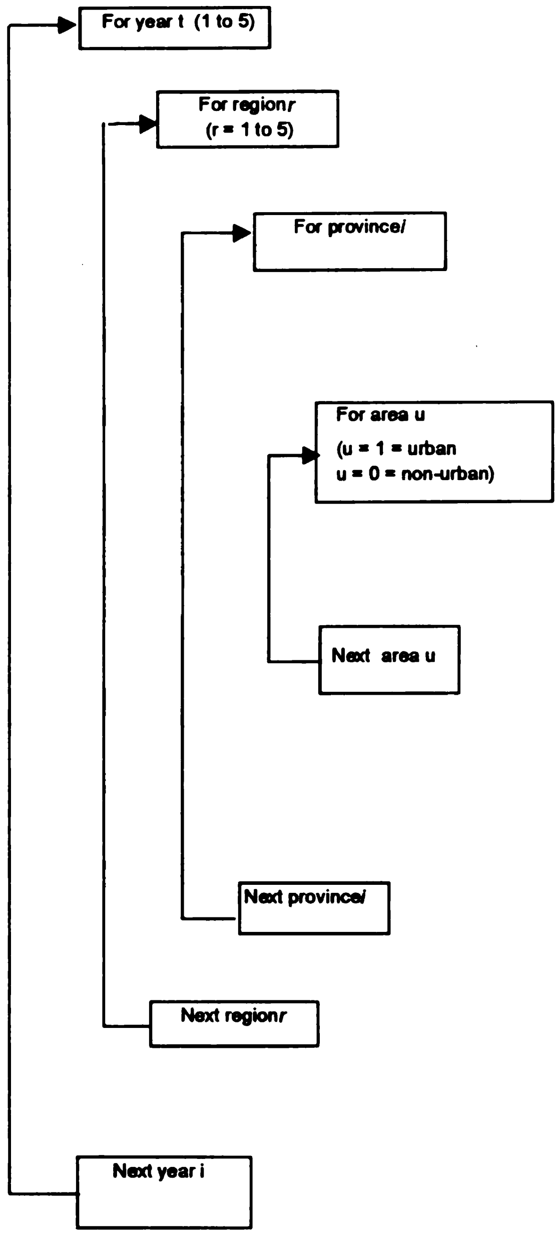


Figure 19: Flow Chart of The Structure of The Population Model

II. PROJECTION RESULTS AND DISCUSSION

This section is divided into three subsections. The first one presents the base year 1994 population and the five-year projection results for the period 1999 to 2019. The projected results are presented at three levels by area of residence: 1) national, 2) regional, and 3) provincial. The discussions of projection results are carried out in more detail under the provincial level subsection because the projections were performed at this level and the results were also used as input to the residential electricity model. The results at the national and regional levels were simply the aggregation of the provincial results. Bangkok was treated as a region and excluded from the central region because of its uniqueness in social, economic and political aspects. The second subsection compares and discusses the projection results between this study and the projections of the NESDB. The last subsection presents and discusses the result of the sensitivity analysis.

3.4 Projection Results

3.4.1 National Level

The projection results at the national level show an increase of the total population from 55.4 to 83.6 million between 1994 to 2019 (See Figure 20). In 2019, Thailand is projected to have 38.7 million people live in urban areas and 44.9 million in non-urban areas. The percent of urban and non-urban population to the total population will be 46.3 percent and 53.7 percent respectively in this year. In the same year, the projected female population is 42.2 million, and the projected male population is 41.3 million. The female population will account for 50.5 percent of the total population. The average annual population growth rate is expected to decline from 2.09 to 1.42 percent in this period. The increase of the total population in Thailand will be largely influenced by an increasing population in urban areas. The share of urban population (urbanization rate) is expected to increase from 40.6 to 46.3 percent in the same period (see Table 5). The percent change of urban population in each projection year will always be higher than the percent increase of non-urban population. However, the change of population in urban areas is expected to increase at a decreasing rate. The percent increase of urban population is projected to be 12.8 between 1994 to1999 and decrease to 10.4 percent between 2014 to 2019. Although the majority of the population of Thailand will still live in non-urban areas, the share of the non-urban population will decline from 59.4 percent in 1994 to 53.7 percent in 2019. The projection curves of urban and non-urban residents in 2019, shown in Figure 20, become closer toward the end of the projection year. This indicates that the difference between population in non-urban and urban areas will become less in the future.

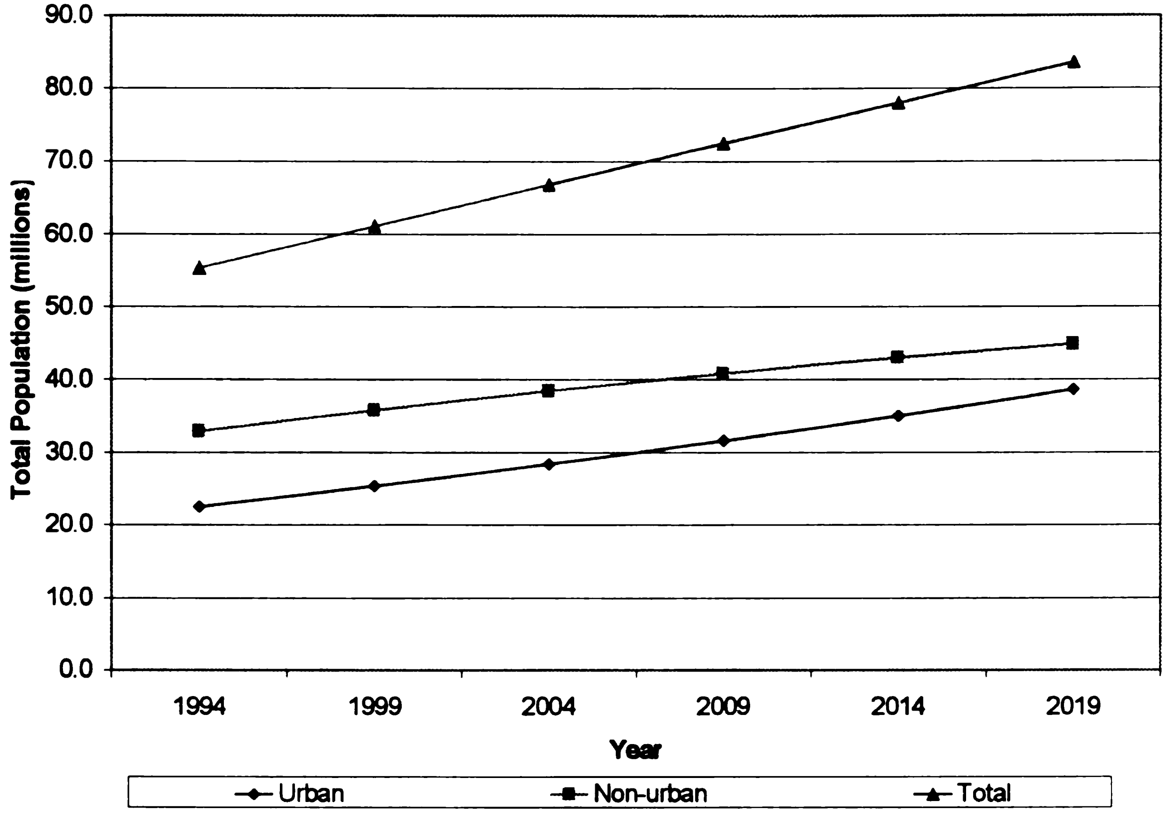


Figure 20: Projected Total Population at National Level, 1999-2019

Table 5: Population Change At National Level By Area, 1999-2019

Year	% Total Population Change	% Urban Population Change	% Non-Urban Population Change	% Urban Population	% Non-Urban Population
1994-1999	10.4	12.8	8.9	41.5	58.5
1999-2004	9.4	12.0	7.5	42.5	57.5
2004-2009	8.4	11.3	6.2	43.6	56.4
2009-2014	7.7	10.8	5.2	44.9	55.1
2014-2019	7.1	10.4	4.4	46.3	53.7

3.4.2 Regional Level

Bangkok

At the base (1994) year, regions ranked by total population from highest to lowest will be the Northeast, North, Central, South, Bangkok, and East region respectively. By the end of the projection year (2019), the region with the largest population will still be the Northeast region, following by the Central, North, Bangkok, South, and East region (see Figure 22). If Bangkok is included with the Central region, this region is ranked the second largest population in the base year and the largest in 2019. Bangkok's population is projected to increase from 5.1 to 10.5 million in 1994 and 2019 respectively. The percent population increase of Bangkok is the greatest in the Country. The change is expected to be 108.1 percent between 1994 to 2019 or a growth of 4.3 percent per year. Bangkok will account for approximately 50% of the region's (Central) population both at the beginning and the end of the projection years. In terms of population share, Bangkok is projected account for 12.6% of the Thai population in 2019. The share of Bangkok's population to the total population in this year will be greater than the share from the South and East region's population. Bangkok is the only province in the country that has an urbanization rate of 100% in this period.

Central Region

The Central region is ranked second to Bangkok as far as population change is concerned. This region is expected to experience an approximately 83 percent increase of population between 1994 to 2019 or a growth of 3.3 percent per year. The population of the Central region is projected to increase from 9.1 to 16.7 million while the share is projected to increase from 10.9 to 20 percent in 1994 and 2019 respectively. The increase of the total population of the Central region will result from an increasing population in urban areas, which is projected to be the greatest in the country. The percent increase of urban population will be 111.4 percent in this period. Approximately 70 and 76 percent of the population in this region will live in urban areas in 1994 and 2019 respectively. Percent urbanization of this region is also expected to increase from 5.9 percent in the base year to 12.6 percent in 2019.

Northeast Region

The population in the Northeast region is projected to increase from 19.7 million in 1994 to 26.5 million in 2019. Although this region will have the largest population in this period, the percent population change of this region will be the second. The estimate of percent change of the population in this period is 34.0 percent or a growth of 1.4 percent per year. The Northeast region is expected to experience a decline of population share from 35.6 percent in 1994 to 31.7 percent in 2019. The decline will take place because of the increased shares of population from Bangkok, the Central and the East region. Approximately 82.7 percent of population in this region lived in non-urban areas in 1994. The share of the non-urban population will not change in 2019. When compared to other regions, this region will have the largest non-urban population in the country. Population in the non-urban area of this region is projected to increase from 16.3 to 21.8 million in

1994 and 2019 respectively. The non-urban population of the region in 2019 will account for approximately 26.1 percent of Thai population. The Northeast region is expected to experience an increase of urban population of 35.8 percent between 1994 to 2019, 2.1 percent greater than the percent increase of non-urban population. However, the Northeast region will experience a decline of urbanization rate from 6.2 to 5.6 percent in this period.

South Region

The population in the South region is expected to increase from 7.2 million in 1994 to 10.4 million in 2019. The percent population increase in this region will be approximately 44 percent or a growth of 1.76 percent per year in this period. The share of population from this region will decrease slightly from 13 percent in the base year to 12.4 percent in 2019. In terms of urban and non-urban population mix, the South region will not experience a significant change in this period. Similar to the Central region, the South region is projected to have more than half of the population living in urban areas. That is 59.5 percent (4.3 million people) and 59.7 percent (6.2 million people) of the region population will live in urban areas in 1994 and 2019 respectively. The share of urban population from the South region will be the second largest from the Central region. However, this region will experience a decline of urbanization rate from 7.7 to 7.4 percent in this period.

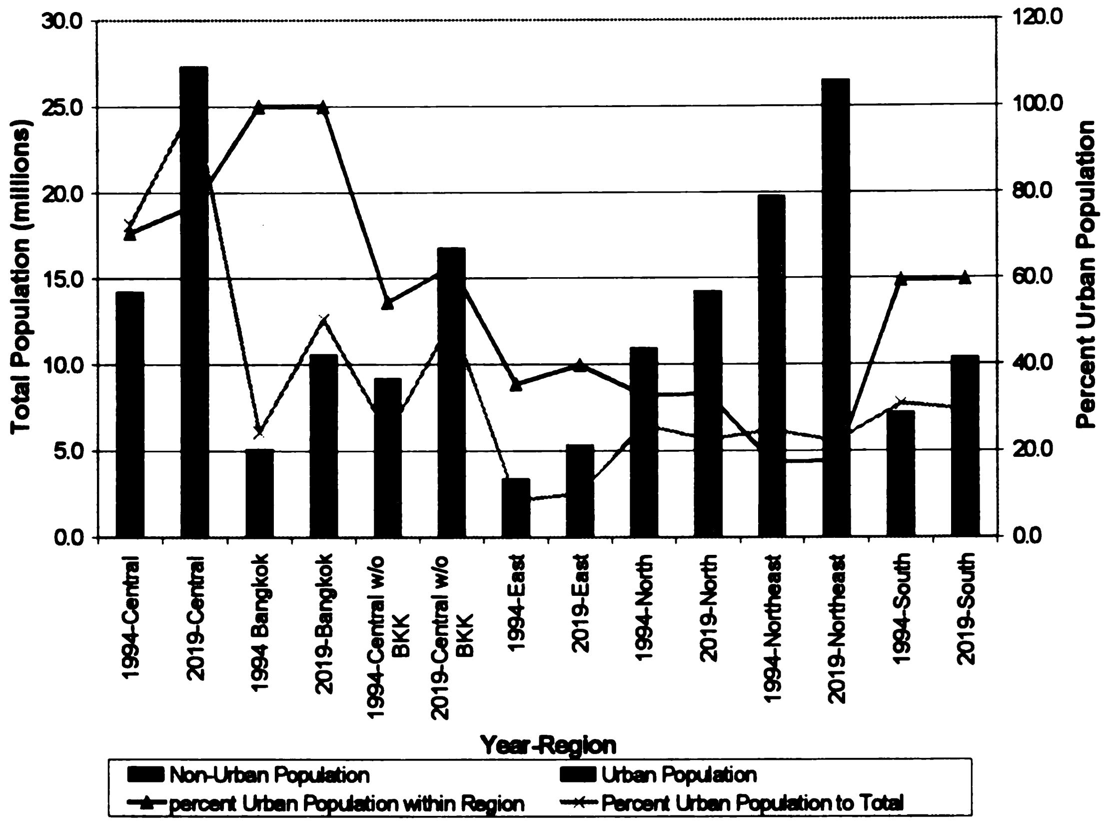


Figure 21: Projected Population and Urbanization Rate By Region and Area, 1999-2010

North Region

The North region will experience a population increase from 10.9 million in 1994 to 14.2 million in 2019. Compared to other regions, this region is expected to have the lowest percent population increase (30 percent) in this period or a growth of 1.2 percent per year. Approximately 67.2 percent of the region's population (7.3 million) in 1994 and 66.9 percent (9.5 million) of the region's population in 2019 will live in non-urban areas. The population share from this region will decrease from 19.7 percent in 1994 to 17 percent in 2019. Similar to the Northeast and the South region, the North region will experience a decline of percent urbanization from 6.5 to 5.6 percent in 1994 and 2019 accordingly.

East Region

The projected population for the East region will be the smallest of the five regions (including Bangkok). The estimate of the population is 3.3 million in the base year and 5.3 million in 2019. The population share from this region will increase from 6 to 6.3 percent in this period. The East region is expected to have a 58.9 percent increase in population between 1994-2019 or a growth of 2.4 percent per year. The population growth in this region will be the result of a high change of population in urban areas (78.8%). The non-urban population is projected to increase by 48% while the share of non-urban population within the region will decrease from 64.6 to 60.2 percent in this period. The East region will face an increase of urbanization from 2.1 to 2.5 percent in 1994 and 2019 accordingly.

Regional Population Summary

The trend of population change in all regions is that urban and non-urban population will increase with the higher percent change taking place in Bangkok, the East and the Central region. The remaining regions will experience an increasing urban population with decreasing shares of regions' population in urban area from the base year to 2019. The Northeast region will experience the highest different between urban and non-urban population. The difference will be 17.2 million people in 2019. The difference will also be found lowest (1.1 million people) in the East region in the same year. In terms of urban and non-urban population mix within the region in the period 1994 to 2019, there will be almost no change (percent change less than 1 percent) in the population mix in the North, Northeast, and South region. The percent changes are estimated to be 8.5 percent in the Central region and 4.4 percent in the East in the same period.

3.4.3 Province Level

The projection results at the provincial level are discussed in terms of changing share and percent increase of total, urban, and non-urban population within each province between 1994 to 2019. Maps are used to illustrate the change in each province. Percent change of population by area was broken down into five ranges using a Natural Breaks classification technique. Natural Breaks uses a statistical formula to identify breakpoints between classes by minimizing the sum of the variance within each of the classes. Natural Breaks finds grouping and patterns inherent in the results (ArcView User Manual, 1995).

For the purpose of the results discussion percent population change was categorized into four levels: very high, high, medium, and low. The level of change was determined based on the mean value and the standard deviation of the percent population change of provinces excluding provinces with percent change greater than 100%. These provinces were excluded because this change was considered as an extreme case, which only a few provinces will experience this change. For the first level, a very high change, the percent change will be greater than 100 percent. After excluding provinces in this group, the mean value of percent population change was calculated to be 36.8 percent and the standard deviation was calculated to be 12.8 percent. The percent change more than one standard deviation (change > 49.6%) was considered the high change level. The percent change between ± one standard deviation (between 49.6 % and 24.0 %) was considered the medium change level. The percent change less than less than minus one standard deviation (< 24%) was considered the low change level.

1) Percent Change and Share of Total Provincial Population

In the period 1994-2019, the 76 provinces in Thailand will experience a wide range of change in total population, varying from as small as 12.4 percent to as high as 283.8

percent. Calculated percent population change of all provinces was distributed relatively evenly, with some extreme values at the high change side (outliner). The very high population change will take place in Bangkok, four provinces in the Bangkok Metropolitan Region (BMR), as well as two provinces in the South region (Figure 22). The largest change will take place in Nonthaburi, a province adjacent to Bangkok rather than in Bangkok. However, Bangkok will still have the largest population and holds the largest share of population in the country. Bangkok, Nonthaburi, and Samut Prakarn deserve special attention because these provinces will experience very high change and have large population (> 2 million). These provinces are relatively well established in terms of economy and housing. The projected very high population change within these provinces will result from large in-migrant population and births from the greater population in the base year of these provinces.

The high population change group will consist of 10 provinces, mostly located in the Extended Bangkok Metropolitan Region (EBMR). These are the areas where development is growing because of the expansion of infrastructure into these provinces. Moreover, these areas become more attractive because Bangkok and the BMR are getting closer to saturation in terms of expansion of housing and industry. For these reasons, provinces in this group will also experience large in-migrant population, which in turn will increase total population in the province. In terms of the population share, there will be only three provinces that will account for more than 1% (approximately one million or more) of total population in 2019. These provinces are Kanchanaburi, Nakhon Pathom, and Chonburi.

The majority (approximately 68.4%) of the provinces in Thailand will experience medium percent population change between 1994 to 2019. These provinces are mostly located in the North, Northeast, some in the Central and the South region. While these provinces are expected to experience medium population change, it does not necessary mean that these provinces will have small populations. In fact, twenty-two out of fifty-two provinces in this group will have a population of more than one million in 2019. The projected second largest population in the country in this year (3.2 million), taking place in Nakhon Ratchasima, is also in this group. While the first two groups (very high and high change group) are expected to experience an increase or the same percent of population in the province to the total population, all provinces in the medium group are expected to experience a small decrease. This decrease results from the increase of the population share of the provinces in the first two groups.

In the case of the low change level, seven provinces will experience a percent change of population below 24%. These include provinces that have relatively small population, small migrant population, and low economic activities (agricultural and industrial activities). Chiang Rai is the only province in this group that is expected to have population more than one million in 2019. The remaining provinces are projected to have population ranging from 223,133 to 524,121. In terms of percent population of a province to the total population, all of the provinces in this group will experience a

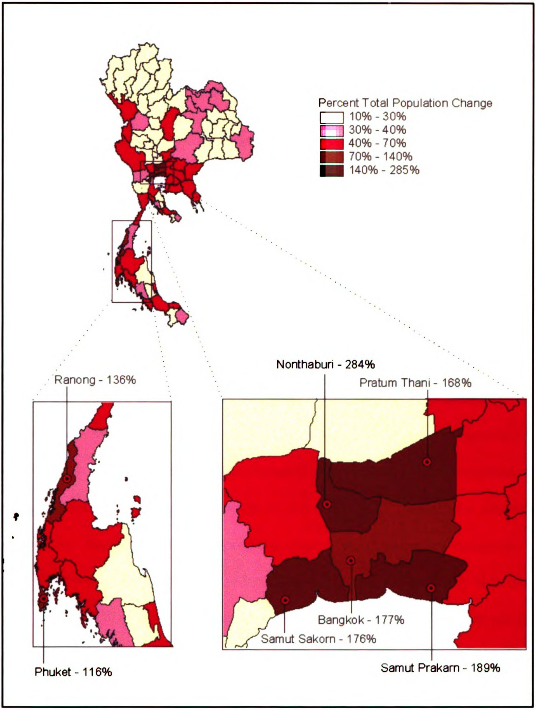


Figure 22: Percent Change of Total Population by Province, 1994-2019

decrease of population share. Chiang Rai, in particular, is projected to have a higher percent change of population share compared to other provinces in the country.

2) Urban and non-urban Population Change

The projection results at the provincial level show increasing urban and non-population in all provinces. The increase of total population in most provinces will be more influenced by the greater increase of urban population in the province. This is shown in an increase of urban population share in most provinces. In 2019, 49 provinces (or 64.5 %) of the provinces will have more than half of the province population in urban areas. There will be five provinces that will have urban population greater than 1 million. Ranking for highest to lowest urban population, these five provinces include Bangkok, Pathum Thani, Nonthaburi, Songkla, and Nakhon Srithammarat. Approximately 63 provinces (or 83%) of the provinces will experience an increased urban population share in the province from 1994. However, the extent of this or the change of urban and non-urban population mix in each province will not be so large except for a few provinces. While most provinces will experience the change of urban population share in the province approximately below 2-3 percent, there will be six provinces that will experience relatively high change ranging from 10.7 to 33.2 percent. These provinces are Phra Nakhon Si Ayudhaya (22.7 %), Chachoengsao (18 %), Saraburi (21.8 %), Chanthaburi (33.2%), Rayong (10.7 %), and Uttaradit (11.7%). All of these provinces except Chanthaburi and Uttaradit are located in EBMR. The percent change of non-urban population share is the opposite of the change experiencing by urban population.

Unlike the small change of urban population share in the provinces, the percent change of urban population in 2019 will be large, ranging from no change to a change of 285 percent. Calculated percent urban and non-urban population change of all provinces was distributed relatively even, with some extreme values at the high change side. These extreme values range from 117.2 % to 284.5 %. When excluding the extreme value and the zero percent change, the percent change of population in urban area of the remaining provinces will be in the range of 13 to 98.9 percent. Provinces that will have a very high percent urban population are Chantaburi, Saraburi, and the same five provinces will have the very high change of total population (see Figure 23). A very high percent non-urban population change will also take place in these same provinces. Within this group, the first two provinces deserve special attention. These provinces are expected to experience more than 100% change of the urban population at the same time relatively large change of urban population share compared to other provinces. However, the urban population in these provinces will still be small, less than 350,000 people. The zero percent urban population change will take place in Amnat Charoen where urban areas do not exist. For the case of the high, medium, and low change level, the level of percent urban population change that a province will experience in the period 1994-2019 will follow the pattern of the case of the total population. This pattern will also apply to the case of percent non-urban population change (see Figure 24).

The different level of percent urban and non-urban population change as well as the population share in each province is based on the different levels of births, deaths, and migrants. The births and deaths were determined by the current population and the birth and death rate. The assumptions formulated for fertility and mortality rate have little to do with the total population in urban and non-urban area in each province because the number of births and deaths of urban and non-urban area in each province were calculated from the national rate. The sensitivity analysis also confirms that the change of population is not sensitive to fertility and mortality input (see Sensitivity Analysis). The births and deaths in each province were influenced more from the current population in the province. The current population also determines migrant populations because migrant populations in each province were calculated based on the fraction of the current population in urban and non-urban areas. In the case of the very high and high percent population change levels, the model assigned the higher probability of settling down in urban area in the provinces the provinces in BMR and EBMR. As a result these provinces will experience the very high and high level of change.

At the provincial level, the pattern of the percent change in total, urban, and non-urban population, and the share of urban and non-urban population to the total population in each province will not be different. The most distinct changes will take place in some provinces in BMR and EBMR. These regions are the areas of the country that have high economic potential. These areas have greater access to ports, markets, government services and superior infrastructure than the rest of the country. For these reasons, these provinces seem to attract population from other provinces. Note that the projection results are in part based on assumptions incorporated into the model. The next subsection presents and discusses the effects of some of the variables and assumptions used in this model.

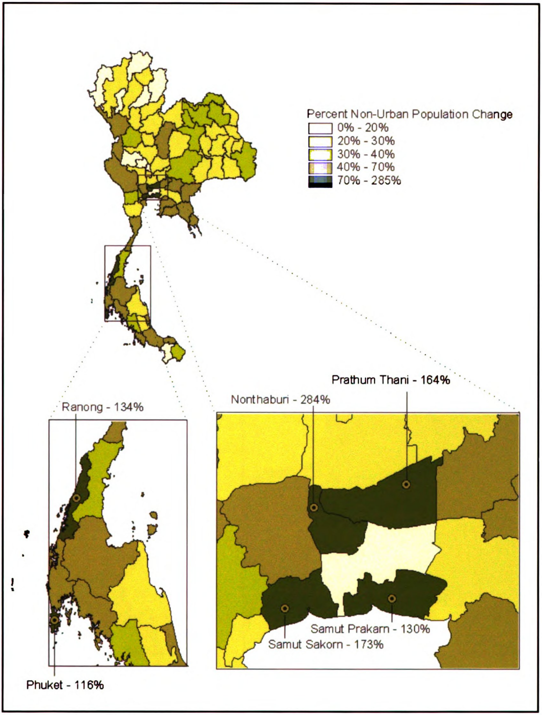


Figure 23: Percent Change of Population in Non-Urban Areas by Province, 1999-2019

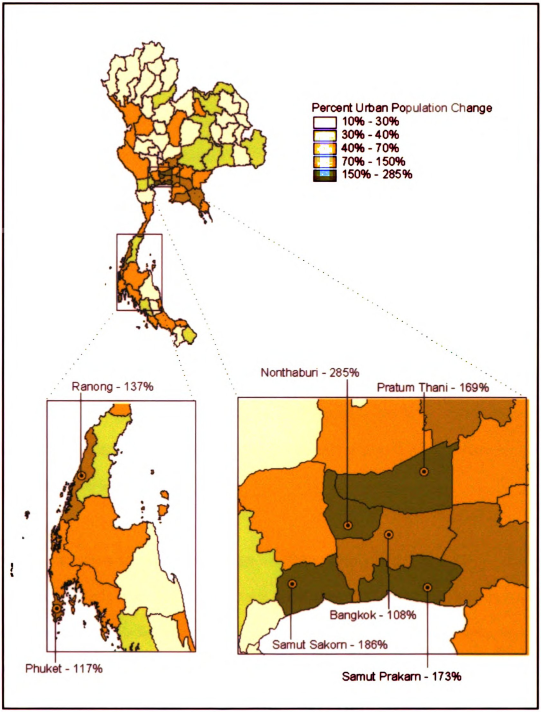


Figure 24: Percent Change of Population in Urban Areas by Province, 1999-2019

3.5 Sensitivity Analysis

The sensitivity analysis was performed in order to better understand how sensitive the results of the population model are to input assumptions. While there are many assumptions formulated for the population model, only major assumptions were examined and these include assumptions of the age and sex specific birth and death rates. The sensitivity of the number of total population to migration assumptions was not examined because migration assumptions will not effect the total population at the national level.

The range of the values used in the sensitivity analysis was a 30 percent increase and decrease of the birth and death rates, with the original rate being 100 percent. This range was chosen in the analysis to match the situation of the birth and death rate change in Thailand. In Thailand, it is unlikely that birth and death rates will change more than 30 percent within the next 25 years.

The sensitivity test was performed through a utility written in MS Visual Basic. The utility was written in order to determine total population of Thailand by changing the birth or death rate while holding other variables constant. For the birth variable, the effect of birth rate on the total population was determined by holding death and migration rates constant and applying different percent change of the birth rate to the original rate. The total population in the year 2019 was computed using the values of birth rate that increase and decrease by 10, 20 and 30 percent of the original rate within 25 years. The percent changes were applied to both trended and non-trended birth rates. Trended birth rate referred to birth rate that was assumed to decrease 1 percent per year or 20 percent during the period 1999 to 2019. The non-trended birth rate assumed that current birth rate used in the population model would remain unchanged in this period. The sensitivity of the projected population to age specific birth rate was calculated using the equation as follows:

$$S = [(P_0 - P_i)/P_0] / [(R_0 - R_i) / R_0]$$

Where:

S	=	Sensitivity
P_0	=	Projected total number of population in year 2019 when there is no change in the birth (death) rate or when R equals 1 or R_0
P_i	=	Total number of population when percent change in rate is i
R_0	=	Percent birth (death) rate of change equal to 1
R_i	=	Percent change in birth (death) rate i where i = 0.7 to 1.3

The effect of death rates on the total population was determined in a similar manner to the birth rate. Birth and migration rates were held constant while death rate varied by an increase and decrease of 30 percent of the current values. The total population was computed using the percent change applied to both trended and non-trended death rates. The trended death rate referred to the rate that was assumed to decrease 2.5 percent in the period 1994 to 2019. The non-trended death rate assumed a constant death rate in this period. The sensitivity of the population model to the assumption of the death rate was calculated using the above equation.

X

The results of the sensitivity analysis are reported in Table 6 for the effects of birth rate and Table 8 for the effects of death rate on the number of total population. The first column of the sensitivity analysis table shows the percentage change on the birth rate relative to the original rates. The population fields show the projected population in 2019 for the trended and non-trended rates. The sensitivity fields show the calculated sensitivity of the total population to the change of both trended and non-trended birth and death rates. Level of sensitivity or responsiveness of the total population to change of birth or death rate is greater when the sensitivity value is 1 or greater.

Table 6: Effect of Birth Variable on Total Number of Population

Percent Change	Age and Sex Specific Birth Rate			
	Trended		Non-trended	
	Population	Sensitivity	Population	Sensitivity
-30%	75,399,592	0.326	78,489,008	0.362
-20%	78,078,159	0.329	81,682,493	0.362
-10%	80,803,129	0.332	84,940,992	0.354
0%	83,574,623	-	88,054,270	-
10%	86,392,593	0.337	91,440,955	0.385
20%	89,257,462	0.340	94,893,032	0.388
30%	92,168,959	0.343	98,410,278	0.392

The results of the sensitivity analysis on the birth rate indicate that the projected total population is not sensitive to changes of the birth rate used in this model. In the case of trended birth rate, the sensitivity values change very little from 0.33 for the 30 percent decrease and to 0.34 for 30 percent increase of the current birth rate. This means that if 30 percent less than the current age specific birth rate was used in the model, every 1 percent change in this rate will increase the projected population by 0.33 percent. For the case that the rate was 30 percent greater than the current rate, the sensitivity value indicates that for every 1 percent change in this rate, there will be approximately 0.34 percent increase in projected population. Similar results were found when sensitivity test was performed for the non-trended birth rate. Population will increase by 0.36 and 0.39 percent for every 1 percent change of the used of the 30 percent decrease and 30 percent increase of the non-trended birth rate. The different between the sensitivity value are very small for both tests.

Table 7: Effect of Death Variable on Total Number of Population

Factor of Rate Change	Age and Sex Specific Death Rate			
	Trended		Non-trended	
	Population	Sensitivity	Population	Sensitivity
0.7	87,412,449	-0.153	87,244,587	-0.155
0.8	86,066,843	-0.149	85,884,378	-0.151
0.9	84,789,085	-0.145	84,593,509	-0.147
1.0	83,574,623		83,367,473	
1.1	82,418,485	-0.138	82,201,183	-0.140
1.2	81,316,862	-0.135	81,090,340	-0.137
1.3	80,265,210	-0.132	80,030,712	-0.133

In the case of death rate, the sensitivity test result indicates that the projected total population is sensitive to neither trended nor non-trended death rates in this model. For the 30 percent decrease trended death rate case, the sensitivity test shows that 1 percent change in death rate will change (decrease) total population by 0.15 percent. The sensitivity value of –0.13 for the 30 percent increase case indicates that for every 1 percent change in the death rate, there will be approximately a 0.13 percent decrease in projected population. The result for non-trended cases is very similar to the trended case (see table 7).

For this model, the output, total population, is more responsive to the input birth rate variable than the death rate variable. Take the case of 30 percent decrease as an example: a 1 percent change in birth rate will cause total population to change 0.33 percent while the 1 percent change in death rate will cause a total population change of about 0.15 percent.

3.6 Discussion and Comparison of Projection Results

This subsection compares the population projection results at the national level between the model in this study and the model of the NESDB. The discussions of projected population and total fertility rates are based on methods used to project birth and death rate used by each model.

The results of projected population from both studies are presented in Figure 25 and Table 8. Notice that the base year population used by both models was different. This is because both models used data from a different source and different year. The NESDB model used the data obtained from the Population and Housing Census, (1990) while this study obtained the data from the Registered Population and Housing, 1994. In 1994, projected population from the NESDB model was 58.7 million, approximately 19.1 percent (13.8 million) larger than the base line population used in this study. By 2019 the projected population from this model will be 83.6 million, larger than the NESDB model that has the estimate of 70.2 million. The curve in Figure 7 shows a steeper slope of the projected population from the model in this study. In addition to the difference in the base year population, the combination of the changes in births, deaths, and migration may also contribute to the different projections. Following is an explanation of each parameter that effects the difference in population.

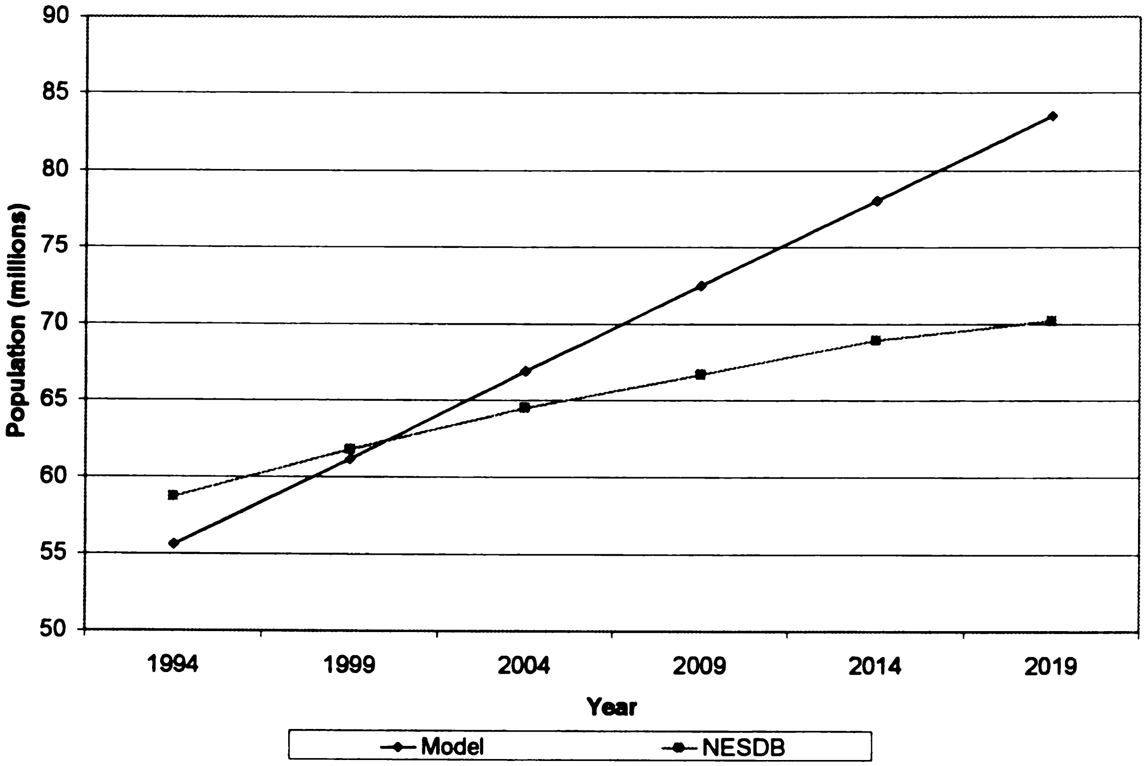


Figure 25: Population Projection Results From Different Studies

Table 8: Projected Total Fertility, Crude Birth and Crude Death Rates, 1999-2019

Year	Total Population (million)		Total Fertility Rate (per woman)		Crude Birth Rate (per 1,000 women)		Crude Death Rate (per 1,000 population)	
	Study	NESDB	Study	NESDB	Study	NESDB	Study	NESDB
1999	61.2	61.8	1.72	1.96	15.3	17.0	6.2	7.9
2004	66.9	64.5	1.63	1.87	13.7	15.7	6.6	8.2
2009	72.5	66.7	1.54	1.81	12.1	14.6	7.0	8.5
2014	78.0	69.0	1.45	1.78	10.9	13.7	7.5	8.8
2019	83.6	70.2	1.36	1.76	10.0	12.9	8.1	9.3

A large population in a certain area generally results from a high birth rate and low death rate. However, low birth rate and very low death rate could also cause the population to increase. The former case better fits the situation in Thailand as observed from historical statistics. The basic measures of birth and death rates, TFR and CDR, are used here to compare the variables used in both models. Projections on TFR and CDR from both models are different. For the birth component, this study used a linear relationship to trend the age and sex specific birth rate. It is expected that TFR will decrease from 1.72 to 1.36 births per woman in 1999 and 2019 respectively, a decrease of 23.3 percent. The NESBD model used a nonlinear relationship (second-degree exponential function, Figure 26) to perform the projection of age and sex specific birth rates. The calculated TFR is expected to decrease from 1.96 to 1.76 births per woman or 10.2 percent in the same period. It is likely that the lower estimate from the NESDB study is the result of the birth rate that was trended to decrease at a faster rate in the NESDB model than in this study.

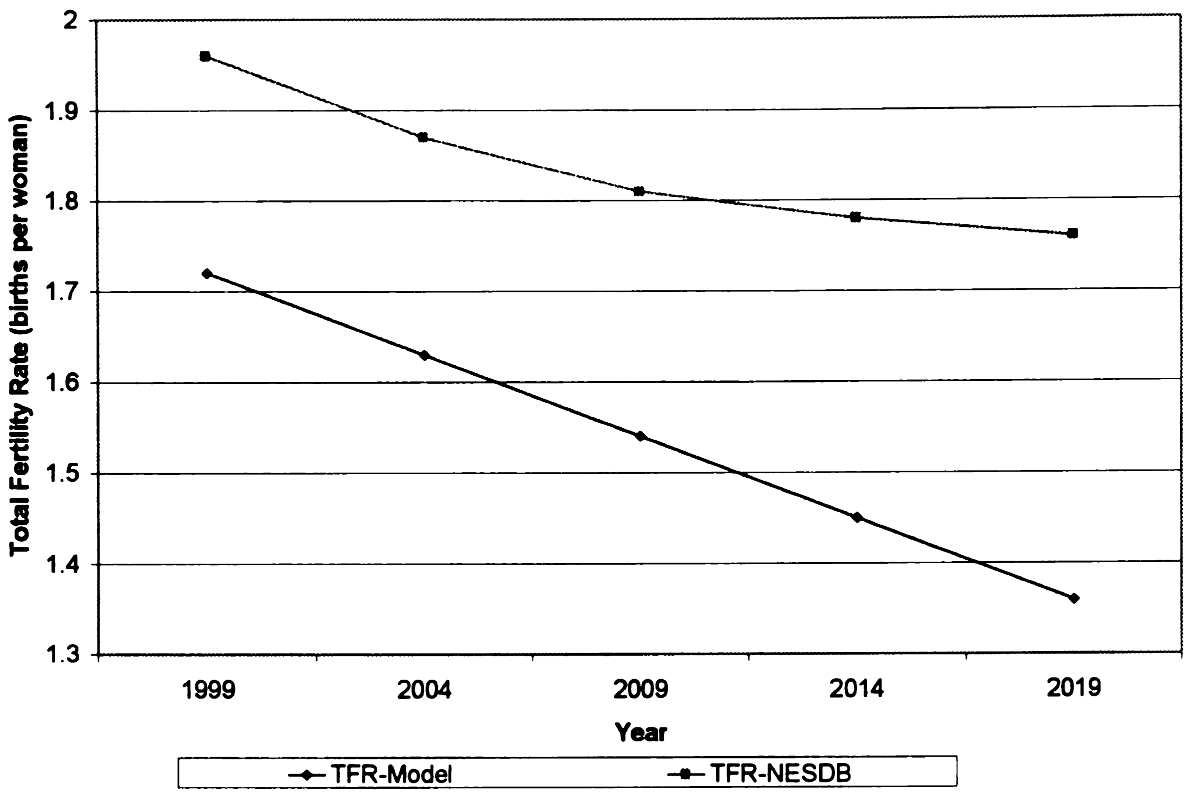


Figure 26: Projected Total Fertility Rate, 1991-2019

In terms of death rate, calculated CDR in this study was derived by dividing the summation of number of deaths in each age group and sex by total population in each year. CDR is expected to increase from 6.2 deaths per 1,000 population in 1999 to 8.1 deaths per 1,000 population in 2019. The explanation for the increase of the CDR is based on assumptions formulated for fertility and mortality. In this study, birth rate was trended to decrease much faster than death rate, a 1% and 0.1 % decrease per year for birth and death rate respectively. When this is the case, the number of deaths will increase faster compared to number of births, and population will increase at a decreasing rate. As a result, the CDR will increase.

The life expectancy at birth for males and females were not calculated because the life table was not available for this study. The NESDB model calculated CDR from the age and sex specific survival rate (survival rate = 1 – death rate). The survival rate was derived from the life table that was used to calculate the expectation of life at birth. The assumption to calculated age and sex specific survival rate was that the life expectancy at birth would decrease at a falling rate. Based on this assumption, CDR is expected to increase from 7.9 to 9.3 deaths per 1,000 population or 17.7 percent increase between 1999 to 2019. The projected CDRs by the NESDB model were higher than the projected CRD in this study in both years. It is not surprising that the NESDB population estimate is lower than the estimate from this study because the NESDB trended TFR to decrease at a faster rate than this study, at the same time used higher CDR

Migration is the other variable that causes population change and deserves special attention when population change in a small area is of major concern. In this case, migration is not a major concern because the comparison is at the national level. Migration within and between provinces will not effect total population. Although migration in and out of the country will effect total population, the impact from these types of migration on total population of Thailand is small because Thailand has a very small rate of immigration and emigration.

In summary, the national projections of population from 1999 to 2019 revealed that the population of Thailand will increase from 61.2 to 83.6 million people and the TFR will decrease from 1.72 to 1.36 births per woman in this period. The change in total population will increase at a decreasing rate and the rate of urban population change (increase) will be higher than the rate of rural population change. By 2019 Thailand is expected to have 46.3 percent of the total population living in urban areas and 53.7 percent of the total population living in rural areas. Regionally, the greatest urban population will be concentrated in the central region while the largest percent growth in urban population would take place in the BMR and the EBMR. At the provincial level, approximately 79 percent of provinces in Thailand will experience an increase in the proportion of urban population while the rest of the province will experience less than 2 percent increase in non-urban population. Major interprovincial migration streams in the period 1994-2019 will be concentrated in the BMR and the EBMR. These are the areas where dramatic urban and non-urban population change would take place.

CHAPTER IV

ELECTRICITY MODEL: GENERAL DISCUSSION AND LITERATURE REVIEW

Chapter 4 is organized into 2 sections. The first section discusses residential electricity consumption in Thailand, in terms of its relation to three issues: population growth and economic performance, electricity end use efficiency, and electricity supply. The second section reviews literature related to residential electricity modeling. The review focuses on three topics. These include previous studies on residential electricity demand modeling, factors effecting the demand, and projection of electricity demand in the residential sector in Thailand.

I. RESIDENTIAL ELECTRICITY DEMAND IN THAILAND

4.1 Population Growth and Economic Performance Outlook

One way to obtain a general idea of residential electricity consumption in Thailand is to observe the previous trend of per capita electricity consumption in the residential sector and to look at the residential electricity consumption per gross domestic product (GDP).

The International Energy Agency (IEA, 1995) reported that per capita residential electricity usage in Thailand increased during the period 1974-1993 with a slight drop in 1985 (Figure 27). Residential electricity consumption per GDP also increased in this period except for 1987 and 1988. These measures indicate the increasing trend of residential electricity consumption as the economy of the nation is expected to continue to grow in the future.

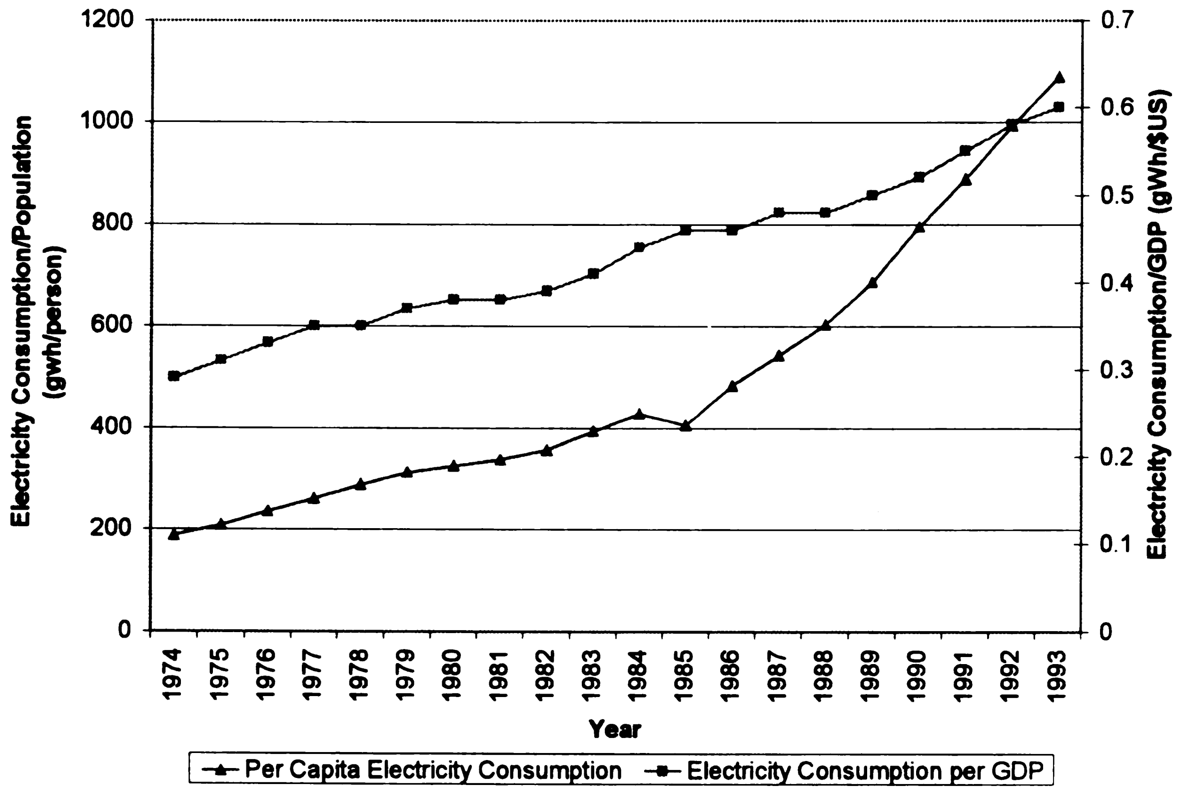


Figure 27: Thailand Residential Electricity Consumption, 1974-1993
(Source: International Energy Agency, 1995)

Another way to examine the relationship between residential electricity consumption, economics, and population is to examine the trends of growth in electricity sales per capita and the growth in electricity consumption per residential customer. Figure 29 shows the relationship between the *electricity sales and per capita income* of countries in the East and South East Asia. At a given income, there is a considerable spread of the sales per capita over time among countries, with the Philippines and Korea at the extremes and Thailand as well as the other countries at an intermediate level. On the contrary, the residential electricity *sale per customer or household* at a given income of these countries except Korea lies close to each other, with little change over time (Figure 28).

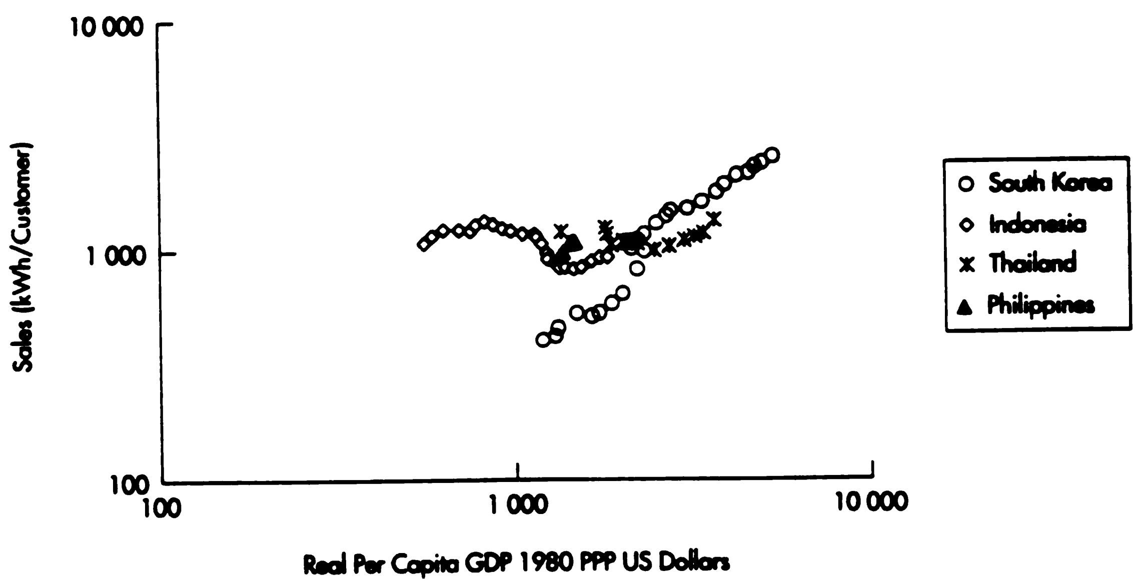


Figure 28: Per Customer Residential Electricity Use
(Source: International Energy Agency, 1997, p.126)

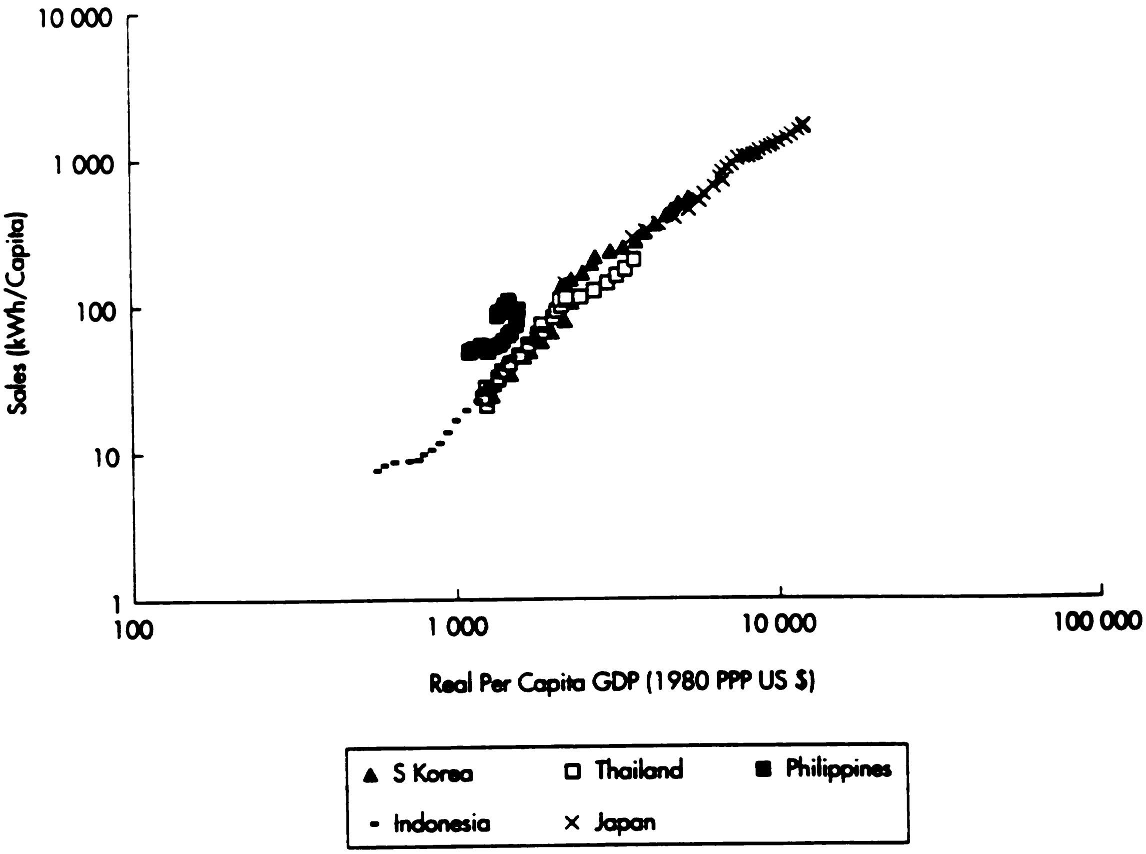


Figure 29: Per Capita Residential Electricity Use
(Source: International Energy Agency, 1997, p.126)

The explanation for these contradictory phenomena is that the growth in sales per capita is caused almost entirely by the electrification of new households. The growth in total sales per capita reflects the increasing electrification of new households in these countries. Korea is the exception because the process of electrification in this country was almost completed by the early 1970s. The electricity sale per customer reflects the ownership of electric appliances and usage. Slow growth in consumption per customer takes place after a household obtains electricity. The rising number of new connected households are usually the low-income users (due to rural electrification programs) with low usage. Consequently, the average consumption per household is pulled down by the low usage of this group. When the electrification of households nears the saturation point and incomes continue to grow, the total electricity use will change based on the number of appliances per household.

The level of urbanization and electrification is related to per capita electricity use at given a GDP. Philippines has larger per capita electric consumption than Thailand as shown in Figure 30 because Philippine households are in urban areas, even though more households in Thailand are electrified.

The historical and current electricity consumption in Thailand can be summarized as follows. The slow growth of electricity consumption per capita during 1974 – 1988 resulted from an increased number of new electrified households, mostly low-income households in non-urban areas (low usage). In 1992, 98.2% of households were electrified. The growth the consumption has increased more rapidly in recent years, driven by the growing numbers of appliances per household accompanied by the growing GDP. However, appliance ownership in Thailand is still far from approaching the saturation point as seen in most western countries such as the U.S., Sweden, and Denmark. The ownership of selected appliances in electrified urban and non-urban households in Thailand is show in Table 9. Appliance ownership is different between urban and non-urban Thai households. Households in urban area generally have an average household income higher than the household income in non-urban areas. Appliance ownership in urban areas is also higher than ownership in non-urban areas for most appliance types.

Table 9: Thailand Selected Appliances Owned by Area (Percent of Households), 1991

Selected housing characteristics and appliance	Total	Urban Area	Non-Urban Area
Electric lighting	89.7	99.0	87.5
Radio	81.3	87.4	79.9
Color television	46.2	77.9	38.6
Electric rice cooker	61.2	90.0	54.3
Electric fan	72.1	93.7	67.0
Refrigerator	36.0	70.8	27.7
Iron	54.5	87.3	46.7

(Source: Housing and Population Census, National Statistical Office, 1990)

4.2 Electricity End Use Efficiency

The residential sector comprised 20.6 percent of total electricity consumption in Thailand in 1994. The distribution of electricity end uses in this sector in 1987 is shown in Figure 30. The highest percentage of electricity uses in that year was for heating and cooking. Lighting and refrigerators shared the same percentage for contribution to total electricity consumption. Share of a use of electricity for space cooling was lowest among other uses.

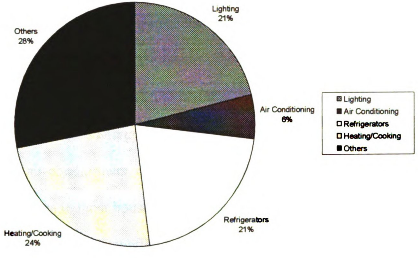


Figure 30: Distribution of Residential Electricity by End Uses (1987)
(Source: Thailand Promotion of Electricity Energy Efficiency Project, World bank and GEF Project Document, April 1993 in International Energy Agency, 1997)

Table 10:Potential for Efficiency Increases in Major Electrical Appliances

Appliance	Potential for Improvement (%)
Fluorescent tubes	20
Domestic refrigerators	22-50
Motors	2-10
Air conditioners (> 2 tons)	25-30
Fans	60
Compact fluorescent	60-75
Air conditioners (< 2 tons)	30-40
Luminaries	30-40
Fluorescent ballast	50-90
Rice cookers	11

(Source: International Institute for Energy Conservation, Bangkok, 1995 in International Energy Agency, 1997)

Electric appliances in most households in Thailand tend to be old and those purchased before 1990 are not energy efficient. The result of a 1995 study on the investment opportunities in energy efficiency industry in Thailand conducted by the International Institute for Energy Conservation (IIEC) indicates significant potential for improving efficiency in various electrical appliances and is summarized in Table 11. The study reveals high potential to increase energy efficiency for home appliances, especially refrigerators, fans and air-conditioners, as well as high efficiency fluorescent tubes and ballast. Electric appliances in most households in Thailand tend to be old and those purchased before 1990 are not energy efficient. It is expected that in the future more efficient appliances will be available affordable prices. As more efficient appliances replace less efficient ones, electricity consumption should fall.

A good understanding of the relationship between appliance efficiency and electricity demand is essential for planning. Determination of the consumption and efficiency of some appliances is not an easy task. Utilization of electric appliances is highly variable among households. For example, the consumption of lighting depends on house size and number of occupants, as well as habits of turning off unused light. Electric irons are important in Thailand because the kinds of fabric Thai people prefer require ironing. Consumption of electricity due to television is driven more by hours of operation and the size of televisions rather than the efficiency which has been remarkably improved.

Residential customers should benefit from greater energy efficient appliances because electricity bills will be lower. People's comfort levels will increase because of less heat generated from electricity used. Although it looks like the higher income group will gain more benefit from the improved efficiency of appliances that are not common to low income groups (such as air-conditioners, refrigerators, and other large appliances), it is expected that these appliances will become more affordable to the lower income group in the near future.

According to the residential energy savings plan in a 1991 Demand Side Management (DSM) Master Plan for Thailand Electric Power System prepared by IIEC, high electricity savings is expected from improving efficiency of home appliances, especially refrigerators, air-conditioners, ballasts, and fluorescent tubes. This plan was reviewed by EGAT, PEA, and MEA, and also was approved by the National Energy Policy Committee. The DSM plan also expects potential long-term total electricity savings to increase from 1,189 gwh in the period 1993-1996 to 22,177 gwh in the period 2007-2011. The DSM plan will attempt to curtail total electricity demand in evening peak hours (6:30 pm. to 9:30 pm.). The program also encourages households to reduce home electricity use by promoting thin-tube fluorescents[8], energy efficient refrigerators, and air conditioners. In 1996, EGAT spent $US 12 million on advertising to stimulate public awareness of energy conservation with a focus on these home electric appliances. The program also works towards creating energy-saving and energy efficiency concepts to be a matter of course and culture.

[8] A thin tube fluorescent refers to newly developed fluorescent tubes that provide an equivalent amount of light and use 10 percent less energy.

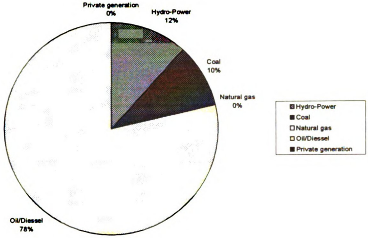
4.3 Electricity Supply Outlook

Generation of electricity in Thailand depends on four sources of fuel input: coal or lignite, fuel oil/diesel, natural gas, and hydro-power and other[9]. According to the Energy and Industry Department, Asian Development Bank, (1993), total electricity generation in Thailand increased from 14,001 gwh in 1980 to 43,189 gwh in 1990. Corresponding to the total generation, changes in generation mix in this period, by fuel type, were illustrated in Figure 31.

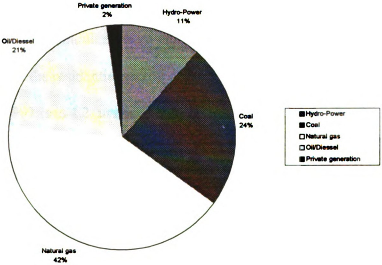
Currently, EGAT (1996) reported that gross electric generation rose 9 percent from the previous year. The country's electricity supply was met by the generation by fuel type consisting of 28 percent from natural gas, 26 percent from bunker oil, 20 percent from lignite, 4 percent from diesel oil, 9 percent from hydro power and 13 percent purchased from private utilities. These electricity shares from all energy sources except natural gas were on the increase. The increases were 6, 19, 50 and 8 percent for bunker oil, lignite, diesel oil and hydro power respectively. The plan for future fuel sources has to take into consideration that fuel choices must satisfy the demand and be environmentally, economically, and socially acceptable. It seems that the future power supply of Thailand will rely on lignite and coal for several reasons. New hydropower projects will be extremely difficult to build because of the opposition to hydro-power schemes. Any new development will be limited to a few economically efficient, small-scale and

[9] Other fuel input includes solar, biomass, geothermal, and wind energy. These inputs are used in small scale to produce electricity at experimental stations.

environmentally benign projects. Although natural gas is a preferred fuel from an environmental perspective, the availability of domestic natural gas seems to be limited. The Petroleum Authority of Thailand (PTT) forecasted that gas production would reach a peak in year 2000 and steadily decline. To diversify away from oil has always been the goal of the country because Thailand has very limited oil reserves. However, depending on the oil price, oil is considered an option for power generation due to higher efficiency. From a supply standpoint, coal/lignite is the most favorable fuel because of a large domestic reserve. The availability of coal in the international market and the stable price make it a competitive fuel. Since power plants produce sulferdioxide, installation of flue gas desulfurisaton (FGD) technology is now required by the Thai government for all new coal fired projects. EGAT also considered nuclear power as an option. The World Bank conducted a study on costs of nuclear power and concluded that it was not a competitive option in Thailand (IEA, 1997). Nuclear power also received strong public opposition as two proposed nuclear power plants by EGAT that were approved by the Cabinet had to be postponed. Eventually, the plants were not included in the current Power Development Plan (PDP) 1995-2001 which was prepared for the NESD plan in the period 1996-2011.



1980 Fuel Source



1990 Fuel Source

Figure 31: Electric Generation Mix by Types of Fuel Source, 1980 and 1990
(Source: Asian Development Bank, 1993)

The last alternative that can be viewed as a "new" fuel source is conservation (or energy savings or rational energy use)[10]. Kleinpeter (1995) referred to the World Energy Council that classified energy savings into four categories. The first category deals with energy savings resulting from changes in user behavior without intervention on a technical level. The second involves energy savings from improving control systems. The third relates to energy savings from system improvement without fundamental changes in the system or energy substitution. The last one focuses on energy savings through fundamental changes in the system or the use of another form of energy or technology. In the case of the residential sector, electricity conservation falls into the first category. Energy policy-makers could explore strategies and incentives that will make users react more cautiously regarding electricity use. An alternative such as improving information or communication on energy savings can be utilized to promote conservation behavior in the residential sector. EGAT pursued this option as it launched the DMS program in 1992 (see 4.2. under Electricity End Use Efficiency).

[10] World Energy Council Energy Dictionary provides following definitions concerning energy as below:

Rational energy use: utilization of energy by consumers in a manner best suited to the realization of economic objectives, taking in to account social, political, environmental and financial constraints.

Energy conservation: term that defines a policy embodying the actions to be taken to ensure the most efficient use of finite energy resources.

Energy saving: measures or the results of measures taken by suppliers and users of energy to limit or avoid wastage.

II. RESIDENTIAL ELECTRICITY DEMAND MODELING

4.4 Studies on Residential Electricity Demand Modeling

Studies conducted in the area of electricity demand in the residential sector, especially in developing countries, are limited. Most studies conducted in the past utilized econometric tools. Electric consumption is considered like other economic goods. That is, income, production, substitution, and prices play a major role in electricity demand related relations and equations. Nelson (1965) stated the possibility of deriving the residential electricity demand from the demand for electricity consuming goods and also found a strong relationship between electricity price and the quantity of electricity consumed in the residential sector. His conclusion that income was not a significant factor that determined electric consumption in households, but that consumption was related to time, was contrary to other studies[11]. Anderson (1973) and Lyman (1994) reported other factors contributing to the demand for electricity in the residential sector to include the price of electricity and its substitution as well as climate. Climate was a factor in utilizing electric heaters and air-conditioners and contributed to a large portion of total electricity in the Northern countries. Another contributing factor was urbanization, as stated in the studies conducted by Anderson (1973), and Westley (1989).

[11] Finding that was opposed to studies conducted Nelson includes studies conducted by Wilson (1971), Anserson (1973), Action, Mitchell, and Mowill, 1976, Westley (1989), Berndt and Samaniego (1984), Economic and Social Commission for Asia and the Pacific (1991), Imaran, and Barnes (1991), and Lyman, 1994.

Berndt and Samaniego (1984) emphasized the effect of accessibility to electricity to the demand.

Recently studies have examined that looked at electricity demand from end uses. The idea was that household electricity is always consumed through electric appliances. In this method, the residential demand is projected from the actual electric appliances owned and used in households. This method is known as the end use method, also called the techno-economic method because it considers both economic and technological parameters. This method, in some respects, addresses the limitations of econometric techniques one encounters when performing electricity projection (Chateau and Lapillonne, 1991). The requirement of reliable historical data for this approach usually constrains the level of disaggregation and the choice of explanatory variables. Parameters estimated using econometric techniques (particularly elasticities) are not stable in time because of the rapid change most countries have to confront. Estimated parameters usually depend upon a regression period. Thus, long term projection is not easy to perform using this technique. Finally, technology change, and electricity savings, in particular, cannot be well reflected in econometric models.

The end use methods also have limitations. They require fairly detailed information that goes far beyond what usually is necessary for econometric modeling. These methods are best used when household appliance ownership and usage information is available. Information from a residential electricity consumption survey and household appliance manufacturer are good information sources. Utilization of end use methods, for electricity projection purposes implies quite a number of assumptions on exogenous variables that have to be reasonably consistent among themselves. The advantage of these methods is that they are straightforward and the results are easy to understand. The calculation simply involves the number of operation hours multiplied by the required watt input to operate the appliance. The end use approach has been successfully applied in many countries for energy demand projections (Division of Energy Information Administration, U.S. Department of Energy (DOE), 1993), for the assessment of energy conservation policies (Division of Energy Information Administration, U.S. Department of Energy (DOE, 1993), as well as for historical energy demand analysis (Department of Housing and Urban Development (HUD), 1972).

In the case of Thailand, there are very few studies that deal directly or attempt to project residential electricity demand. Most studies were conducted by international organizations and performed analysis of residential electricity from historical trend data. The Asian Development Bank (ADB, 1993) conducted a study on the relationship between electricity consumption, and real GDP. They found that electricity elasticity was 1.43 for Thailand compared to 1.15 for Newly Industrialized Economies (NIEs) in the period 1980 – 1990. This means that if the real GDP increases by 1 unit, the residential electricity consumption will increase by 1.43 unit. Other studies conducted on residential electricity end use were performed by EGAT (1997) and The International Energy Agency (IEA, 1997). Both studies concluded that the main growth in residential electricity demand is due to the increasing consumer demand for electric household appliances such as air conditioners and refrigerators. These and many other appliances, once considered luxuries are now standard in many households because the appliances are available at much lower prices.

4.5 Factors Effecting Residential Electricity Demand

Contributing factors effecting the residential demand for electricity in Thailand seem to be similar to the findings in previous studies. Explanatory variables that are likely to influence the demand for electricity in the residential sector of Thailand include income level per household, climate, the share of households located in urban areas, electricity price, the price of electricity substitution, accessibility to electricity, ownership of appliances per household, and technology change.

The ideal for this study is to incorporate as many as possible variables into the model. However, this study focuses more on household and housing variables or characteristics because of inadequate data on other variables. The following section provides an overview of the Thailand household and housing characteristics that effect home electricity usage.

4.5.1 Household Characteristics

Household characteristics that are related to household electricity usage or demand are the number of households in the study area and the average number of people in each household. The number of existing and new households determines the number of electricity users, which in turn determines the household electricity demand. Therefore, housing stock is important information for residential electricity demand projections. In Thailand, HOMES (Household Model for Economic and Social Studies; Mason and Campbell, 1993) is used to project the housing demand and required residential construction at the national level. The model takes into account population growth and changes in composition as well as tenure composition. The projections show an increase of Thai households from 10.2 million in 1985 to 21.9 million in 2015 with an average annual growth rate of 2.5 percent and a population growth rate of 1.3 percent.

Following housing stock, locations of households or the percent of households in urban and non-urban areas also effect the demand for electricity more at the regional and provincial level. So far, there has not been any attempt to project the number of households in urban and non-urban area at these levels. The share of urban and non-urban households, however, could be derived from the population in each area divided by the average of the household size.

Because electricity is a shared household resource, electricity consumption is more closely related to the number of households than to total population. The average household size is used to determine the number and types of households. According to Mason and Campbell (1993), the average household size for Thailand was 4.6 members in 1990 and was estimated to reduce to 3.5 members per household by 2010. The difference of household size in urban and non-urban areas was not large. The Population and Housing Census, 1990, reported the average number of members in households in urban areas to be 3.5 – 4.6 persons per household and 3.7 – 5.1 persons per household in non-urban-areas.

4.5.2 Housing Characteristics

As far as electricity demand is concerned, there are three housing characteristics that effect the demand for residential electricity consumption: 1) housing type, 2) size of housing, and 3) accessibility to electricity and ownership of appliances. First, the housing types in Thailand are categorized into detached house, row house, town house, and apartment or condominiums. The number of each type of housing is important for determining housing stock. In Thailand, 96 percent of households are family households. These households are detached, row houses and town houses (1990, Population and Housing Census).

The second housing characteristic is the size of housing which refers to floor space of houses. The floor space of a house determines the amount of energy used for cooling, heating and lighting a house. The other aspect of a house that largely effects the cooling and heating system of a house is the thermal shell of the house in which it is installed. In Thailand an efficient thermal shell is not commonly installed in typical households. If the thermal shell is installed, the purpose of it is for shielding the house from the outside heat. The more important aspects of housing that relates to the comfort level of a household in Thailand are building materials and roofing. However, no information regarding building material has been collected. For roofing information, the National

Committee Rural Development's survey (NCRD, 1994) reveals that corrugated tin roofing is a relatively common roofing material used by households in non-municipal areas of the nation. The tin roofing attracts heat better than other roofing material and thus makes a house uncomfortable due to heat buildup.

The third important housing characteristic relates to electricity services or the accessibility to electricity. Approximately 87.5 percent of private households in non-urban areas and 99 percent of households in urban areas in Thailand have had access to electricity since 1992. These numbers indicate that Thailand almost approaches the saturation rate in terms of electrification. Therefore, the determining factors for residential demand for electricity depends on the penetration rates of electric household appliances rather than the electrification rate. Currently, the ownership of most electric appliances per household in urban areas is higher than non-urban areas (see Table 10). However, appliance ownership in urban Thailand is still far from saturated levels.

4.6 Residential Electricity Demand Projection in Thailand

Thailand estimates the electricity demand in the residential sector at the national level by extrapolation from historical trend. However, it has been proposed to use the end-use approach in order to perform projections of household electricity demand (EGAT, 1997). The model attempts to estimate future demand at the national level using the end-use approach to represent household electricity consumption behavior based on electric appliance ownership and the use of the appliances. The model can be described mathematically as:

$$\Sigma E_{ijkt} = S_{ijkt} * ESR_{ijkt} * U_{ijkt}$$

where:

E = Electricity consumption

S = Saturation rate / share of appliances own per household

ESR = Number of watts required for each appliance (watts)

U = Utilization of each appliance (hours)

i = Type of appliance

j = Income

k = Types of households

t = Projection year

Data preparation for the model can be described as follows.

1. Project of number of dwelling

Estimated number of dwelling will be performed based on future population and number of household. Projected population will be obtained from NESDB (EGAT, 1997). Number of population per household was obtained by extrapolation from previous time trend data.

$$\text{Number of Household} = \frac{\text{Number of Population}}{\text{Number of Population per Household}}$$

2. Classify and project dwelling by income

Classification of dwelling by income will be based on a survey conducted by EGAT and the NSO report on social and economic of households in Thailand. The dwelling will be classified based on household income per month into 6 groups which can be listed as:.

1) Income less than 5,000 baht[12]/month
2) Income is between 5,000 – 7,000 baht/month
3) Income is between 7,000 – 15,000 baht/month
4) Income is between 15,000 – 25,000 baht/month
5) Income is between 25,000 – 50,000 baht/month
6) Income more than 50,000 bath/month

Projection of dwelling by income will be made based on the assumption that the number of low income dwellings will decrease while the number of medium and high income groups will increase on the condition that income from each group multiplied by average income of the nation equals to Gross National Product.

3. Classify and project types of dwelling based on income

Types of dwelling based on income were classified into 5 groups which is listed below:

1) Detach
2) Rowhouse
3) Townhouse
4) Apartment and Condominium
5) Other

[12] $US 1 is approximately 36 baht as of November 1998.

Projection of dwelling by income will be carried out based on the housing construction permit data and the assumption that the proportion of number of dwelling in each type will be not changed from the period of conducting survey (short term) and the projection period (long term)

4. Obtain data on electric appliance ownership, input watts required for each appliance and utilization of the appliances.

Only electric appliances that had a high rate of ownership per household and utilization rate will be used in the projection of household electricity demand. Appliances which will be included in residential electricity model for MEA are air conditioners, refrigerators, fans, light bulbs, electric rice cookers, washing machines, color televisions, and irons. Washing machines and irons will be taken out of the list and replaced by black and white televisions and freezers for the case of PEA.

5. Efficiency Factors

$$\textit{Efficiency Factors} = 1 - \frac{C}{N} * E$$

where:

C = substitution + new appliance

N = number of appliances

E = Rate of efficiency of electric appliances

Projections of the residential demand for electricity are currently interpolated from historical trends. The results of residential electricity demand projections, using the interpolation method, by MEA and PEA are presented in Figure 32 and 33 accordingly.

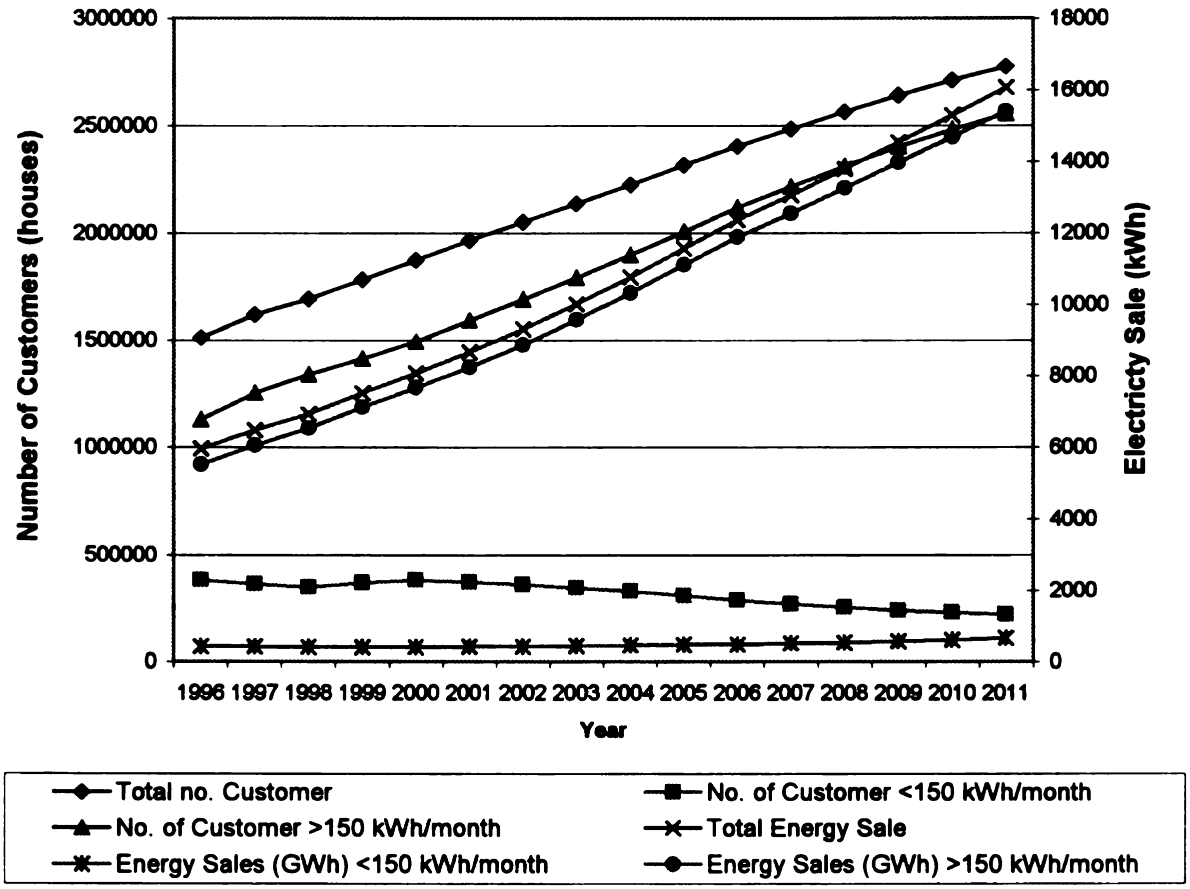


Figure 32: Projections of the Residential Electricity Demand for Bangkok Metropolitan Region by MEA (Very Low Case): FY 1997-2001
(Source: Metropolitan Electric Authority, 1996)

The projections of MEA indicate increases in both the total number of customers and sales in the period 1997-2011. However, if these two measures are examined by quantity consumption, the projections reveal different results for the case of smaller electricity users (<150 kWh per month users). The number of small users decreases gradually over this period while the sale for this group increases very little. Both the number of customers and sale for large quantity users (>150 kWh per month users) increases at a higher rate than the rates of total customers and sales. The projections of MEA suggest that the large quantity users in the Bangkok Metropolitan Region (BMR) play an important role, in terms of electricity usage, because this group are the major consumers of electricity in this country and will continue to grow; into the next decade.

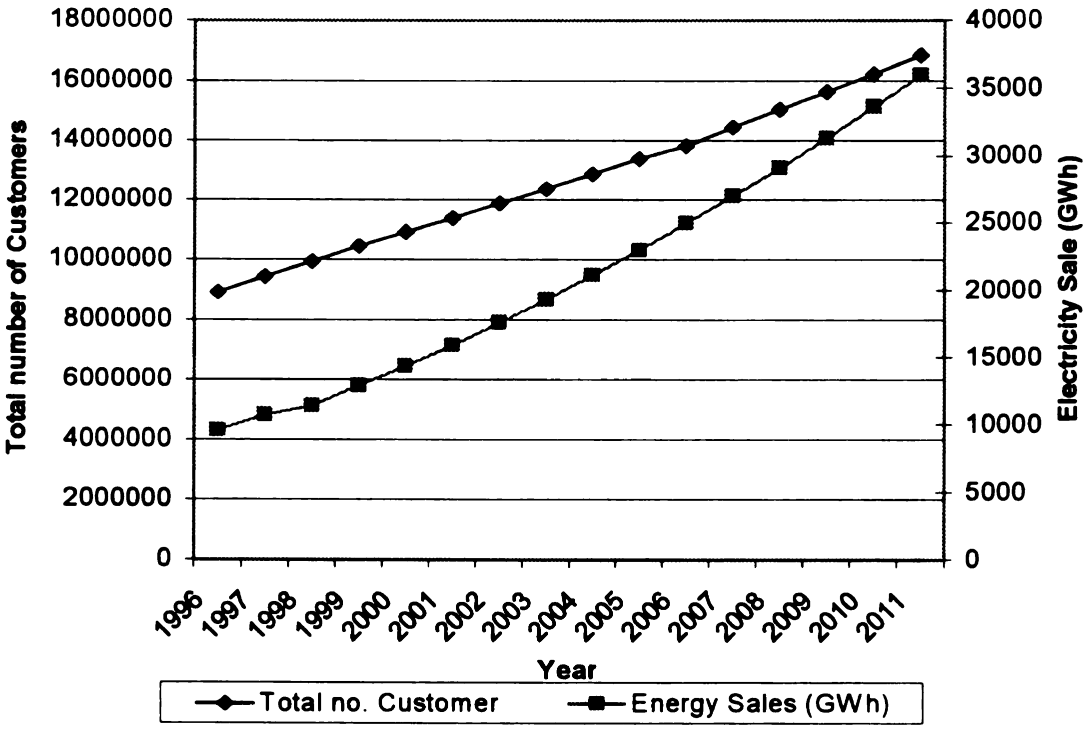


Figure 33: Projections of the Residential Electricity Demand for 73 Provinces by PEA (Very Low Case): FY 1997-2011
(Source: Provincial Electric Authority, 1996)

The projections from PEA do not show the breakdown of customers in terms of the quantity of electricity consumed per household (Figure 33). Over all, both the number of customers in 73 provinces, excluding BMR and electricity sales, increase over time. The growth of energy sales increases at a higher rate than the increase of total customers.

Both MEA and PEA projections indicate the near saturation of electrified households in the country because the sales increase at a higher rate than the number of customers. In other words, the increasing sales are driving the increasing number of appliances per households, rather than the increasing number of new customers.

In summary the demand for residential electricity is growing rapidly in Thailand, primarily because of the increasing number of customers and the increasing number of customers who acquire more appliances over time. Information concerning household characteristics and the behaviors of electric appliance users is crucial for electricity projections. Improved technologies, in the future, would make appliances available at lower costs and, at the same time, make appliances that are more energy efficient. The ability to assess the impact of changes in electricity consumer behavior and technology is an important task, especially when demand side management is to be pursued. Modeling electricity consumption or demand in the residential sector, using an end use approach, serves this purpose.

CHAPTER 5

RESIDENTIAL ELECTRICITY MODELING: METHODOLOGY AND RESULTS

Chapter five is divided into 2 sections. The first section discusses the methodology for residential electricity demand modeling. The methodology section includes an explanation of the types and sources of data as well as processing and data preparation in this study. The assumptions and calculations involved in the model are also discussed in this section. The second section presents and discusses the results, and compares projections of residential electricity demand from different studies.

I. METHODOLOGY

5.1 Introduction and Overview of the Model

Residential electricity modeling, in this study, looks at electricity consumption as a function of the number of household rather than total population, because electricity is a shared household resource. For example, a color television is shared by members of a household, whether the number in the household is 3 or 6. Accordingly, the total number of color televisions is more closely related to the number of households than to the total population. In general,

Residential electric usage	=	f (Households, appliances, usage level)
Household	=	f (Population, household size)

This study incorporates the end-user approach to reflect the aforementioned relationship in projecting electricity usage in the residential sector of Thailand. The model developed in this study characterizes the long-term structure of electricity consumption for typical Thai households in urban and non-urban areas in each province under differing assumptions. This model incorporates the roles of changing social (population and household), economic (appliance ownership and usage), and technological (unit consumption of electric appliance) variables based on other studies, appliance manufacturer guidelines, and expert opinion. Expert opinion, in this case, was based on reading materials, the local knowledge and educated assumptions of the researcher to project future demand for electricity. The output of residential electricity consumption is the consumption in terms of total electricity usage and electricity usage by types of appliances for urban and non-urban areas at national, regional and provincial levels.

Electricity usage of households in each area was calculated from the saturation rate of each appliance, appliance usage intensity, unit input (watts) of appliance, and number of households. The future changes of these input parameters were depicted using expert opinion and applied to the model using trending methods. The scenario approach was also used to look at the relationships between these variables under different levels of parameters. Three scenarios (low, medium and high) were formulated to reflect these changes. The results provide a range of future consumption rather than just one number.

5.2 Data Sources and Inputs to the Model

The residential electricity consumption model requires input data at the household level in urban and non-urban areas in each province of Thailand. Two major types of inputs were identified and obtained from multiple sources. These include housing characteristics and electricity appliance inputs.

5.2.1 Housing Characteristic Inputs

Households are the basic unit of the residential electricity consumption model. The number of households was used to derive the electric utility customers in the residential sector. There are two variables that determine the number of utility customers. The first variable is the household size or the average number of persons per household by areas (urban and non-urban). These data were obtained from the 1990 Provincial Population and Housing Census. The second variable is the total population in urban and non-urban areas for each province, which was obtained from the projection results of the population model. Dividing the projected population number by the average household size yields the number of utility customers.

5.2.2 Electric Appliance Data Inputs

There are two types of data associated with electric appliances in the model: ownership, and unit input power and the intensity of usage. The first type, appliance ownership data, was obtained from the 1990 Provincial Population and Housing Census. These data are in a tabular form for urban and non-urban areas in a province. The rows contain a list of nine types of electric appliances. For each row, there is a column with information on the number of households that own the appliance listed in the associated row. Appliances included in the model are radios, color televisions, black and white televisions, VCRs, electric irons, electric rice cookers, electric fans, refrigerators, and air conditioners. Two additional appliances were incorporated into the model. Computers were added because of the increasing use of personal computers in households. The other, so called appliance, is lighting. It is necessary to include lighting into the model because lighting accounts for a large portion (24% in 1995) of the total residential electricity consumption in Thailand.

The second type of electricity appliance data is the unit input power (or size, also known as wattage) and the intensity of usage of appliances. Both sets of data are usually obtained from the household survey on electricity. In the absence of current survey data on electric appliance usage for Thailand, the data used in this study was obtained from other sources listed as follows:

- *Metropolitan and Provincial Electric Authority Thailand*: Electricity sale data, number of customers, and total electricity consumption at national level.
- *Asian Development Bank Study on Energy End Use*: India Household Survey
- *Hawaiian Electric Company*: Consumer Guide to Energy Costs for Household Appliances.
- *BECi*: Residential Services and kWh usage of electric household appliances.
- *Edison (International) Electric Institute*: Energy house consumption patterns and appliance descriptions
- *Solardome:* Energy Consumption of Household Appliances

Information on the power input and intensity of usage of electric appliances from the above sources was used as a starting point for a base data in the model in this study. Average power input of appliance and intensity of each appliance usage were chosen based on educated assumptions of the researcher.

5.3 Preparation of Baseline Data

Baseline data preparation involved processing two types of data: population and housing data and electric appliance data. Both types of data were entered and processed in MS Excel. After the processing, both data were exported and stored with other data in MS Access.

5.3.1 Population and Housing Data

Population and average household size data were used to determine the number of households. Population data used in residential electricity model was obtained from projected population in urban and non-urban areas from the population model at the provincial level. Data on number of persons per household, obtained from the provincial Census, was not classified based on urban and non-urban areas in each province. The classification of this data was based on administrative boundary, which was divided into five areas: municipal area, sanitary district, urban sanitary district, and non-municipal area and outside sanitary district. This classification needed reclassification so that the household size data would conform to the projected population data.

Based on the Ministry of Interior definition of municipal areas and urban subdistricts, the definition is similar to the definition of urban areas in the population model. Therefore, these areas within in each province were grouped together and the NCR2D provincial codes were assigned for each province. The sanitary districts, and non-municipal area and outside sanitary district were also grouped together and recoded.

5.3.2 Electric Appliance Data

A table of appliance ownership was created with the rows containing a list of provinces by urban and non-urban areas and 11 columns of appliances, indicating the number of households that own the appliances. The NRC2D codes were assigned to provinces. The ownership data was used to calculate the saturation rate for each appliance in each area.

Since the census did not provide computer ownership data, this data was assigned to households based on household location. It was assumed that households in non-urban areas did not have personal home computers. Ownership of computers (number of household with computer) for households in urban areas was assigned based on the percent of total households in each area. The criteria for assigning computer ownership value was that urban areas with major universities and areas closer to Bangkok received higher values than urban areas located further away from Bangkok. The assigned numbers were 10 percent for Bangkok, 5 percent for urban areas in the 3 provinces in the Bangkok Metropolitan Region, 5 percent for the urban areas of provinces with major universities (Chaingmai, Khon Kan, Nakhonratchasima, and Songkhla), and 1 percent for the rest of the urban areas of the country, and none for the rural areas. The criteria and percent were formulated based on the educated assumption of the researcher.

In the case of lighting (light bulbs), data on the average lighting used per household by urban and non-urban areas in each province was not available. Therefore, this number was calculated from the total electricity sales divided by the total number of households and multiplied by the proportion of lighting to the total electricity consumption (24%). The derived value was assumed to be the same for every household with access to electricity. This assumption was necessary because baseline data of variables for projection of average lighting consumed per household such as, floor space, types of light bulb and tubes were not available. Moreover, modeling detailed household lighting is tedious and complicated and is beyond the scope of this study.

Because of limited available data, some input variables that effect ownership and the intensity of usage of appliances are not included in this study. These variables include lifetime of appliances, purchase price, substitutability, efficiency of appliance, and electricity price. The first four variables influence ownership and the last variable effects the intensity of appliance usage.

5.4 Residential Electricity Consumption Model

The residential electricity consumption model in this study was developed by integrating the results from the population model and using this result as the base for projecting the electricity consumption in a household. Calculation of the residential demand for electricity was performed based on average use of electric appliances owned by an average single family in urban and non-urban areas in each province of Thailand. The relational database MS Access was used to create necessary tables, to store data, and to report the results. The Visual Basic programming language was used to define and run the model.

Projection of residential electricity demand involves modeling kilowatthours consumed from appliance usage in Thai households. The model includes three key variables for appliances throughout the course of the projection: ownership, and intensity of usage and power input/size. When combined with the number of electrified households, these variables determine the residential sector electricity usage of Thailand. The relationship of these four variables are described in the equation below:

$$E_a = \Sigma\ (Usage\ *\ Size_a\ *\ Ownership_a\ *\ Number\ of\ electrified\ households) \qquad (5.1)$$

Where:

E_a = *Total electricity consumption of an appliance per year*

a = *A household electric appliance type a, a = 1 to 11 types*

Projections of E_a in this study were performed at the provincial level for the urban and non-urban households of 76 provinces of Thailand. The process involves formulation of assumptions and the projection can be described in the steps and orders as the calculations were performed in the model. The assumptions and calculations are summarized below.

5.4.1 Numbers of Electrified Household for each Province

Calculation

The calculated number of electrified households in urban and non-urban areas was used as a representation of number of electrified households. The calculations were performed by dividing the projected number of urban and rural populations in each province by the average number of people per household in urban for the urban household case and rural for the non-urban household case. This calculation is presented as equation follows:

$$\text{Number of electrified household}_A = \frac{\text{Projected population}_A}{\text{Average People per house}_A} \qquad (5.2)$$

Where:

A = *Areas in a province, A = urban and non-urban area.*

Assumptions

Projections of the number of electrified urban and non-urban households were based on three assumptions regarding the household types and sizes.

1) *Electrification rate in urban areas is equal to the rate in non-urban areas and has reached the saturation rate.*

National statistics on electrification showed relatively high electrification rates of households in both urban and non-urban areas of the country. The rates are 99 % for urban areas and more than 90% for the non-urban areas. This assumption was formulated because there is no information on electric accessibility at the level of disaggregation required in this model.

2) *The major of type of households in Thailand is single family housing where the average household size varies from 3.5 – 4.6 and 3.7 – 5.1 persons per household in urban and non-urban areas respectively.*

The above household sizes are the ranges of the number of family members per household from the Provincial Census. Since there is limited data on types of households at the provincial and urban versus non-urban level, the above household size ranges were then assumed to belong to single family households that are the majority of the housing type in Thailand.

3) The household size will decrease by 25 percent within 25 years and the rate of decrease is constant.

The 25 percent decrease was used and was based on the NESDB average household size projection. The NESDB reported the percent decrease of household size from 1990 to 2015 to be 28 percent

It should be noted that the projection of electrified households or housing stock[14] should consider other variables such as housing decay rates[15] and vintage blocks[16]. These variables were not included in the model partly because of inadequate data. It is also not the purpose of this study to perform detailed projections of housing stock.

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[14] Housing stock refers to number of houses occupied in the base year (1994).
[15] Decay rate is the rate at which existing houses are removed from the housing stock.
[16] Vintage blocks are houses existing in 1994 versus houses built after 1994.

5.4.2 Ownership or Saturation Rate

Calculation

An electric appliance saturation rate represents the proportion of households owning the appliance to the total number of households. Saturation rates of all appliances in urban and non-urban households were calculated using the equation below:

$$\text{Saturation Rate}_{a,A} = \frac{\text{Number of household with appliance}_{a,A}}{\text{Number of household with appliance}_{a,A} + \text{Number of household without appliance}_{a,A}} \quad (5.3)$$

Assumptions

1) *The maximum number of each type of appliance owned in a household is one. In other words, the saturation is less than or equal to one.*

According to the census, saturation rates for most types of appliance are still low for Thai households. Therefore, it is reasonable to assume that no household owns more than 1 of each type of appliance.

2) *Consumer behavior in terms of appliance usage intensity is the same in urban and non-urban households across the country.*

This assumption was formulated because of inadequate information on electricity consumption behavior of households in Thailand.

3) The *adoption rate of electric appliances in urban areas increases at a higher rate than the non-urban areas.*

This assumption deals with future saturation rates of each electric appliance. In general, the change of appliance saturation rate over time of households in urban areas increases more rapidly than the change of the rate of households in non-urban areas (Figure 34). Future rates were determined and trended by applying percent increases of saturation rates to the current rate. Two curves that determine percent increases of saturation rates were created as shown in Figure 35. Because of insufficient historical data on appliance ownership, no mathematical equation was derived to represent the relationship between saturation rate and time. Instead, the current saturation rate of appliances was classified into 3 ranges: low (0-0.33), average (0.33-0.66), and high (0.66 to 1.0). Increase of saturation rate was assumed to increase at a higher rate and decreases as saturation reaches 1. That is, for non-urban households, the percent increase of the saturation rate (the slope of the curve) over the five-year period was assumed to be10 percent for appliances with a current rate within the low range, 5 percent for appliances with a current rate within the average range, and 0.5 percent for appliances with a current rate within the high range.

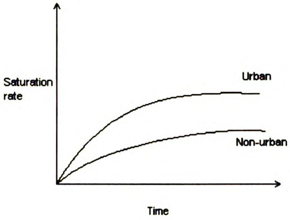

Figure 34: Change of Appliance Saturation Rate of Households in Urban and Non-urban Areas over Time

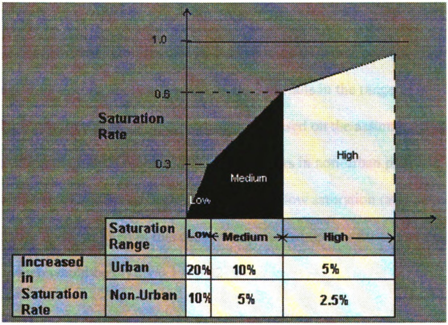

Figure 35: Trend of Saturation Rates of Electric Appliances

For urban households, the percent increase of the saturation rate over the five-year period was 20 percent for appliances with a current rate within the low range, 10 percent for appliances with current rate within the average range, and 5 percent for appliances with current rate within the high range. The percent increase of saturation rates in this model was assigned based on the researcher's opinion. These numbers could be changed later, based on other expert or policy maker opinions on various factors that may effect the appliance ownership situation.

The percent increase of saturation rate was applied for every five-year period. Future rate was estimated based on the current rate and the percent increase. An example of determining the increase of the saturation rate for an appliance can be illustrated as follows. The following example assumes a current saturation rate for air conditioners in a non-urban Thai household in province A in 1994 to be 0.02 or 2 percent. From Figure 37, the rate of 0.02 is considered a low saturation rate (falls in the range of 0 – 0.33). The increase of the rate for this range is 10 percent (0.1) based on the assumption in this study. Therefore, the saturation rate for air conditioners in non-urban province A in 1999 is the 0.02 + 0.1 = 0.12. This rate still falls within the low saturation rate range. The 10 percent increase is still applied in this case when calculating the saturation rate for the year 2004, which would be 0.12 + 0.1 = 0.22.

As far as calculations and assumptions for electric appliance input data is concerned, there are three points to be considered. The first one concerns applying trend and types of appliances. This study grouped electric appliances into 3 types: luxury or superior[17], normal and inferior goods[18]. Luxury goods include air conditioners, computers and VCRs. Normal goods include refrigerators, color televisions, radios, irons, and lighting. Inferior goods include black and white televisions and fans. All the inferior goods and some normal goods, (irons and lighting), were not trended. The reason for not trending these goods was based on the fact that these goods are relatively low price or affordable. Therefore, most consumers (households) will have already purchased these goods if they have access to electricity. This means that ownership of these goods will not significantly change in the future. Refrigerators and color televisions were trended based on the above mentioned criteria. For superior goods, the percent increase of the adoption rates in non-urban areas was assumed to be the same as the percent increase of the rates in urban areas. The percent increase of luxury goods in urban areas also followed the slopes in Figure 35.

The second point involves an issue of the substitutability of some of the household electric appliances. The appliances in this study that can be considered as substitute for each other are color televisions and black and white televisions, and air conditioners and fans. However, these goods are imperfect substitutes. For example, an "average" household that purchases a new color television will not discard an old black and white television. The household will use the old black and white television in a different room in the house. For these reasons, this model treats these goods as non-substitute.

[17] Superior goods are goods that demand increase with higher incomes.
[18] Inferior goods are goods that decrease in demand when incomes increase.

The third point is related to the issue of migration between urban and non-urban areas. By assigning different percent increase to appliance saturation rates based on areas, it is assumed that people who migrate into a new area will develop the consumption behavior in both appliance ownership and usage as residents of the new area within five years (the projection is performed every five years). Because household income was not factored into the model, the study assumed that the income earning potential in urban areas is higher than non-urban areas. Therefore, people who migrate to urban areas will have more income and are able to purchase and use more appliances than people in non-urban areas.

5.4.3 Annual Electricity Consumption by Types of Appliance

The calculation of annual electricity consumption was performed by types of appliance based on the intensity of appliance usage and the power required to operate each appliance. The equation used for the calculation was as follows:

$$\text{Annual Electric Consumption}_a \text{ or } kWh_a = (\text{Kilowatts Power Input}_a)(\text{Hours of operation per day}_a)(\text{Days of operation per year}_a) \quad (5.4)$$

where:

a = A household appliance type, a = 1 to 11

By summing up electricity usage of each appliance for all households in each area of a province, the model calculated total electricity consumption in the residential sector for each province by urban and non-urban areas. The calculation is represented in the equation as follows:

$$\text{Total } kWh_a = kWh_{a1} + kWh_{a2} + \ldots + kWh_{a12} \qquad (5.5)$$

Where:

kWh_a = *kilowatthours of appliance type a, while a = 1 to 11*

5.4.4 Three Scenarios of Household Electricity Consumption Projection

The projections of annual residential electricity consumption in each province were performed based on changing household size, saturation rate of appliances, number of hours of appliance usage (intensity of usage), and the unit power input of the appliances. Three scenarios – low, medium (base), and high - were used to reflect these changes.

Base scenario

This scenario looks at total household electricity consumption in each area when the average household size decreases one percent per year or 25 percent within the next 25 years (1994-2019), and the usage intensity and unit input power of each appliance remain unchanged in this period (see Appemdix B for information on the intensity of usage and the unit power input of each appliance)

Low Scenario

The low scenario estimates total electricity consumption in each area based on a 20% decrease of current appliance usage hours and power input (energy efficiency) of all appliances except for air conditioners.

High Scenario

Under the high scenario, total household electricity consumption in each area was projected based on a 20% *increase* of current appliance usage hours and energy efficiency of all appliances except for air conditioners.

Note that trending of usage of all appliances, except air conditioners, was done based on fraction percent of the current usage. Most end use energy consumption studies, especially in industrialized nations, treat air conditioners separately and in great detail because of the high saturation rate, high contribution to the total electricity demand, and the complex physical and economic interactions that characterize air conditioner systems in a household. For the case of Thailand, a detailed end use model for air conditioners at present is not necessary because the saturation rate of this appliance is still very low (lowest among other appliances). However, the intensity of usage and power input of air conditioners were trended separately in this study, but not in great detail. Because of its high input power compared to other household appliances, it is highly likely that the decision on the intensity of usage of air conditioners will be different from other

appliances. In the case of air conditioners, three scenarios were developed to reflect the change in the number of hours for operating air conditioners in a household. For the low scenario, the number of hours per day and the number of days per year operating air conditioners decreased from 8 to 6 hours a day and 300 to 200 days per year respectively. For the high scenario, the number of hours per day running an air conditioner did not change, but the number of days in a year was increased from 300 to 365 days.
All changes in each scenario were formulated as fractions or percent change from the current values (of household size, electricity consumption from each appliance) rather than changing individual values of each parameter because of the lack of historical data and insufficient current information on household appliance usage. It is not possible to determine accurately the future intensity of appliance usage.

It is also crucial that planners are able to assess the impact of technological improvement of high power input requirement appliances such as air conditioners. The model in this study was built in a manner that is capable of assessing such impact by changing values of power input variable in the model. However, assessment of technological impact was not part of this study. Therefore, this variable was assumed to remain unchanged during 1994-2019.

In summary, the residential electricity consumption model in this study projected the total electricity usage in urban and non-urban households that was based on the change in the mix of population in each province and the change in household electric appliance ownership and usage. The relationship among these variables is not linear because of different rates of adoption in different areas. The model utilized the projected urban and non-urban population number from the population model as the base for the calculations of the average number of electrified households. The projections of the residential electricity demand were performed based on a low, medium, and high saturation rate scenario and percent change of appliance usage. The projection results included total urban and non-urban electricity consumption of 11 appliances from year 1999 to 2019 at the provincial level, which was the aggregated to regional, and national level as well. The results were reported in terms of the share of electricity consumption by appliance types and total residential electricity consumption.

II PROJECTION RESULTS

This section is divided into two subsections. The first subsection presents base year electricity consumption as well as the projection results from year 1999 to 2019. The projection results are reported in two ways. The first shows the results in terms of projected number of households, total electricity consumption at national, regional, and provincial levels. The second presents the projection of electricity consumption by types of appliance. The results are reported in terms of the share of each appliance to the total electricity demand at the national level. Unless it is mentioned, the results reported the medium scenario. The second subsection is a comparison of residential electricity consumption projections between this study and the utility authorities in Thailand.

5.5.Projected Households

Households in Thailand were projected to increase from 12.7 million households in 1994 to 25.7 million households in 2019 or 102 percent increase in this period. In 2019, provinces in Thailand will experience a range of household increase from 2 to 16.4 percent per year (see Figure 36). Provinces that will face large percent increase within the next 25 years will be the same provinces that are expected to experience large percent increase in population. These provinces include Nonthaburi (16.5%), Samut Sakorn (6.9%), Samut Prakarn (10.5%), Prathum Thani (10.3%), Ranong (8.6%), Phuket 7.5%), and Bangkok (7.1%). In terms of percent increase of households by areas, Thailand will experience an increase of households of 81.7 percent in urban areas and 127 percent in non-urban in the same period. The increase of household in the country will be dominated by higher increase rate of household in urban areas.

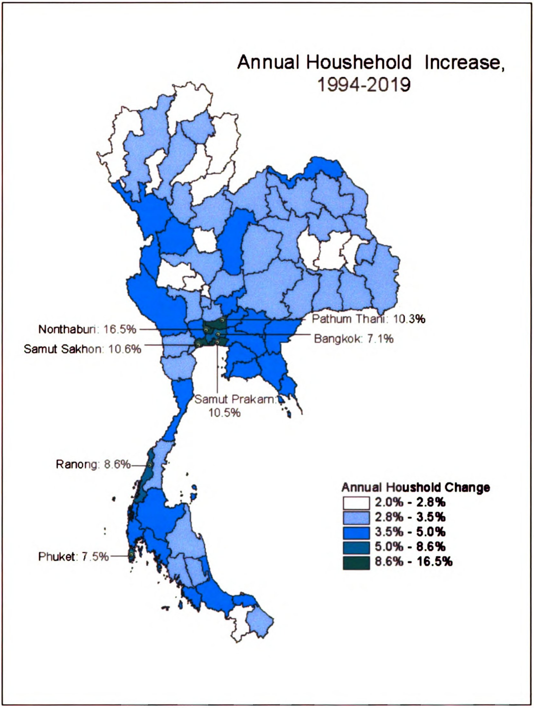

Figure 36: Projected Percent Annual Increase of Household in Thailand, 1994-2019

5.6 Projected Total Residential Electricity Consumption

5.6.1 National Level

The results of the residential electricity consumption projections at the national level are presented in Figure 37 (see Appemdix B for result tables). The results can be summarized by scenario and area as follows. The high scenario shares the total residential demand to increase from 26.4 to 127 GWh, a 382 percent increase between 1994 and 2019. Under the medium scenario, it is expected that the demand will change from 18.9 to 81 Gwh (330 percent increase) in the same period. The low scenario shows the increase of 312 percent of the demand or the change from 14.4 to 59.5 Gwh in the next 25 years.

By area, the demand for electricity in urban areas will increase from 12.8 Gwh in 1994 to 49.4 Gwh in 2019. The demand in 2019 in urban areas is higher than the demand in non-urban areas by 11 Gwh. However, the percent change of the demand for electricity in non-urban households in this year from the base year is expected to be higher in the non-urban areas. The increase will be 424 percent in non-urban area and 285 percent in urban areas.

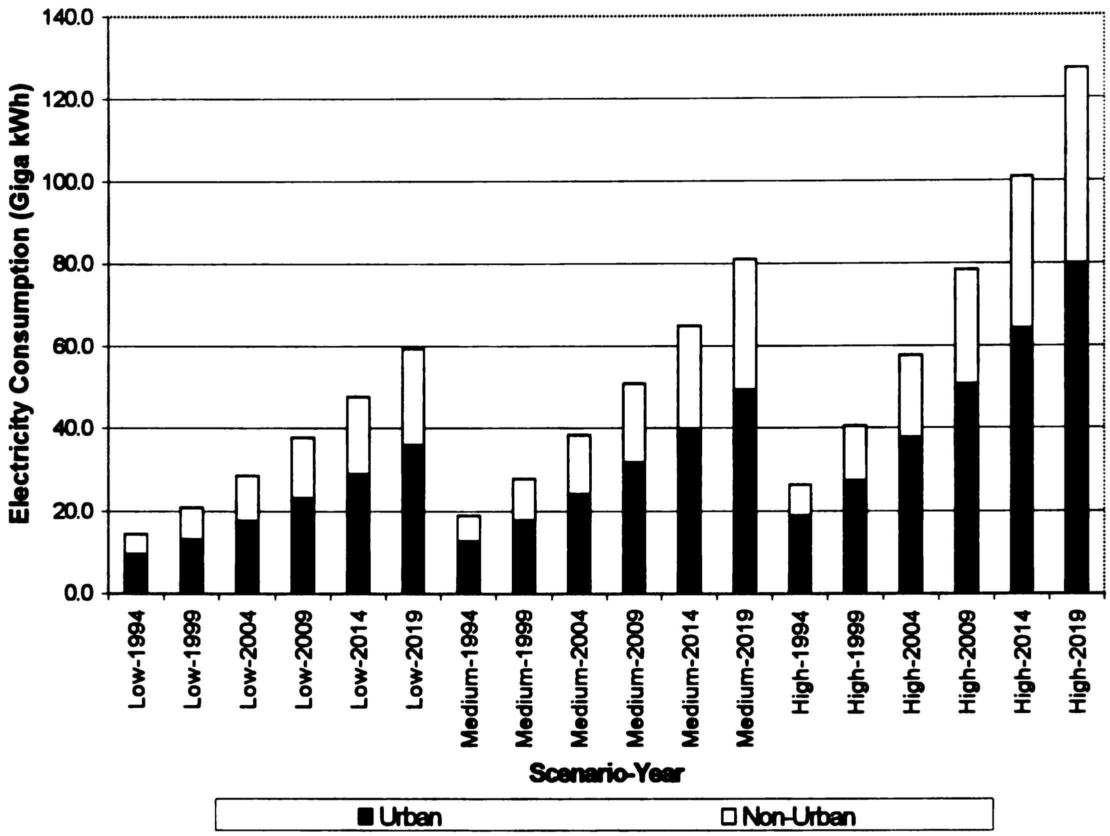

Figure 37: Total Electricity Demand by Areas from Three Scenarios, 1994 and 2019

In terms of the share of electricity in each area to the total consumption, the share of electricity demand in urban areas is projected to increase from 32 percent in 1994 to 39 percent in 2019 or 7 percent increase in the share within the next 25 years. This indicates that the increase of the future consumption for electricity in the residential sector in Thailand will be driven more by the demand of households in non-urban areas of the nation.

The total residential electricity consumption or the average consumption per household will increase at a decreasing rate over time. It is expected to decline from 9.53 percent in 1999 to 4.98 in 2019. In terms of total electricity consumption by areas, it is projected that the annual residential electricity consumption in urban areas will be much higher than the consumption in non-urban areas. The percent increase of the consumption in urban areas is expected to increase at a slower rate than the percent increase in the non-urban areas. The difference between the annual household consumption in these two areas will become larger from 1994 to 2009 and start to decline until 2019. The explanation for this is related to the saturation rate. Based on the assumption of percent increase of the adoption rate in urban areas, the model uses the 5 percent increase for appliances with a current saturation rate greater than 0.6 (high range) instead of the 10 or 20 percent for the medium and low range respectively and for the projection in the urban areas. In the period 1994 to 2009, most high contribution electric consumption appliances (refrigerators, irons, fans and lighting) except air conditioners in urban areas will have adoption rates close to saturation. Therefore, the impact of residential electricity consumption from these appliances in urban areas will be small. Although, the adoption rate of air conditioners in urban areas will be lower than other appliances, the rate of this appliance since 1999 will be greater than 0.3 and become larger than 0.6 in 2019. This means that the model will use the percent increase of the medium saturation rate for the period 1994 to 2014 and use the high saturation rate for the period 2014 to 2019 to calculate the electricity consumption. The saturation of the same appliances in the same period in non-urban areas will still be in the low saturation range for air conditioners throughout the next 5 years and will be in the medium saturation range for other appliances in this period. Therefore, the model will use the higher percent increase of adoption rate than the urban area to calculation the residential electricity demand.

When comparing the change of annual growth rate between residential electricity consumption, population, and household, the annual growth rate of electricity will be relatively higher than the rate of population and household growth throughout the next 25 years (Figure 38). The trend of the decline of the population growth rate will be similar to the trend of household growth rate because the number of households was calculated from the population. The decline of these two trends will be much slower than the decline of annual electricity consumption. This is an indication that the increase of residential electricity consumption in Thailand will be more influenced by the increase of appliance ownership than the increase of (electrified) households.

The projected consumption in terms of total kWh usage or consumption provides the overall picture of the amount of the electricity required in the typical household in each area of Thailand. This information is necessary for production planning, but is less meaningful to energy policy makers to direct energy plans and programs (i.e., energy conservation) in the country. The information on electricity usage by end use appliances can better serve this function. In this study, the model projected adoption or penetration rates for each appliance by areas and determined the electricity consumption share of each appliance to the total demand for electricity for a household in urban and non-urban areas in Thailand. The model performed this task at the provincial level, however, the results were aggregated and reported at the national level by urban and non-urban areas. The results are illustrated in Figure 39, 40, and 41 (also see Appemdix B, for detail results).

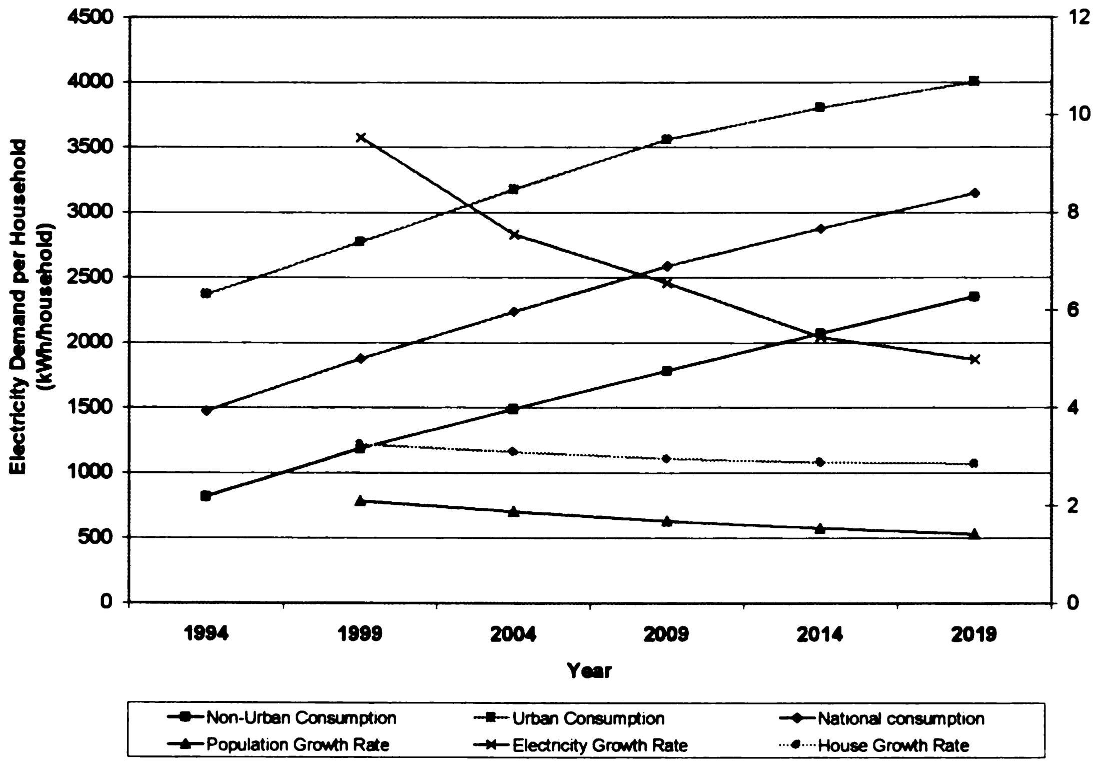

Figure 38: Residential electricity Consumption and Annual Growth Rate of Population and Electricity Consumption, 1994-2019

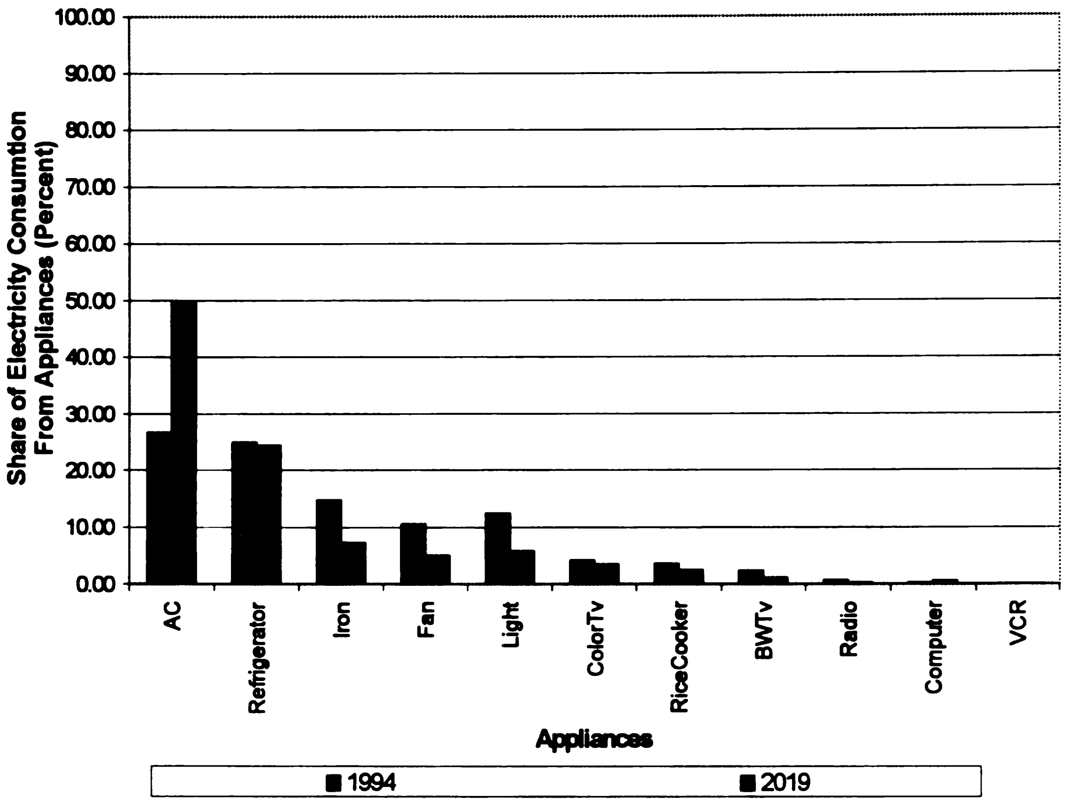

Figure 39: Share of Electricity Consumption from Appliances, 1994 and 2019

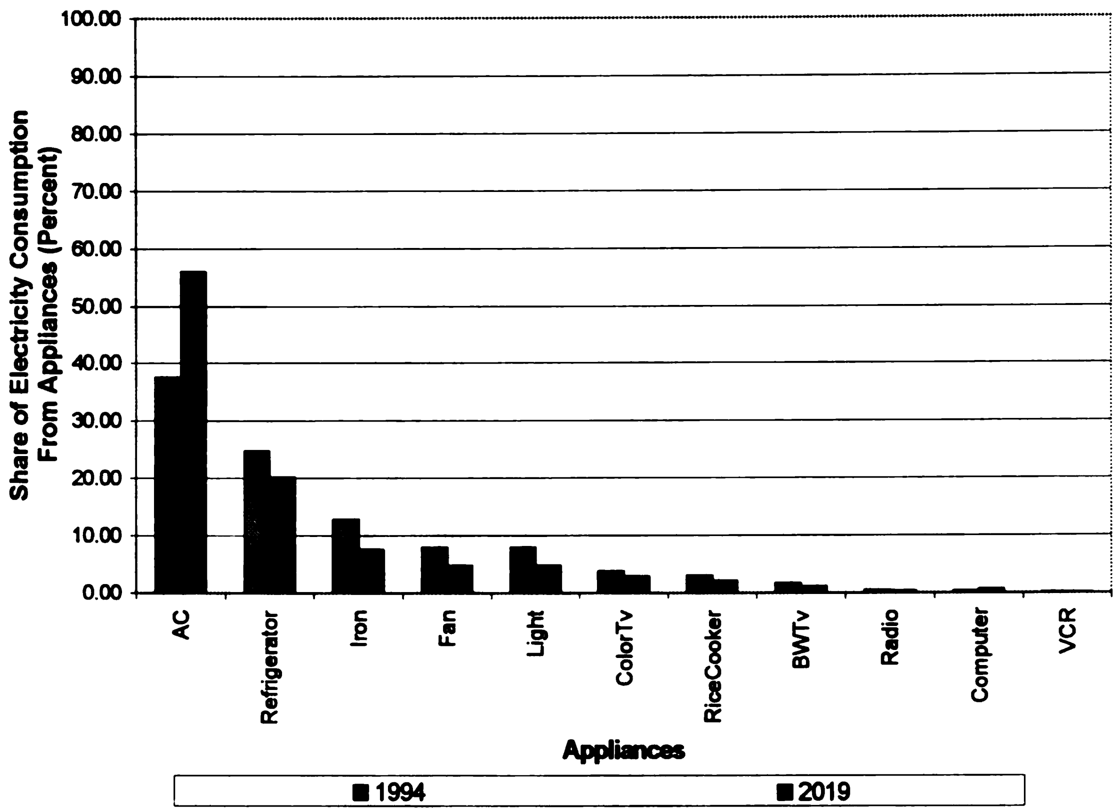

Figure 40: Share of Electricity Consumption from Appliance Types in Urban Area, 1994 and 2019

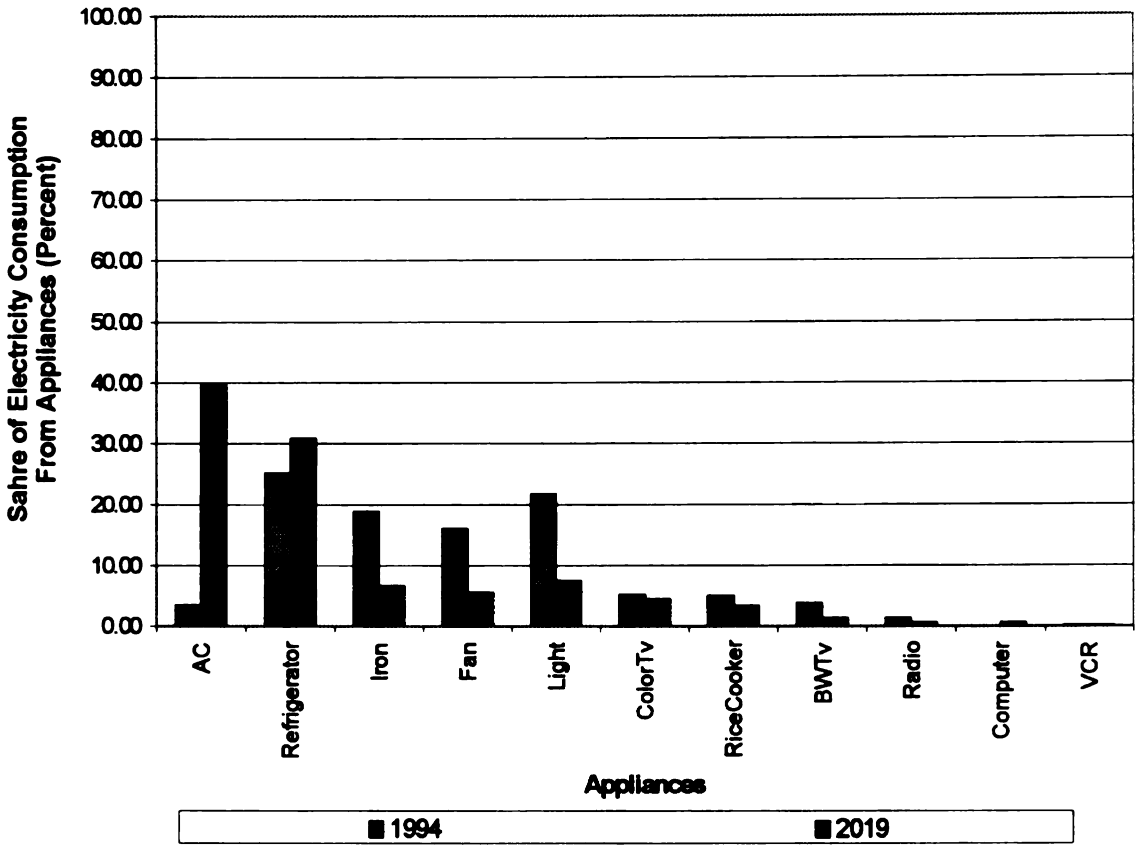

Figure 41: Share of Electricity Consumption from Appliance in Non-Urban Areas, 1994 and 2019

The share of electricity consumption by appliances indicates that the major end use of electricity in Thailand's residential sector for both urban and non-urban areas, ranging from highest to lowest share, will be air conditioners, refrigerators, irons and lighting. The level of consumption from each appliance is projected to be different in both areas. The difference is found to be larger for these four appliances and smaller for the rest of appliances. The share of electricity consumption from all normal and inferior goods is estimated to be higher in urban areas in the base year. The share from these appliances, except the iron, is also expected to remain higher in non-urban until the year 2019.

Among the major end use appliances, there will be a distinct different between the share of electricity consumption from air conditioners and lighting in urban and non-urban areas. It is expected that the contribution of electricity consumption from air conditioners will increase from 3.4 percent to 39.5 percent in non-urban areas and 37.5 to 55.9 in urban areas in1994 and 2019 respectively. In the case of lighting, there will be a decline of the share from lighting in both areas with the higher reduction from 21.7 to 7.4 percent in non-urban areas and from 7.9 to 4.7 percent in urban areas in the same period. The difference between the share from refrigerators and irons is also expected to decline. The decline of the electricity consumption share in non-urban and urban areas will be 5.6 and 4.58 percent from refrigerators and 12.2 and 5.12 percent from irons accordingly.

The difference in household electric consumption between urban and non-urban areas in this study can be looked at through the four variables in the model: number of households, appliance ownership, penetration rates, and the intensity of appliance usage in the households. At the household level, this study assumed that the intensity of appliance operation for each appliance is constant over time and is the same throughout the country. In addition, the input power for each type of appliance is also assumed to be the same in every household. Therefore, the increase of consumption is dependent on the saturation rate and the changing number of households. Both variables were trended to increase linearly for households and non-linearly for saturation rate over time. The impact of the increase of number of households to total electricity consumption is a linear relationship. Therefore, it is important to look at the change in saturation rate of each appliance over time and how this change contributes to the total electricity consumption in the residential sector. Figure 42, 43 and 44 presents the change in saturation rate by type of appliance in total, urban and non-urban areas respectively.

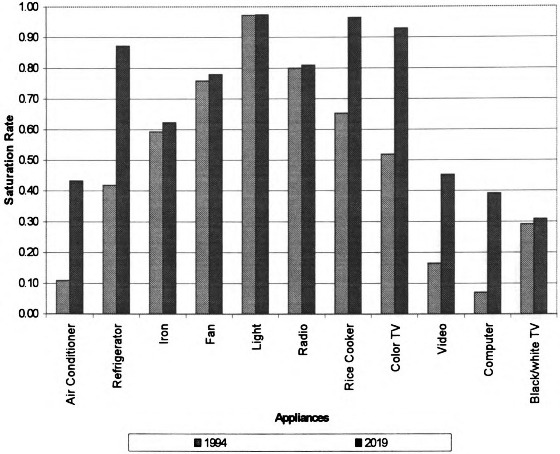

Figure 42: Saturation Rate by Appliances at National Level, 1994 and 2019

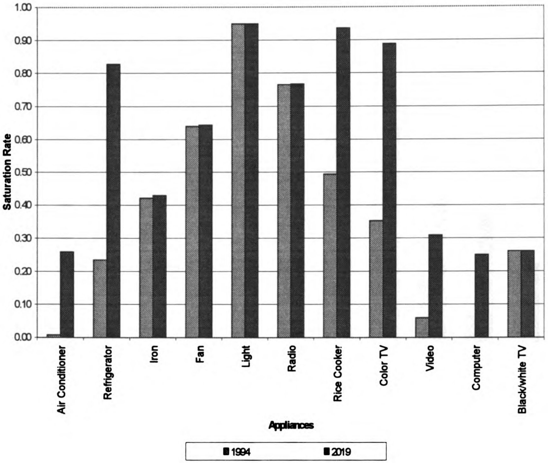

Figure 43: Saturation Rate by Appliances in Urban Areas, 1994 and 2019

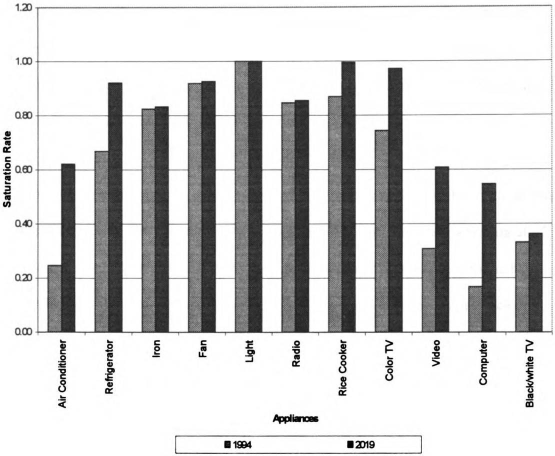

Figure 44: Saturation Rate by Appliances in Non-Urban Areas, 1994 and 2019

For the purpose of the analysis, appliances are categorized into 3 groups based on the change of the saturation rate from base year to 2019. The first group is referred to as the low change rate group. This group includes appliances that are not trended in the model. These appliances are irons, fans, lighting, radios, and black and white televisions. The change in the saturation rate is estimated to range from 0.0 to 0.03. While these appliances were not trended to change, the increasing rate is the result from the number of households that were trended to increase. Of all the appliances belonging to this group, irons and fans are the ones that deserve special attention because of their relatively high contribution to total electricity consumption.

In the case of electric irons, the explanation for the moderate high contribution from this appliance is technologically and culturally involved. The high required power input of irons and the relatively high intensity of its usage in households contribute to the high share to the total electricity consumption. An iron is a small household appliance that requires power input as high as 1,000 watts. Ironing clothes is also one of the major household chores in Thailand because of the preferred cotton fabric that usually requires ironing. This applies more to households in urban areas as the saturation rate of this appliance is higher and its share of the total electricity consumption will be higher in 2019.

Unlike the case of irons, the contribution of fans to the total electric consumption is not the result of high power input and the intensity of usage, but more from a high saturation rate. In 2019, the saturation rate of fans is expected to be high in urban areas (0.93) and relatively high in non-urban areas (0.64) as well. Although a fan is not a perfect substitute for an air conditioner, the expected high increase of air conditioners make the share from this appliance decline from 10.5 to 5.2 percent in the period 1994 to 2019.

The second group is referred to as the medium-change saturation rate group. This group includes air conditioners, rice cookers, VCRs, and computers. All appliances in this group except rice cookers have very low saturation rates in the base year (0.07 to 0.16) and medium saturation rates (0.29 to 0.43) in 2019. Other than air conditioners, it is expected that the electricity consumption share of these appliances to the total electricity consumption will be less than 4 percent in 1994 and decrease to less than 2.5 percent in 2019. The appliance that will most impact future demand of electricity in the residential sector is air conditioners. At present, air conditioners have one of the lowest saturation rates among other appliances (0.01 percent in non-urban areas and 0.25 percent in urban areas) but contribute the most to total household appliance usage, especially in the urban areas where the contribution is as high as 37.5 percent. In 2019 the saturation rate of air conditioners is projected to be 0.26 with a share to the total consumption of 36.2 percent in non-urban areas. In urban areas in the same year, the saturation rate is expected to be 0.63 with a share to the total consumption of 55.9 percent. The high contribution to total electricity consumption from this appliance is partly caused by the high power input of the typical air conditioner used in Thai households. Improvement of the efficiency of air conditioners will certainly reduce the total electricity demand in the residential sector. However, changing the intensity of air conditioner usage such as setting the air conditioner at a comfortable temperature (not too low) will also lessen the total residential electricity consumption.

The last group of appliances is referred to as the high change rate group. The appliances belonging to this group are refrigerators and color televisions. Color televisions are not a major concern in this case because the saturation rate of this appliance is projected to be relatively high while the share to total electricity consumption will be relatively low. Refrigerators also will have high share and saturation rate in the future. The share in the non-urban areas will be as high as 30.7 percent, with the saturation rate of 0.83 in the base year. The share is expected to be 20.1 percent, with the saturation rate of 0.92 in urban areas in the year 2019. A refrigerator is a relatively high priced and a non-substitute good. It is the only electric appliance in a household that is operated 24 hours a day and 365 days a year. The fix in the intensity of usage and the near saturation of this appliance in Thai households explains the slight change in the share from this appliance in the period 1994 to 2019. The share is expected to decrease from 24.9 percent in this period. Because all households operate refrigerators all day and all year long, the only way to reduce the amount of electricity consumption from this appliance is through efficiency improvement or a decrease in the unit power input of the refrigerator.

At the country level, the increase of residential electricity consumption will be driven by the increase of consumption in the non-urban areas of the country where the majority of the population (and households) are. The projection of the increasing saturation rate for all appliances, especially in non-urban areas, will be a key factor that drives the higher electricity consumption in Thai households. The near saturation rate of lighting since 1999 confirms that the increase of residential electricity demand will result from the increase of appliance ownership in non-urban areas in particular. The share of electricity consumption in the residential sector from appliances also indicates the high impact of air conditioning to the total residential electric consumption in Thailand.

5.6.2 Regional Level

Bangkok

It is crucial to look at projection results of Bangkok separately from the Central region because of differences in the social, economic, and political structure of Bangkok compared to the rest of the country. The estimate of consumption of electricity in the residential sector in Bangkok is approximately 5.42 Giga kWh in 1994. It is estimated that the consumption will increase to 18.1 Giga kWh in 2019. The electricity consumption in 2019 will be approximately 22.3 percent of the total electricity consumption in the residential sector of the country. Although the electricity consumption in Bangkok is projected to be second highest from the Northeast region, the percent change of the consumption in Bangkok is projected to be the lowest in the country. A large percent change of electricity consumption is not expected in Bangkok because appliance ownership of most appliances in Bangkok households was relatively high compared to households in other regions in the base period. When the saturation rates of appliances were in the high range, the model used a low percent increase of saturation rates to estimate total electricity consumption. Therefore, the change of the consumption in Bangkok will be small.

Central Region

If Bangkok is included in the Central region, residential consumption for electricity of this region in 2019 will be 43.1 percent of Thailand's total electricity consumption in residential sector. By not including Bangkok in the Central region, this region is projected to experience a change of the residential electricity consumption from 3.4 Giga kWh in 1994 to 16.9 Giga kWh in 2019. The region will experience a change of a regional share of the consumption from 18 to 20.8 percent in this period. The increase of the residential electricity demand of the Central region was calculated to be approximately 15.9 percent per year. The residential consumption for electricity within this region will be dominated by urban areas. The urban areas will account for 64.4 and 69 percent of total electricity consumption of the region in 1994 and 2019 respectively. The region's contribution from the urban area to the country's consumption is projected to change from 2.7 to 14.4 percent in this period. This is a significant increase compared to the rest of the region, which is expected to experience a decline of the share from urban area in this period. Share of the residential consumption of non-urban areas of the Central region in this period is also expected to increase from 1.5 to 6.4 percent.

Northeast Region

The result from this study reveals that the Northeast region will experience a change of electricity consumption in the residential sector from 3.6 to 18.6 Giga kWh in 1994 and 2019 respectively. In 2019, the Northeast region is expected to be the largest electricity consumer in the country. The change of the consumption of this region will be approximately 16.6 percent per year, the highest percent change in the country (see Figure 47). The increase of the residential consumption in this region will be dominated by the demand in non-urban areas. There will be a change of approximately 20.4 percent annually in these areas of the region. The residential electricity consumption share from the non-urban areas of the Northeast reigon in 2019 will be as high as 74.6 percent of the region consumption and 16.8 percent of the national consumption.

East Region

The East region is ranked the lowest in terms of electricity consumption and the share of consumption of the region, as well as the consumption in urban and non-urban areas. It is normal for the East region to experience the low change because this region has the lowest population and household in the country. Estimates of total electricity consumption in this region are 0.96 Giga kWh in 1994 and 4.75 Giga kWh in 2019.

The consumption was calculated to be a share of the consumption in this region approximately 5 percent in this period. It is interesting that projection results show that this region will experience the second highest percent change of residential electricity consumption. The estimate is 15.8 percent per year. An explanation for this is because of the relatively high increase of population, households, as well as saturation rate of appliances. While most regions will experience a decline in the consumption share in urban areas and an increase in non-urban areas, the East region will be the only region that will experience an increase of urban and non-urban shares of the consumption from 1994 to 2019. However, the region's contribution to the total electricity consumption in the residential sector will not change in this period. In terms of consumption for electricity by area within the region, neither urban nor non-urban areas will dominate the region's consumption in the period 1994 to 2019.

South Region

The estimated residential electricity demand of the South region is 2.24 and 9.55 Giga kWh in 1994 and 2019 respectively. This increase will be approximately 13.1 percent per year. Percent residential demand for electricity of the South region to the national demand will remain unchanged at approximately 11 percent at the beginning and the end of the projection period. The residential demand for electricity in this region has always been concentrated in households in urban areas. The urban households in the South region are expected to be the second largest electricity consumers in the country compared to remaining urban households in each region. Domination of urban area in this region will decrease as shown in Figure 48. Urban households of the South region will experience a decreasing electricity consumption share within the region, from 74.6 to

69.6 percent in 1994 and 2019 respectively. However, the region's share from urban area to the total electricity demand in Thailand will be less significant than the former case. It is found to decline from 8.84 to 8.2 percent or a decrease of 0.64 percent in this period.

North Region

The North region is expected to experience an increase of electricity demand in the residential sector from 3.2 Giga kWh in 1994 to 13.2 Giga kWh in 2019. The increase of the demand will be approximately 12.3 percent per year in this period. Excluding Bangkok, this change will be the smallest percent increase of the demand compared to other regions. In terms of the region's share to the national consumption, the consumption in the North region is expected to account for 16.3 percent in 2019, a decline from 17.2 percent in 1994. A consumption pattern within this region will change from a higher consumption in urban areas in 1994 to a higher consumption in non-urban areas in 2019. The difference between the share of urban and non-urban household consumption in this region will be 5.2 percent in 1994 and 12.5 percent in 2019. The difference of 7.3 percent is relatively small compared to other regions except the East region. The difference between the electricity demand in urban and non-urban areas is expected to be less than 2 percent for the East region and more than 20 percent for the other regions.

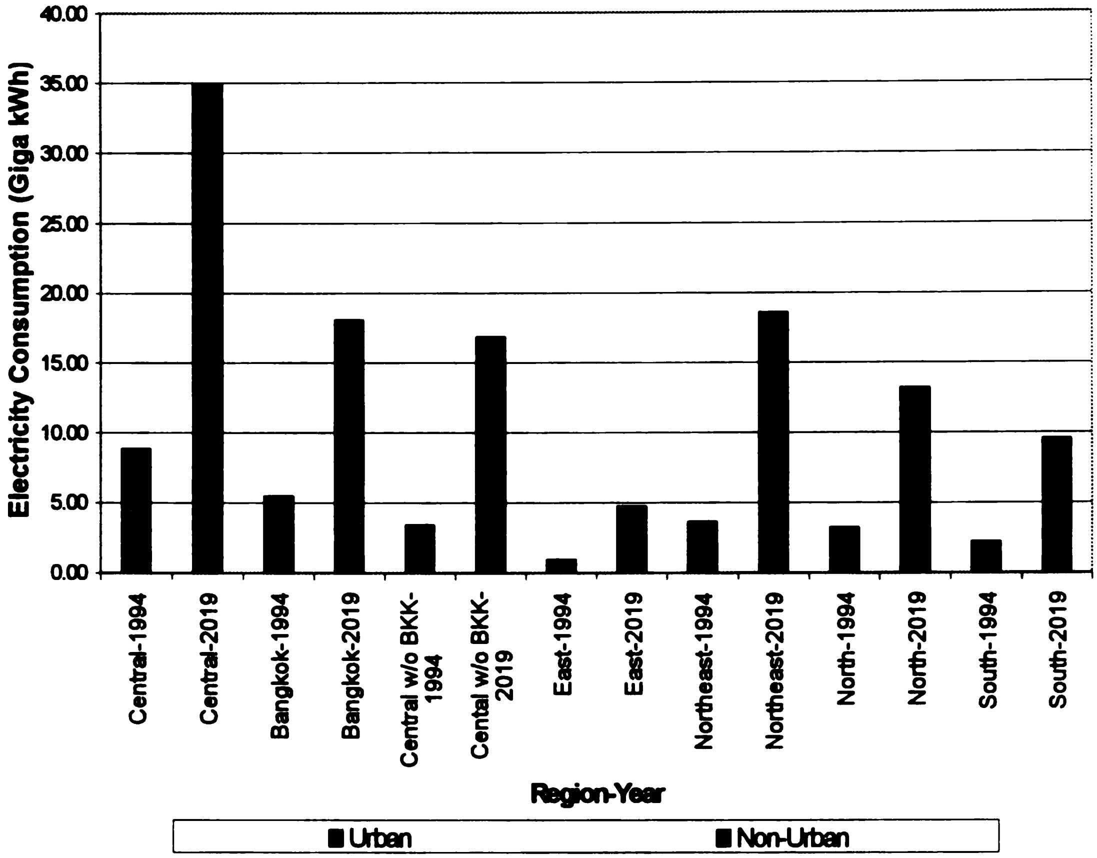

Figure 45: Residential Electricity Consumption by Region, 1994 and 2019

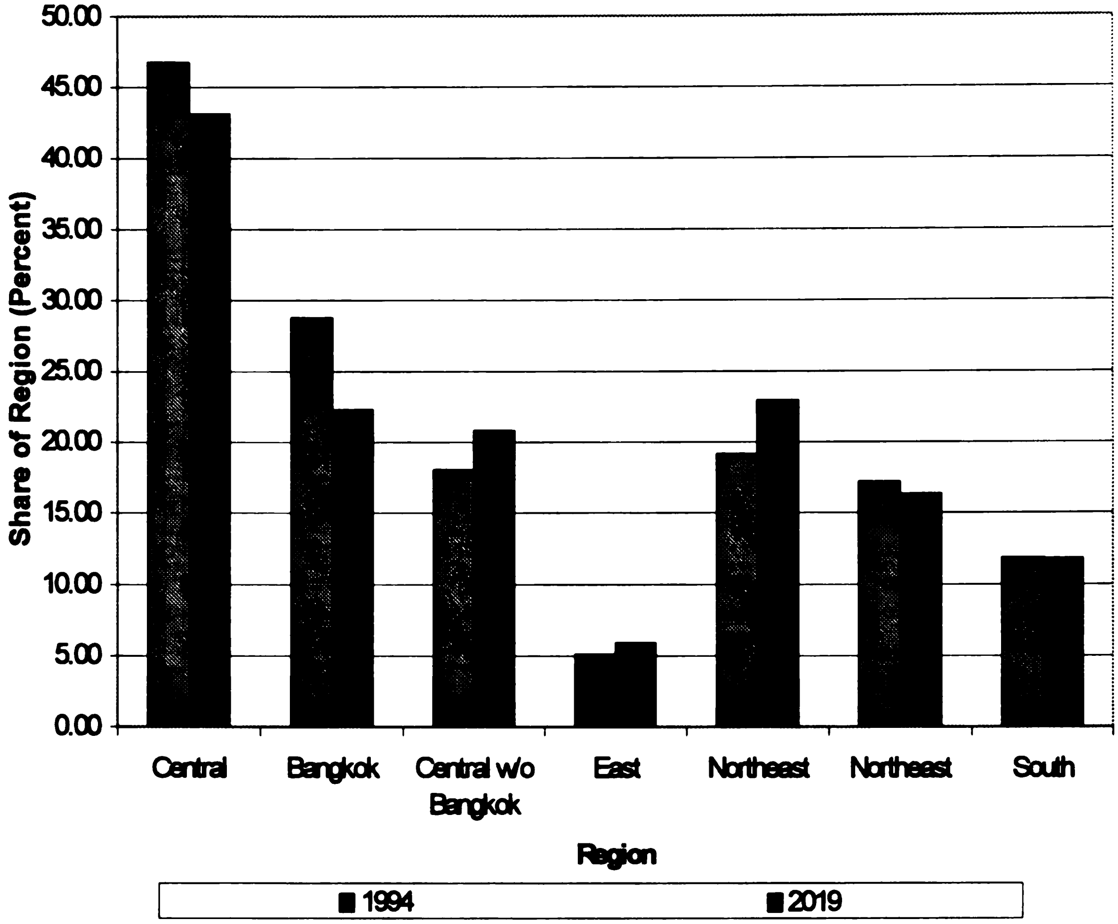

Figure 46: Share of Residential Electricity Consumption by Region, 1994 and 2019

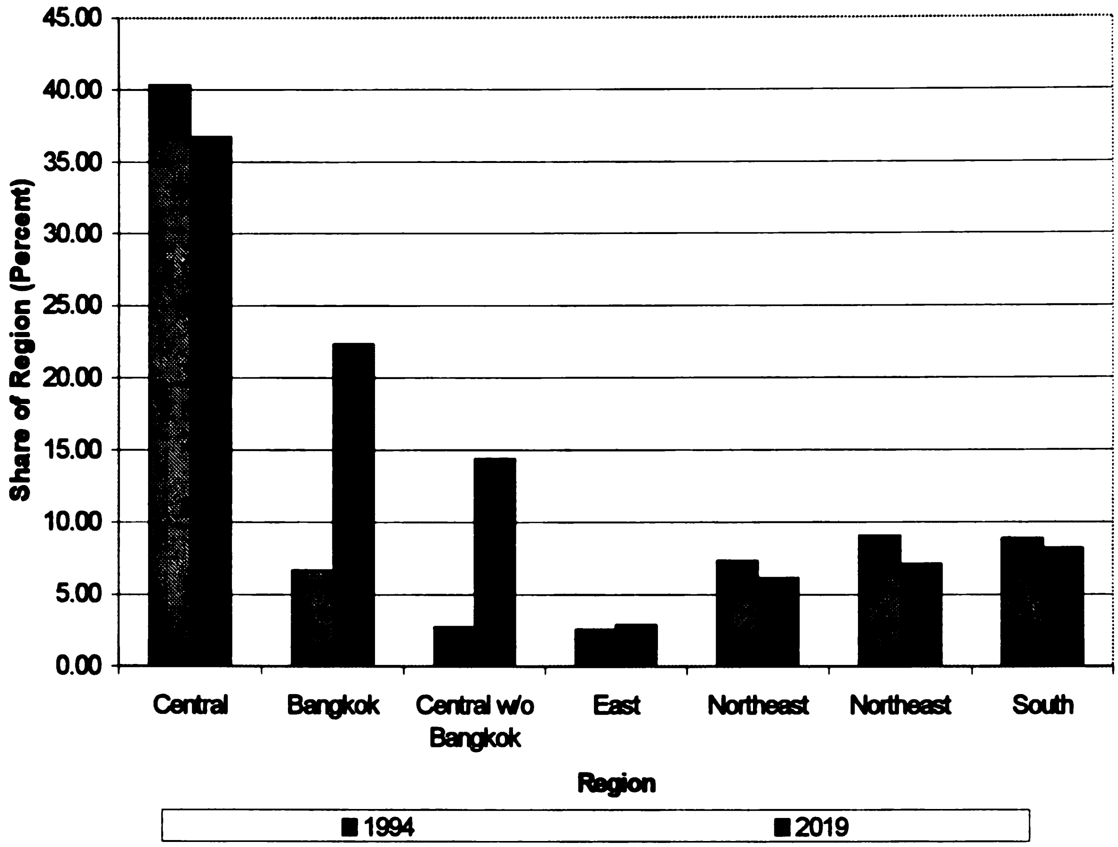

Figure 47: Residential Electricity Consumption by Region in Urban Areas, 1994 and 2019

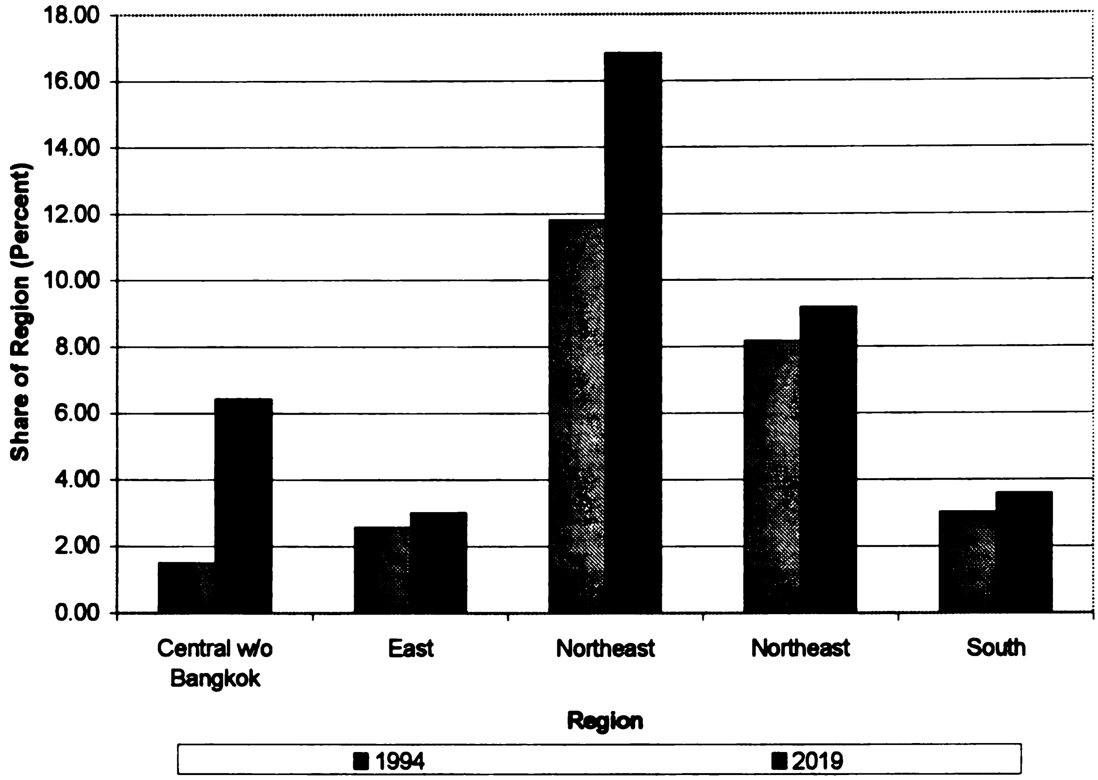

Figure 48: Residential Electricity Consumption by Region in Non-Urban Areas, 1994 and 2019

The electricity consumption in the residential sector at the regional level can be ranked from the highest to the lowest as the Central (including Bangkok), Northeast, North, South and East region during 1994 to 2019 (Figure 45). By areas, the consumption in urban areas is found to be the highest in Bangkok, followed by the Central, the South, North, Northeast, and East regions in 2019. For non-urban areas, the major consumption is expected to take place in the Northeast region, followed by the North, Central, South and East region in the same year. In terms of the percent change of total demand within each region, the highest and the lowest change will take place in the Northeast and Bangkok respectively in this period. The region that will experience the highest and the lowest percent change of the demand in urban areas will be the East region and the North region. In non-urban areas, the projection results reveal that the lowest percent change in the residential electricity demand will take place in the Central and the highest percent change will take place in the Northeast region in the same period.

5.6.3 Provincial Level

Projection results at the provincial level are presented as the consumption in 2019 of each province (see Figure 49) and percent increase of the consumption from 1994-2019 (see Figure 50). Spatial change of the household electricity consumption has to be examined in terms of actual consumption as well as percent increase. Planners should know estimates of future consumption of each province in order to prioritize resources for provinces with the high future consumption. At the same time, planners have to be informed and aware of provinces that show a high potential for increased future consumption. These provinces include provinces that are estimated to have large percent increase of the consumption in the period of 1994-2019. Estimates of the residential electricity consumption of each province are also presented in terms of percent increase of the consumption in urban (see Figure 51) and non-urban areas (see Figure 52).

High residential electricity consumption is expected to take place in provinces that are the center of each region. High consumption is expected to be largest in Bangkok, followed by Nonthaburi and Samut Prakarn, the three center provinces of the Central region. The fourth and fifth largest consumption will be in Nakhon Ratchasima, the center province of the Northeast region, and in Chiangmai, the center province of the North region respectively. The consumption in these provinces is expected to be high because these provinces have high population, households, and urbanization rate. However, the percent change of the consumption in some of these provinces is not large. In fact, Bangkok, which shows the highest future consumption, will experience very low percent increase of the consumption. This is because in the base year Bangkok was already highly urbanized and saturation rate of most appliances was also the highest in the country. Therefore, Bangkok will not show large change in the consumption, but the consumption will still be very high.

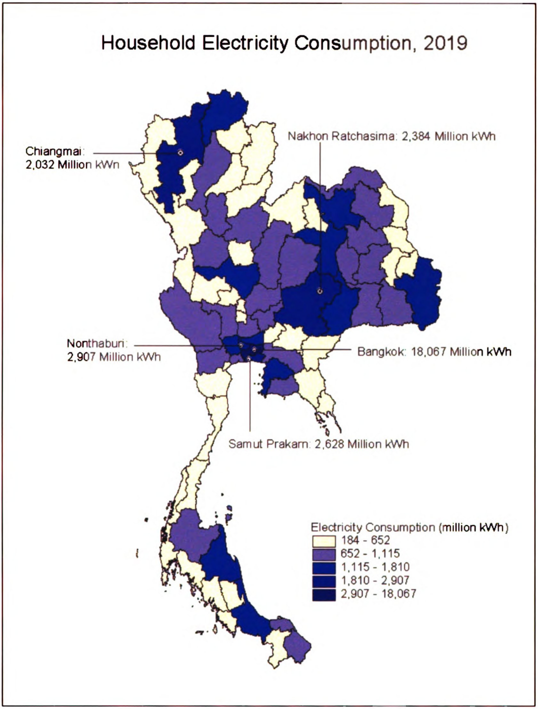

Figure 49: Projected Residential Electricity Consumption of Provinces in Thailand, 2019

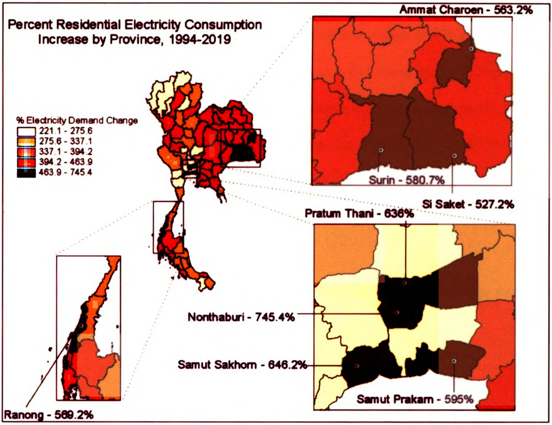

Figure 50: Percent Electricity Consumption Change in Thailand, 1994-2019

Other provinces that will experience a large percent increase of electricity include the BMR provinces. It is not a surprise that these provinces will face high future consumption as well as a large percent change because these provinces are still under going development process. Unlike Bangkok, these provinces have high percent increase of households as well as adoption rate of appliances, which makes the future consumption and the percent increase in the consumption to be high.

The interesting provinces that show large percent increase but relatively low future electricity consumption are provinces in the Northeast region, which include Amnat Charoen, Surin, and Si Saket. The large increase in the consumption in these provinces will be the result of large increase of the consumption in non-urban households. Households in these provinces had low adoption rate of appliances in the base year. Therefore, percent increase of saturation rate of appliances of households in these provinces will be high which in terns makes the change in the consumption to be high.

Electricity consumption of each province for urban and non-urban areas is shown in Figure 51 and Figure 52 respectively.

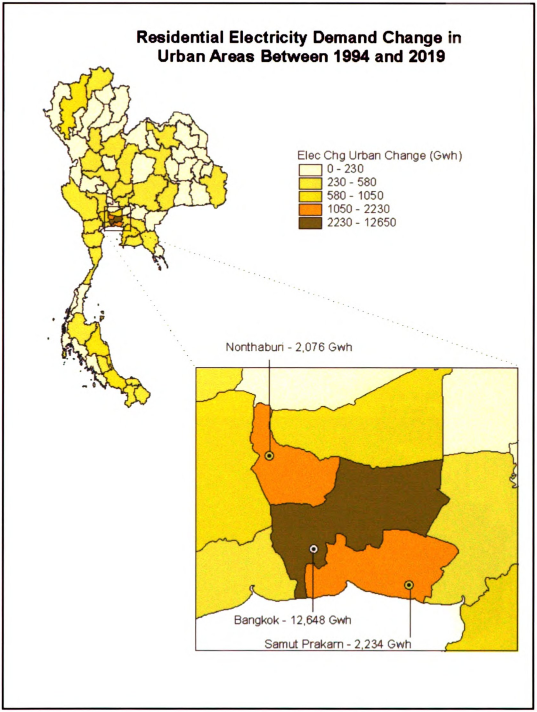

Figure 51: Percent Change of Residential Electricity Consumption in Urban Areas by Province, 1994-2019

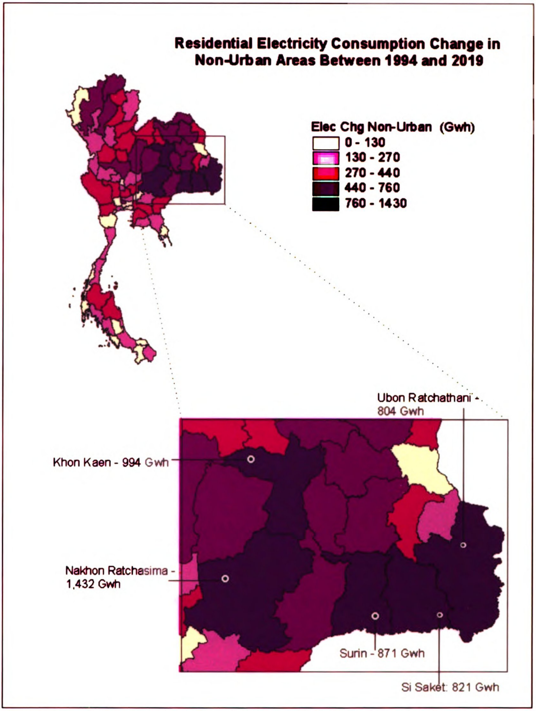

Figure 52: Percent Change of Residential Electricity Consumption in Non-Urban Areas by Province, 1994-2019

The result from the regional level indicates that the highest change will take place in the urban areas of the Central region. The results at the provincial level shows that provinces in the Central region that will experience a large increase in residential electricity consumption, ranking from high to low, are Bangkok, Nonthaburi, and Samut Prakarn accordingly. Figure 51 confirms that the high change of the total consumption in these provinces will result mainly from the change in urban areas and from the minor changes of the non-urban areas, as these provinces will experience a small change in demand in non-urban areas.

The regional results indicate the highest change in residential electricity consumption in non-urban areas to take place in the Northeast region. The provincial results show that these changes will take place in non-urban areas of five provinces in the Northeast region (see Figure 52). Most non-urban areas of the provinces in this region will also experience relatively medium to high changes in residential electricity demand.

5.6.4 Electricity Consumption by Type of Appliance

The other way to look at changes of residential electricity consumption is to look at the consumption in terms of contribution of each household appliance to the total electricity consumption. The consumption from each appliance was projected and the difference of the consumption in the period 1994 to 2019 was calculated and presented as total change in each province, and change in urban and non - urban areas within in a province.

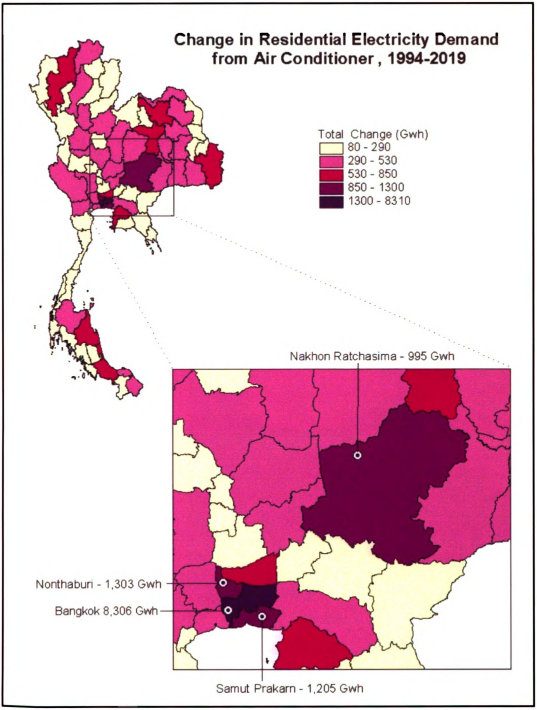

Figure 53: Change of Electricity Consumption by Air Conditioner, 1994-2019

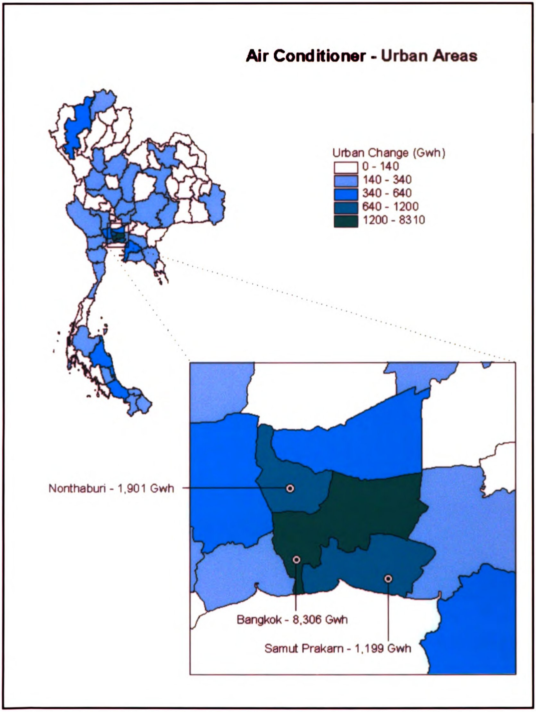

Figure 54: Change of Electricity Consumption by Air Conditioner in Non-urban Area, 1994-2019

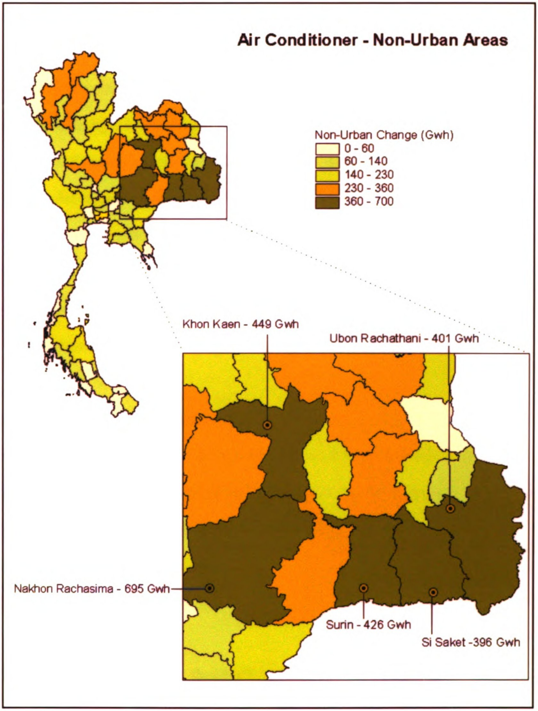

Figure 55: Change of Electricity Consumption by Air Conditioner in Non-urban Area, 1994-2019

Contribution of air conditioners to total electricity usage of households is expected to be the highest among other appliances. Therefore, air conditioning is used as an example to illustrate the capability of this model to estimate detailed electricity consumption usage of each appliance at the provincial level by urban and non-urban areas. The results are presented as change of the consumption as total in Figure 53, change in urban areas in Figure 54, and change in non-urban areas in Figure 55. Provinces with a large increase in the residential electricity usage from air conditioners will take place in the same province that will experience a large increase in total electricity consumption, both in urban and non-urban areas. This is because air conditioners are a major end use appliance with the highest share to the total consumption. The contribution of this appliance is expected to be approximately 50 percent of the total consumption of the country in 2019.

Electricity consumption from each appliance in each area is closely related to the saturation rate of appliances and the number of households in the area. Similar calculations were performed to calculate the change in number of households, and appliance saturation rate for urban and non-urban areas in all provinces of Thailand. The results can be found in Appendix B

5.7 Comparison of Estimated Residential Electricity Consumption

This subsection compares the residential electricity demand projection results obtained from this study and the combined projection results of the Metropolitan Electric

Authority (MEA) and Provincial Electric Authority (PEA). This includes comparisons of projected numbers of households or customers and the annual household electricity demand. While the projection period of the three studies is different, the discussions are limited to the period from 1994-2009, which is the projection period that all studies have in common. The discussion is based on the result and assumptions of the model in this study since the methodology and assumptions of MEA and PEA studies are not available.

5.7.1 Estimated Households

The MEA&PEA projected an increased number of households from 12 to 18 million households or an increase of 49 percent from 1994 to 2019. This study shows an increase in the same period to be approximately 32 percent or an increase from 15 to 20 million houses (see Figure 56). The curves from both studies seem to be linear. The steeper slope of the MEA&PEA curve indicates a slightly higher percent increase the agencies used to estimate future households.

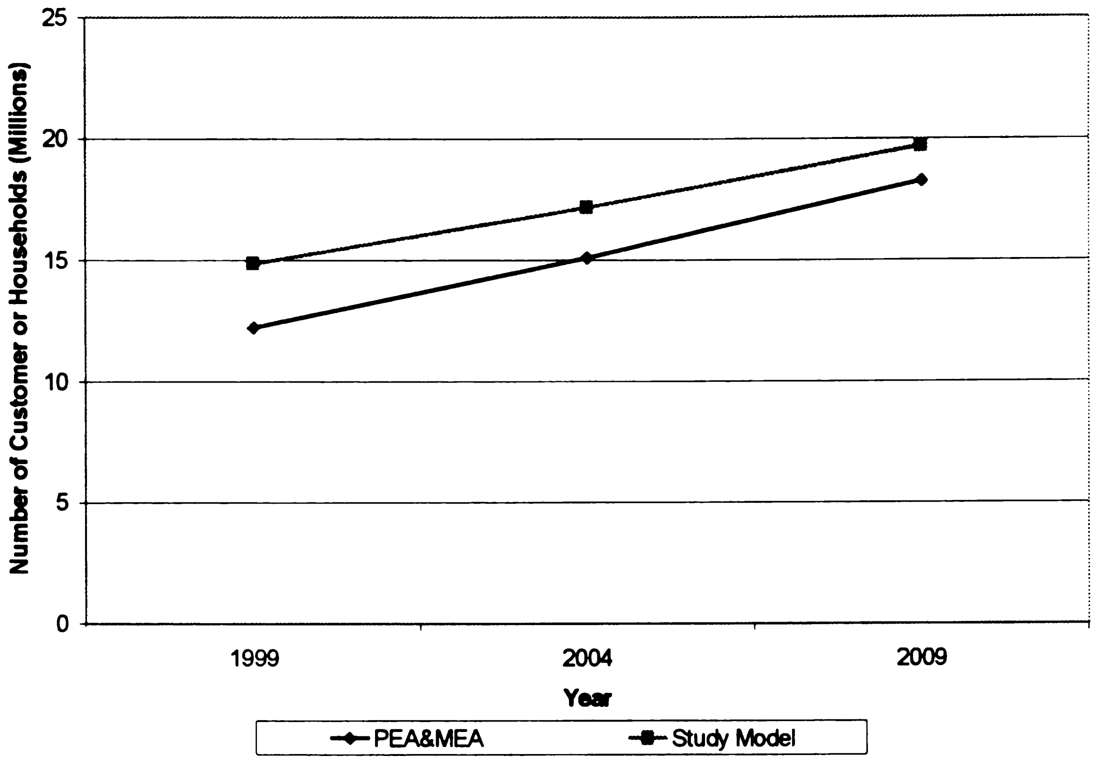

Figure 56: Projected Total Number of Households (Customers) in Thailand, 1994 - 2019

5.7.2 Estimated Total Residential Electricity Consumption

Figure 57 shows a slightly more rapid increase of future electricity consumption in the period 1999-2009 than the low and medium scenario in this study. The estimates of PEA&MEA will be closer to the low scenario of this study at the beginning of the projection and will be closer to the medium scenario as time progresses. The difference between the estimates from both studies could be a function of the different percent increase used to estimate future households. This study yields a higher estimate in 2019 than the other study because this study used has a higher estimate of number of households. However, it seems that the PEA&MEA may use a higher percent increase to estimate future number of household in the low and medium scenario in this study. If the projection curve of the PEA&MEA were extended further, future estimate from the PEA&MEA study will exceed the estimate from this study.

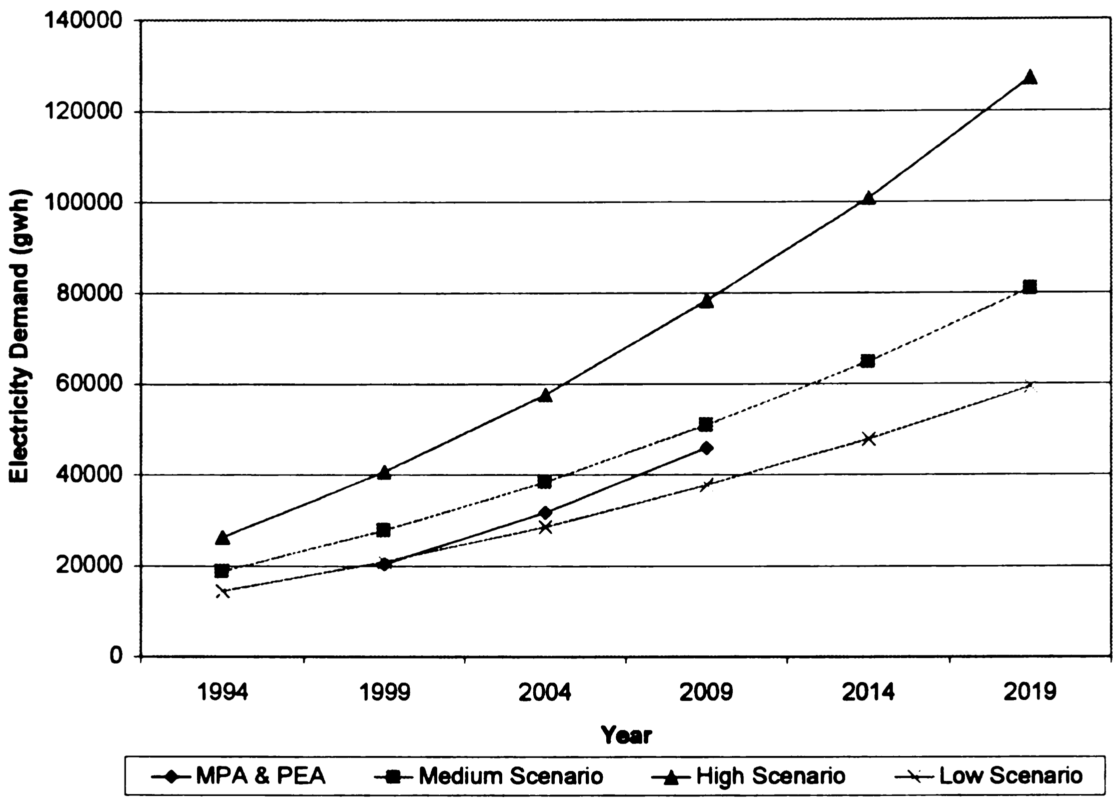

Figure 57: Residential Electricity Consumption Projected under Different Scenarios

Saturation rate, power input and usage intensity of appliances also play important role in the projection of future electricity consumption in the residential sector. The data on these variables are usually obtained from an electricity consumption household survey, which is not currently available in Thailand. These data, used in this study, were drawn from other studies combined with the research's knowledge, and educated assumptions that may not reflect the true situation of appliance adoption and electricity usage of households in Thailand. Types of electric household appliance included in this study were based on the types of appliance included in the Census. The eleven types of appliance included in the model do not represent all appliances owned in a typical Thai household. Some large appliances (i.e., washer and dryer) as well as small appliances (i.e., microwave oven, dishwasher, sewing machine, coffee maker, toaster, and hair dryer) were not incorporated in this model partly because of lack of data on these appliances and partly because of their low saturation rate in Thailand. Of all these appliances, some appliances such as dishwashers and toasters require high input power to operate (1190 – 1250 watts for dishwasher and 1100-1250 watts for a toaster). Not including these appliances into the model results in conservative projections.

In summary, the residential electricity demand model was developed at the provincial level. Projections of the demand for urban and non-urban household electricity consumption from each appliance were performed based on assumptions formulated for changes of number of households, appliance saturation rates, intensity usage and power input of appliances in each area. Three scenarios were established to reflect the relationship between residential electricity demand and the changes of these variables. The results from the scenarios provide ranges of potential demand for energy planners and policy makers to choose in order to meet the demand. National and regional projections were not performed separately. They were calculated by aggregating the projection results at the provincial level.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter is divided into 4 sections. The first section summarizes the results of this study at three levels: national, regional, and provincial. The second section presents the implications of this study for energy planning. This includes policy options to meet estimates of the potential range of electricity demand in households of Thailand. The third section provides recommendations for further study and the last section is final remarks.

6.1 Summary of Results

Population and residential electricity consumption in Thailand were projected at the provincial level. Projection results were aggregated to obtain the regional and national population and electricity usage in residential sector. Because the projections involved estimations of future values for many variables, the results should be viewed in the context of these estimates (and assumptions in some cases). A summary of results follows, presented in 2 subsections; population estimates and residential electricity consumption estimates.

6.1.1 Population Estimates

National Perspective

The national projection results show an increasing population from 55.4 million in 1994 to 83.6 million in 2019. During this period, more than half of the Thai population lives in non-urban areas. However, the non-urban population is expected to increase with a decreasing rate as reflected in percent non-urban population decreasing from 58.5 to 53.7 percent in this period. Average population growth rate in the same period will decline from 2.08 to 1.42 percent annually.

Regional Perspective

In the period 1994-2019, Bangkok is expected to face an increase of population from 5.5 to 10.5 million, with all of the population living in urban areas. By 2019, Bangkok will account for 12.6 percent of population in Thailand. For other regions, the percent total population will be 31.7 percent for the Northeast region, 20 percent for the Central region (without Bangkok), 17 percent for the North region, 12.4 percent for the South region, and 6.3 percent for the East region in the same year. The highest percentage increase of population will take place in Bangkok, followed by the Central, East, South, Northeast, and North region in this period. After Bangkok, the regions that will experience the largest change in population in urban and non-urban areas will be the Central and the Northeast region respectively.

Provincial Perspective

At the provincial level, population growth between 1994 and 2019 will be large, ranging from 12.4 to 283.3 percent or a range from 0.5 to 11.3 percent per year. The mean value of the percent increase of population in this period will be 48.7 percent with a standard deviation of 42.7 percent. According to criteria established to group provinces based on percent population increase (see Chapter 3 for the criteria), the most interesting group include provinces that are expected to have a very high percent increase in population (172 percent to 184 percent), and a population more than 2 million people. This group includes Bangkok, Nonthaburi and Samut Prakarn in the Central region or Bangkok Metropolitan Region (BMR). Provinces in the Extended Bangkok Metropolitan Region (EBMR) including Nakhon Pathom and Chonburi are also expected to have population more than 1 but less than 2 million and a percent population increase in the high range, 65 percent for Nakhon Pathom, and 67.5 percent for Chonburi. Some provinces in the Northeast region including Nakhon Ratchasima, Khon Kaen, and Ubon Ratchathani are expected to have a population of more than 2 million people. However, the percent increase of population in these provinces will not be high and below the average value (38 to 41 percent). A high percent population change of 67 to 135 percent is also found in provinces that will have relatively low population (35,000 to 70,000 people) in 2019. These provinces include Ranong and Phuket in the South and Rayong and Chanthaburi in the East region. A medium level of change is expected to take place in Saraburi, Sa Kaeo, Trad in the East region, Phangnga in the South region, and Kanchanaburi in the Central region. The remaining provinces will experience a low percent increase of population in this period.

6.1.2 The Residential Electricity Consumption

National Perspective

The result of the residential electricity consumption under the base scenario is an increase of the consumption from 18,857 Giga Watt-hour (GWh) in 1994 to 81,011 GWh in 2019. The low scenario shows the increase to be from 14,425 to 59,494 GWh in the same period. The increase is estimated to be from 26,367 to 127,130 GWh in this period for the high scenario.

For the base scenario, the additional annual electricity consumption of 62,154 GWh in 2019 is calculated to be an average increasing total electricity consumption in the residential sector of 6.8 percent per year. The increase of the total consumption in the urban and non-urban households per year in this period will be 8.0 and 6.2 percent respectively. The average percent increase per year of total residential electricity demand will be four times as much as the average percent population increase per year (1.7 percent) in the same period. The percent of electricity consumption by end use in 2019 is projected to be 49.5 percent from air conditioners, 24.3 percent from refrigerators, 5.8 percent from lighting, 17.2 percent from irons, 5.1 percent from fans, and 8.1 percent from other appliances at the national level. This compares to 26.6 percent from air conditioners, 24.9 percent from refrigerators, 12.4 percent from lighting, 14.7 percent from irons, 10.5 percent from fans, and 10.9 percent from other appliances in 1994.

Regional Perspective

The regional share of the residential electricity consumption in 2019 is estimated to be 43.1 percent from the Central region (including Bangkok with 22.3 percent from Bangkok), 22.9 percent from the Northeast region, 16.3 percent from the North region, 11.8 percent from the South region, and 5.9 percent from the East region. The ranking of the projected share of the electricity consumption, by region, corresponds to the ranking of the share of population by region. That is, the region with the highest expected population in 2019 will also have the highest household electricity consumption. By area, the results indicate that the highest electricity consumption in urban areas will take place in the Central region and the highest consumption in non-urban areas will take place in the Northeast region. In terms of percent increase in consumption, non-urban areas will experience a higher percent change in the consumption than the urban areas in all regions. The range of percent change will be from 10 to 15.6 percent per year in urban areas and from 13.2 to 20.4 percent per year in non-urban areas in 2019. The percent change is expected to be the highest (20.4 percent per year) in the non-urban areas of the Northeast region and to be the lowest (10 percent per year) in the urban areas of the South region.

Provincial Perspective

The percent increase of the residential electricity consumption in the period 1994 to 2019 among provinces in the same region is found to be smaller than the percent increase of provinces located in different regions. Within each region, there is at least one province that shows a remarkably high increase in the consumption. This high increase, especially in urban areas, will be recognized in Bangkok and some provinces in the Bangkok Metropolitan Area (BMR) such as Nonthaburi, Samut Prakarn, Pathum Thani, and Samut Sakhon. These are provinces that will experience high population increase as well. Large electricity consumption will also be found in the center provinces of each region where population is already high but the percent change of the population in this period will not be significant. These provinces include Chaingmai in the North region, Chonburi in the East region, Songkla and Nakhon Si Thammarat in the South, and Nakhon Ratchasima, Khon Kaen, and Ubon Ratchathani in the Northeast region. For these provinces, the increase of residential electricity consumption will be more influenced by an increase of ownership of household appliances than an increase of population in the provinces. A high percent increase in the consumption will also be found in some small provinces with relatively low population in the base period but a large percent increase of the population estimate by the year 2019. These provinces include Ranong and Phuket in the South region.

Projected Per Capita Electricity Consumption and Number of Households

The per capita electricity consumption is expected to increase from 340 kWh per person per year in 1994 to 969 kWh per person per by the year 2019. The per capita electricity consumption in Thailand will increase at a decreasing rate in this period. It is estimated that the percent increase of per capita electricity consumption will decrease from 33.7 percent in the period 1994-1999 to 16.7 percent in the period 2014-2019. Over the next 25 years from 1994, per capita electricity consumption in Bangkok will always be above the national average and is expected to increase from 1,070 to 1,713 kWh per person. By areas, the per capita consumption will always be larger in urban than non-urban areas. The per capita consumption will increase from 571 to 1,279 kWh per person (including Bangkok) in urban areas and 183 to 703 kWh per person in non-urban areas. The annual growth rate of electricity consumption per household is found to reduce from 9.5 percent in 1994 to 5.0 percent in 2019. This increase will be larger when compared to the annual population increase, which is estimated to decrease from 2.9 to 1.42 percent and the annual change of number of households (housing), which will decrease from 3.2 to 2.9 percent in the same period. This indicates that the higher estimated electricity consumption in the residential sector in Thailand will be more influenced by the increase of electric appliance ownership in households rather than the increased number of households and population.

The findings from this study reveal that provinces in Thailand will undergo changes in terms of population and electricity demand at different rates during the period 1994 to

2019. Provinces with high increases of population will also face a large increase of household electricity consumption. However, there will be provinces with moderate population increase that will experience dramatic increases of the consumption within provinces on a percentage basis. It is necessary that any change in energy development strategies acknowledge areas with large increase of total and percent increase of population and electricity consumption estimates.

6.2 Implications for Energy Planning

The electricity model provides estimates of the potential range of energy demand in the residential sector to the year 2019. The findings provide information for planners to manage electricity from both supply and demand sides. From the supply side, the low and high estimates indicate the potential range of electricity demand in the residential sector that Thailand will have to meet within the next 25 years. In 1996, EGAT generated 74,460 million kWh of electricity from the mix of fuel consisting of 28% natural gas, 20% lignite, 9% hydro-power, 26% bunker oil, 4% diesel oil, (with 3% purchased). If unchanged fuel mix and production efficiencies are assumed, rough estimates of the fuel supply required to meet the projected residential electricity demand can be calculated.

For the low scenario, the estimates for fuel supply to generate 60,000 gigawatt-hour in 2019 includes an increase from the base year 1994 to 2019 of 40,000 to 164,000 million cubic feet of natural gas, 2.7 to 11 million tons of lignite 7,000 to 29,000 million cubic meters of hydro-power 900 to 3,700 million litres of bunker oil and 170 to 700 million litres of diesel oil respectively. For the high scenario, to supply 127,000 gigawatt-hour to Thai households in 2019 will require approximately 351,000 million cubic feet of natural gas, 23 million tons of lignite, 61,000 cubic meters of hydro-power, 8,000 million liters of bunker oil, and 1,500 million litres of diesel oil. The increase of estimated required fuel supply will be approximately 4 times more for each fuel type in 2019 from the base year for the low scenario and 5 times more for the high scenario over the same period. The fuel supply estimates for the generation of electricity in the residential sector accounts for only a small percentage of the total energy consumption of the country. The share of residential electricity in final energy consumption of the country was approximately 3.3% in 1994 (The share of residential electricity demand in total electricity consumption of the country was 20.6% and the share of total electricity consumption in total energy demand of the country was 16.2%; OECD/IEA, 1995).

From the fuel resource perspective, fuel resources are utilized and have to be allocated for both electricity and non-electricity uses in various sectors such as coal in the industrial sector, petroleum products in transportation and residential sectors, and gas in the industrial and residential sectors. The fuel mix of electricity generation in 1994 shows more than 50% of electricity fuel resources utilized to come from nonrenewable resources (fossil fuels such as natural gas and oil). The reserves of these fuels in Thailand are relatively limited. According to OECD/IEA (1997), Thailand has proven reserves of oil estimated to be approximately 206 million barrels or 327,478 million liters.

Based on the current (1994) oil production rate of 57,000 barrels per day, Thailand will exhaust the oil reserve within 9 years. For this reason the country must be heavily dependent on imported oil as the energy (including electricity) resource supply.
If oil will be chosen as a medium and long-term fuel option for electricity generation, energy planners have to take into consideration concerning the limited domestic resource as well as the fluctuation of the price of oil in the global market. The option suggested by OECD/IEA (1997) is to require the new oil fired power plants to be able to use both oil and natural gas as fuels.

For natural gas, the most likely reserves in Thailand were estimated to be somewhere between 10,962 to 21,100 billion cubic feet (bcf) as of 1993 (OECD/IEA, 1997). With the current production rate of 1,500 million standard cubic feet per day, it is estimated that Thailand will exhaust the most likely gas reserves (16,450 bcf - EGAT's estimate) in the year 2020. Natural gas seems to be a better alternative fuel than oil in terms of availability, however, energy planners must be aware that as the production of gas continues to grow, at the same time there will be an increase of non-electricity use of natural gas and its products such as direct use of natural gas by industries. This means that less natural gas will be left as a fuel supply for electricity generation and that much of it will have to be imported if natural gas is the choice of future fuel for electricity generation.

Lignite is a competitive fuel option for Thailand because the estimated domestic reserve of this fuel is as large as 2,069 million tons. The availability of lignite in the global market and its relatively stable price makes lignite a more favorable option. However, the Thai government recently has required the installation of flue gas desulfurisation (FGD) in all new coal fired power plants. This requirement makes lignite less competitive compared to other fuel options because of the high cost of FGD.

Another fuel option for Thailand is the renewable energy resource of hydro-power. The total domestic hydro-power potential in Thailand is approximately 12,734 megawatts (MW) (OECD/IEA, 1997). Currently, Thailand has utilized only 26.5% of the total potential. However, the use of the remaining domestic water resources for hydroelectric generation will be difficult because of the strong protests by concerned citizens and environmentalists opposed to dam construction. The remaining water resources in Thailand are also suitable for only medium and small-scale electricity projects. Thailand could consider obtaining electricity through international sources by trading electricity and forming joint projects on hydroelectric production along Thailand's border.

The other fuel resource option is nuclear power. Similar to hydro-power, the perception of nuclear power in Thailand is that of an environmentally damaging energy resource. The opposition to nuclear power among Thai people caused the Thai government to announce the indefinite postponement of the two proposed nuclear power plants that had already been approved by the Cabinet (Wongwaikul, 1994). A study conducted by the World Bank in 1993 (OECD/IEA, 1997) on the cost of nuclear power in Thailand also concluded that nuclear power is not a competitive option for Thailand when compared to other fuel resources. Because of lack of domestic resources, Thailand has to import uranium and plutonium, the fuels resource for nuclear power. For the Thai government to pursue nuclear power as a long-term fuel option, the Thai government has to allocate significant resources for human resource development and training, site selection, disposal technologies, as well as public education.

The last option, which can be considered as the other fuel option, is conservation. When less electricity is used or conserved, less fuel will be needed. Activities for the conservation of electricity in Thailand have not been practiced in great extent because of lack of public awareness. More information and education has to be provided to public to create such awareness (more discussion under Demand Side Management)

Decision on future fuel supply and mix depends on the availability of current and future fuel resources, the current capacity of the production, transmission, distribution systems, potential electricity trade, as well as related laws and regulations. Energy planners must take into consideration of these conditions when planning for the supply of the fuel in order to meet with future estimate of the consumption with guarantee of continuity of supply.

While an option is to continue to meet the demand by increasing the supply through costly investment in new facilities and fuel resources, this option is certainly not the best long-term option for Thailand, where resources are limited. Another option is to reduce electricity consumption. The residential electricity can be reduced through management from the demand side. Demand side management (DSM) attempts to reduce future electricity demand in the residential sector by improving the efficiency of electric appliances by consumers. The results of electricity demand by types of appliance in this study allows energy planners to assess the impact of electricity consumption from each appliance and look at the potential for energy conservation by focusing on the electric appliances that have major shares of the total consumption. A study conducted by the World Bank (OECD/IEA, 1997) shows high potential for improving electricity end-use efficiency through DSM in Thailand. Although the DSM program has been in place in Thailand since 1991, there are still many limitations to the success of the program. The limitations include the high initial cost of the DSM program, weak public knowledge and awareness of energy conservation, a lack of energy efficiency baselines (efficiency testing), and inadequate cooperation from electric appliance manufacturers and government agencies. There are several policy options available to the Thai government or energy planners to reduce these barriers. These options are known to work best together.

The first option is information and educational programs. Programs should aim to educate the public on energy conservation, energy efficiency and its benefits. More information relating to energy efficient appliances should be made available to the public. For example, a guideline for consumers to purchase efficient appliances or a booklet that contains information on how to save electricity at home could be written. The educational programs should also be geared toward changing consumer attitudes and behavior to be more efficient in everyday usage of electric appliances such as, a routine behavior of turning the light off before leaving a room. In Thailand, a few public education programs that are directed toward encouraging energy conservation have been implemented. An educational curriculum was developed to educate Thai children on energy conservation and energy efficiency (IEA, 1997). It is necessary for the Thai government to provide continuing support for these programs because educational programs take a long time to become effective. In the past, some programs in this country failed because of the lack of continuing support from the government.

The second option is regulation. This option is used by many European governments to mandate appliance efficiency labeling (IEA, 1995). A few European countries also have mandatory efficiency standards for home appliances. Unlike these countries, Thailand uses the market-based voluntary approach. The labeling program in Thailand is voluntary and there is not any efficiency standard for electric appliances in the residential sector (efficiency standard exists in the commercial and industrial sector). Appliances that have efficiency labels include refrigerators and air conditioners. Since the program is voluntary, very few manufacturers have participated in this program.

The third option is for the Thai government to support transfer of energy efficient technology available in the global market. It is important that cooperation between the DSM agency (EGAT) and other government agencies be strengthened. An example of a useful cooperation is for the ministry of Finance to provide tax reductions for imported energy efficient technology, equipment, and appliances for the DSM program especially at the initial stage.

The last option is electricity pricing. In general, higher electricity prices encourage investments of consumers in energy efficient appliances and discourage electricity-using activities. On the other hand, lower prices stimulate increased usage of appliances by consumers and reduce the cost-effectiveness of efficiency investments. Electric utilities play an important role in supporting the electricity end-use efficiency program. The decision for utilities to adopt the program will be based on the benefits and costs for adopting the program. By adopting the program, utilities have to pay for the cost of the program and lose the revenue as a result of the electricity savings induced by the program. Nevertheless, utilities will gain long-term savings by not having to generate and supply more electricity. Based on situations in each country, each government can use electricity pricing as a market force to improve end-use efficiency. In Thailand, electricity utilities have historically been publicly controlled monopolies. Privatization in this business has just begun and is being encouraged by the Thai government. Electricity pricing in Thailand is usually kept below economically efficient levels. Since electric utilities will become more privatized in the future, the Thai government could reexamine their electricity pricing structure in order to see if readjustment of the price could be done to encourage investment in energy conservation or end-use efficiency programs by future growing utilities.

No matter which options are selected, energy planners will have to make policy to meet the estimated future demand. To meet the low estimate could require implementation of policy with restrictions. With no restrictions, future demand will likely be in the range of the base and high estimates.

6.3 Future Research

Future research that will compliment this study is the study of electricity fuel resources or supply that will meet the estimated future demand for electricity in Thailand. A study could be conducted by building a model that has the ability to track the flow of electricity fuel supply as well as project current and potential fuel resources. The flow of the fuel supply should include both current and future domestic and non-domestic resources. The model should take into consideration the impact of economic, social, and technological changes to the demand of the fuel resources. With the addition of a supply model to the demand model developed in this study, energy planners would have an effective tool for assessing the multiple energy options that exist for Thailand in the future.

The other research that will compliment this is the study of energy consumption in other sectors by other users. The framework of the residential electricity consumption model developed in this study can be applied to estimate energy consumption by other resources (petroleum, natural gas, and coal) by other users (industrial, transportation and commercial).

6.4 Final Remarks

It should be recognized that this study pertains to only one sub-component of the entire energy planning process. That is, it is an estimation of the demand for one resource (electricity) by one sector (residential) of one country (Thailand). Energy planners must consider the supply as well as the demand for multiple resources, used by multiple sectors, influenced by local, regional and global factors. The development and use of detailed models of sub-components, such as developed in this study, should provide a better understanding of each component, and consequently, a better understanding and management of the entire energy planning process. A better understanding of the energy and enhanced modeling capabilities should lead to better planning and control, as we endeavor to effectively manage our natural resources for the future.

APPENDICES

APPENDIX A

APPENDIX A

POPULATION MODEL INPUTS AND RESULTS

I. POPULATION MODEL INPUTS

1) Fertility and Mortality Component

Table 11: Birth and Death Rate of Population by Age, Sex, and Area, 1995

Age Group	Urban*	Birth Rate	Male Death Rate	Female Death Rate
0-4	1	0	2.3	1.7
0-4	0	0	2.3	1.7
5-9	1	0	0.6	0.4
5-9	0	0	0.6	0.4
10-14	1	0	0.7	0.4
10-14	0	0	0.7	0.4
15-19	1	42.8	2.3	0.7
15-19	0	42.8	2.3	0.7
20-24	1	106.4	3.4	0.9
20-24	0	106.4	3.4	0.9
25-29	1	103.9	4.3	1
25-30	0	103.9	4.3	1
30-34	1	66.8	4.5	1.2
30-34	0	66.8	4.5	1.2
35-39	1	30.2	4.8	1.6
35-39	0	30.2	4.8	1.6
40-44	1	10.1	5.4	2.3
40-44	0	10.1	5.4	2.3
45-49	1	2.7	6.7	3.3
45-49	0	2.7	6.7	3.3
50-54	1	0	9	4.9
50-54	0	0	9	4.9
55-59	1	0	11.9	7.1
55-59	0	0	11.9	7.1
60-64	1	0	18.1	11.2
60-64	0	0	18.1	11.2
65-69	1	0	27.7	18.6
65-69	0	0	27.7	18.6
70-74	1	0	63.3	54.5
70-74	0	0	63.3	54.5
75up	1	0	63.3	54.5
75up	0	0	63.3	54.5

* Urban code "1" refers to Urban Areas and "0" refers to Non-Urban Areas"

2) Migration Component

Table 12: Migration Distribution of Females and Males in Thailand by Age, 1990

Age Group	Percent Male Migrant	Percent Female Migrant
0-4	3.3	4.1
5-9	8.7	10.3
10-14	6.5	7.4
15-19	9.7	16.4
20-24	31.6	22.4
25-29	15.2	14.9
30-34	9.7	8.8
35-39	5.1	5
40-44	3.2	3.3
45-49	2.3	2
50-54	1.7	1.7
55-59	1	1.3
60-64	0.8	0.9
65-69	0.5	0.5
70-74	0.7	1
75up	0	0

(Source: United Nations, 1995 from the National Statistical Office, 1993.)

II. POPULATION MODEL RESULTS

Table 13:Projected Population by Region and Area, 1994 and 2019

Year - Region	Urban Population	Non-Urban Population	Total Population
1994-Bangkok	5,066,073	0	5,066,073
2019- Bangkok	10,544,488	0	10,544,488
1994-Central	4,172,771	10,031,973	14,204,744
2019-Central	6,229,005	21,044,780	27,273,785
1994-East	2,151,133	1,176,831	3,327,964
2019-East	3,182,824	2,104,474	5,287,298
1994-North	7,337,456	3,584,606	10,922,062
2019-North	9,505,796	4,697,596	14,203,392
1994-Northeast	16,317,855	3,417,500	19,735,355
2019-Northeast	21,813,646	4,641,338	26,454,984
1994-South	2,915,783	4,276,078	7,191,861
2019-South	4,176,574	6,178,590	10,355,164

Table 14: Projected Population of Thailand by Province, 1994 and 2019

Province Coce	1994 non-urban	1994 Urban	1994 Total	2019 Non-Urban	2019 Urban	2019 Total	% Population Change	Annual Population Growth
01	215432	102106	317538	319055	155094	474149	49.3	9.9
02	428873	216232	645105	648172	326874	975046	51.1	10.2
03	766450	157183	923633	972915	204612	1177527	27.5	5.5
04	440705	254336	695041	634365	371390	1005755	44.7	8.9
05	1212983	422815	1635798	1708606	601654	2310260	41.2	8.2
06	301088	109543	410631	422943	268503	691446	68.4	13.7
07	377495	196432	573927	495713	363531	859244	49.7	9.9
08	379055	506692	885747	629454	849340	1478794	67.0	13.4
09	321005	13659	334664	359875	16179	376054	12.4	2.5
10	882686	168731	1051417	1171695	224805	1396500	32.8	6.6
11	272649	112474	385123	371677	153414	525091	36.3	7.3
12	754970	304173	1059143	887648	359257	1246905	17.7	3.5
13	699451	690581	1390032	906061	910995	1817056	30.7	6.1
14	312618	196348	508966	431772	271080	702852	38.1	7.6
15	115942	75261	191203	176634	114391	291025	52.2	10.4
16	236398	135889	372287	340489	202445	542934	45.8	9.2
17	471368	47396	518764	591590	61128	652718	25.8	5.2
18	71912	146002	217914	104523	216368	320891	47.3	9.5
19	120188	551436	671624	191861	920852	1112713	65.7	13.1
20	512259	128800	641059	686841	173861	860702	34.3	6.9
21	1865052	421417	2286469	2575553	590638	3166191	38.5	7.7
22	561904	847367	1409271	748104	1135263	1883367	33.6	6.7
23	687217	342448	1029665	895939	454803	1350742	31.2	6.2
24	159675	550045	709720	608865	2115127	2723992	283.8	56.8
25	215048	366916	581964	291617	506667	798284	37.2	7.4
26	330989	111376	442365	394395	129726	524121	18.5	3.7
27	1115737	254805	1370542	1476838	344629	1821467	32.9	6.6
28	111547	392077	503624	294335	1055561	1349896	168.0	33.6
29	191540	227276	418816	281819	340193	622012	48.5	9.7
30	296597	91334	387931	431080	133434	564514	45.5	9.1
31	158679	390978	549657	228675	575718	804393	46.3	9.3
32	0	5066073	5066073	0	10544488	10544488	108.1	21.6
33	492997	152272	645269	576321	254178	830499	28.7	5.7
34	77665	137043	214708	119255	217354	336609	56.8	11.4
35	173691	287742	461433	232886	366410	599296	29.9	6.0
36	382237	152299	534536	481233	189337	670570	25.4	5.1
37	465546	315851	781397	600887	415879	1016766	30.1	6.0
38	161739	244793	406532	211659	319974	531633	30.8	6.2
39	734910	203938	938848	1066853	299611	1366464	45.5	9.1
40	355874	124933	480807	442412	154263	596675	24.1	4.8
41	12660	163770	176430	26157	355774	381931	116.5	23.3
42	677623	206273	883896	860249	259972	1120221	26.7	5.3
43	154316	26346	180662	190060	33073	223133	23.5	4.7
44	48910	318493	367403	56261	358455	414716	12.9	2.6
45	1118092	143108	1261200	1402266	179408	1581674	25.4	5.1
46	76447	75137	151584	178759	178282	357041	135.5	27.1
47	219021	183108	402129	327639	353150	680789	69.3	13.9

Table 14 (cont'd)

Province Coce	1994 non-urban	1994 Urban	1994 Total	2019 Non-Urban	2019 Urban	2019 Total	% Population Change	Annual Population Growth
48	333851	379091	712942	468013	531473	999486	40.2	8.0
49	317137	380257	697394	427145	497063	924208	32.5	6.5
50	615852	168059	783911	800589	225016	1025605	30.8	6.2
51	180492	215533	396025	223706	262474	486180	22.8	4.6
52	475130	108904	584034	638178	145062	783240	34.1	6.8
53	1227649	90747	1318396	1579176	121141	1700317	29.0	5.8
54	818778	202272	1021050	1106704	272531	1379235	35.1	7.0
55	220786	855717	1076503	322515	1281181	1603696	49.0	9.8
56	75112	170199	245311	112291	253447	365738	49.1	9.8
57	9438	851069	860507	21689	2321455	2343144	172.3	34.5
58	88108	96997	185105	109866	126659	236525	27.8	5.6
59	143288	221933	365221	361386	634995	996381	172.8	34.6
60	344765	176596	521361	458185	356874	815059	56.3	11.3
61	152018	52112	204130	182306	62574	244880	20.0	4.0
62	270678	303499	574177	344416	387319	731735	27.4	5.5
63	504777	264160	768937	643548	338279	981827	27.7	5.5
64	494182	251788	745970	737550	370451	1108001	48.5	9.7
65	1235681	67572	1303253	1622972	95424	1718396	31.9	6.4
66	700001	126013	826014	1007128	180969	1188097	43.8	8.8
67	219913	49893	269806	279437	65614	345051	27.9	5.6
68	1031838	375955	1407793	1425198	517535	1942733	38.0	7.6
69	426381	34669	461050	533375	49549	582924	26.4	5.3
70	255188	49922	305110	318664	62444	381108	24.9	5.0
71	1228304	364404	1592708	1663985	492734	2156719	35.4	7.1
72	346252	150754	497006	444704	190015	634719	27.7	5.5
73	188809	111314	300123	249327	146225	395552	31.8	6.4
74	461935	14461	476396	699361	22125	721486	51.4	10.3
75	445528	19791	465319	616443	29010	645453	38.7	7.7
76	343887	0	343887	457982	0	457982	33.2	6.6

Table 15: List of Provinces in Thailand

Region Code	Province Code	Province Name
S	01	Krabi
C	02	Kanchanaburi
NE	03	Kalasin
N	04	Kampaeng Phet
NE	05	Khon Kaen
E	06	Chanthaburi
E	07	Chachoengsao
E	08	Chonburi
C	09	Chainat
NE	10	Chaiyaphum
S	11	Chumphon
N	12	Chiang Rai
N	13	Chiang Mai
S	14	Trang
E	15	Trad
N	16	Tak
NE	17	Yasothon
C	18	Nakhon Nayok
C	19	Nakhon Pathom
NE	20	Nakhon Phanom
NE	21	Nakhon Ratchasima
S	22	Nakhon Si
N	23	Nakhon Sawan
C	24	Nonthaburi
S	25	Narathiwat
N	26	Nan
NE	27	Buriram
C	28	Pathum Thani
C	29	Prachuap Khilikhan
E	30	Phachinburi
S	31	Pattani
C	32	Bangkok
C	33	Phra Nakhon Si
S	34	Phangnga
S	35	Phatthalung

Table 13 (cont'd)

Region Code	Province Code	Province Name
N	36	Phichit
N	37	Phitsanulok
C	38	Phetchaburi
N	39	Phetchabun
N	40	Phrae
S	41	Phuket
NE	42	Maha Sarakham
N	43	Mae Hong Son
S	44	Yala
NE	45	Roi Et
S	46	Ranong
E	47	Rayong
C	48	Ratchaburi
C	49	Lopburi
N	50	Lampang
N	51	Lamphun
NE	52	Loei
NE	53	Si Saket
NE	54	Sakon Nakhon
S	55	Songkhla
S	56	Satun
C	57	Samut Prakarn
C	58	Samut Songkham
C	59	Samut Sakhon
C	60	Saraburi
C	61	Singburi
N	62	Sukhothai
C	63	Suphanburi
S	64	Surat Thani
NE	65	Surin
NE	66	Nong Khai
C	67	Ang Thong
NE	68	Udon Thani
N	69	Uttaradit
N	70	Uthai Thani
NE	71	Ubon Ratchathani
N	72	Phayao
NE	73	Mukdahan
E	74	Sa Kaeo
NE	75	Nong Bua Lamphu
NE	76	Amnat Charoen

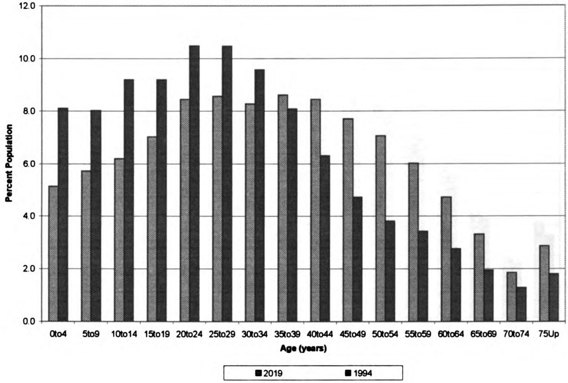

Figure 58: Age Distribution of Projected Population in Thailand, 1994 and 2019

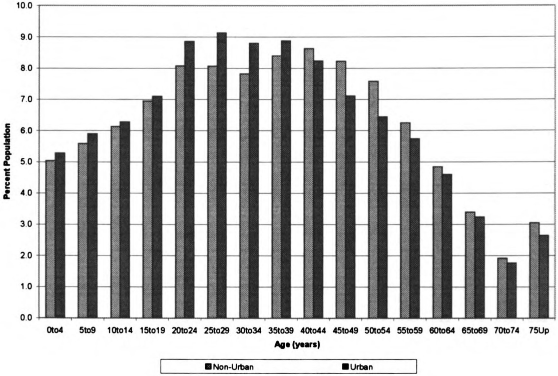

Figure 59: Age Distribution of Projected Urban and Non-Urban Population in Thailand, 2019

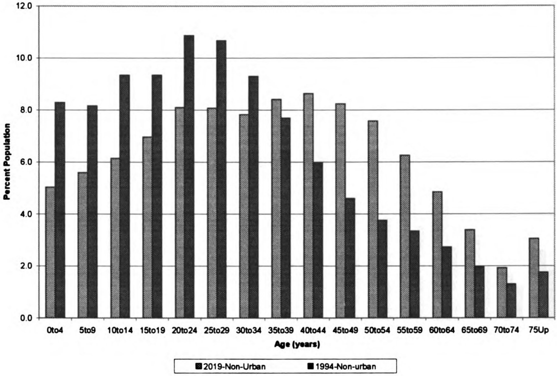

Figure 60: Age Distribution of Projected Non-Urban Population in Thailand, 1994 and 2019

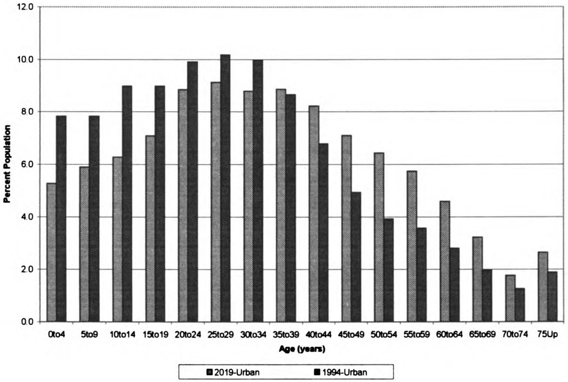

Figure 61: Age Distribution of Projected Urban Population in Thailand, 1994 and 2019

APPENDIX B

APPENDIX B

RESIDENTIAL ELECTRICITY DEMAND MODEL INPUT AND RESULTS

I. RESIDENTIAL ELECTRICITY DEMAND MODEL INPUT

Appliance Input Power and Usage Intensity

Table 18: Electric Household Appliance by Types and Usage for Average Scenario

Types of Appliance	Average Electricity Usage (kwh)	Power of appliance (kW)	Number of Hours	Number of Days
Radio	13	0.035	24	365
Color television	117	0.08	4.0	365
Black and white TV	117	0.08	4.0	365
Video	7.2	0.06	2.3	52
Iron	365	1.00	1.0	365
Rice-cooker	82	82.0	0.45	365
Fan	204	0.07	8.0	365
Air-conditioner	2400	2	6	300
Refrigerator	876	0.	24	365
Computer	47	0.13	1	365
Light	187	187 kwh[a]		

a: 187 kwh was total electricity consumption per household from lighting.

II RESIDENTIAL ELECTRICITY DEMAND MODEL RESULTS

1) National Electricity Consumption in the Residential Sector

Table 19: Projected Residential Electricity Consumption in Thailand, 1994-2019

Low Scenario-Year	Total		Urban Area		Non-Urban Area	
	Giga kWh	% Change	Giga kWh	% Change	Giga kWh	% Change
Low-1994	14.4		9.6		4.8	
Low-1999	21.0	45.6	13.2	37.2	7.8	62.3
Low-2004	28.6	36.3	17.7	33.9	10.9	40.4
Low-2009	37.7	31.7	23.2	31.0	14.5	33.0
Low-2014	47.8	26.7	29.0	25.3	18.7	28.9
Low-2019	59.5	24.5	35.9	23.6	23.6	25.9

Base Scenario-Year	Total		Urban Area		Non-Urban Area	
	Giga kWh	% Change	Giga kWh	% Change	Giga kWh	% Change
Base-1994	18.9		12.8		6.0	
Base-1999	27.8	47.7	17.8	38.9	10.0	66.3
Base-2004	38.4	37.8	24.1	35.2	14.3	42.5
Base-2009	51.0	32.8	31.8	31.9	19.2	34.4
Base-2014	64.8	27.3	39.9	25.6	24.9	29.9
Base-2019	81.0	24.9	49.4	23.8	31.6	26.7

High Scenario-Year	Total		Urban Area		Non-Urban Area	
	Giga kWh	% Change	Giga kWh	% Change	Giga kWh	% Change
High-1994	26.4		19.0		7.4	
High-1999	40.6	54.1	27.3	43.8	13.3	80.6
High-2004	57.7	42.1	37.8	38.5	19.9	49.3
High-2009	78.4	35.7	50.8	34.3	27.6	38.6
High-2014	100.9	28.8	64.3	26.6	36.6	32.8
High-2019	127.1	26.0	79.9	24.4	47.2	28.8

2) Regional Electricity Consumption in the Residential Sector

Table 20:Projected Residential Electricity Consumption in Thailand by Region, 1994 and 2019

Region	House-hold	Total Demand (kWh)	Electricity Demand (kWh)										
			AC	Refrigerator	Radio	Color TV	Black and White TV	VCR	Iron	Rice Cooker	Fan	Computer	Light
Central-1994	3,352,619	8.81E+09	3.99E+09	1.85E+09	3.86E+07	2.87E+08	1.71E+08	7.05E+06	9.70E+08	2.47E+08	6.37E+08	1.73E+07	6.23E+08
Central-2019	8,543,924	3.49E+10	1.96E+10	7.10E+09	9.82E+07	9.90E+08	4.52E+08	3.46E+07	2.53E+09	7.01E+08	1.63E+09	1.92E+08	1.58E+09
Central w/o BKK-1994	2,174,463	3.40E+09	5.25E+08	1.08E+09	2.44E+07	1.73E+08	5.64E+07	3.57E+06	5.69E+08	1.56E+08	4.00E+08	1.12E+07	3.97E+08
Central w/o BKK-2019	5,274,315	1.69E+10	7.84E+09	4.26E+09	5.96E+07	6.07E+08	1.36E+08	1.93E+07	1.44E+09	4.32E+08	9.85E+08	1.14E+08	9.68E+08
East-1994	793,451	9.59E+08	9.44E+07	2.86E+08	8.33E+06	4.87E+07	2.20E+07	6.90E+05	1.80E+08	4.61E+07	1.28E+08	1.37E+06	1.44E+08
East-2019	1,684,234	4.75E+09	2.11E+09	1.26E+09	1.76E+07	1.83E+08	4.58E+07	4.88E+06	3.89E+08	1.34E+08	2.73E+08	2.80E+07	3.06E+08
Northeast-1994	4,230,969	3.61E+09	3.18E+08	8.72E+08	3.98E+07	1.60E+08	1.22E+08	2.06E+06	6.39E+08	1.49E+08	5.39E+08	7.62E+06	7.59E+08
Northeast-2019	7,562,282	1.86E+10	8.13E+09	5.24E+09	7.10E+07	7.54E+08	2.19E+08	1.77E+07	1.15E+09	5.66E+08	9.65E+08	1.10E+08	1.36E+09
North-1994	2,752,614	3.24E+09	4.11E+08	9.39E+08	2.92E+07	1.61E+08	7.46E+07	2.71E+06	5.64E+08	1.34E+08	4.17E+08	8.01E+06	4.98E+08
North-2019	4,764,699	1.32E+10	5.88E+09	3.61E+09	5.05E+07	5.14E+08	1.30E+08	1.35E+07	9.77E+08	3.74E+08	7.22E+08	7.92E+07	8.62E+08
South-1994	1,657,577	2.24E+09	2.07E+08	7.45E+08	1.73E+07	1.21E+08	4.56E+07	2.23E+06	4.16E+08	1.10E+08	2.60E+08	8.69E+06	3.04E+08
South-2019	3,183,588	9.55E+09	4.37E+09	2.48E+09	3.32E+07	3.57E+08	8.53E+07	1.08E+07	8.00E+08	2.61E+08	5.01E+08	6.54E+07	5.84E+08
Bangkok-1994	1,178,156	5.42E+09	3.47E+09	7.75E+08	1.43E+07	1.14E+08	1.15E+08	3.47E+06	4.01E+08	9.14E+07	2.36E+08	6.10E+06	2.26E+08
Bangkok-2019	3,269,609	1.81E+10	1.18E+10	2.85E+09	3.86E+07	3.83E+08	3.16E+08	1.53E+07	1.09E+09	2.68E+08	6.44E+08	7.84E+07	6.11E+08

3) Provincial Electricity Consumption

Table 21: Projected Residential Electricity Consumption in Urban Areas of Provinces in Thailand by Types of Appliance, 2019

Province Code	Household	Total demand ($X10^6$ kWh)	Electricity Demand (kWh)										
			AC	Refrigerator	Radio	Color TV	Black and White TV	VCR	Iron	Rice Cooker	Fan	Computer	Light
01	27010	135.7	81759861	27811437	258293	3850271	252369	172299	8153884	2461796	4835540	1130065	5050870
02	50817	250.0	165152952	40818780	549872	6144562	1112801	322687	11093632	5056828	8098061	2134951	9502779
03	26281	149.2	96025220	27105185	257786	3841409	626942	185684	7470374	2767328	4696673	1289178	4914547
04	59275	309.5	195669006	57492006	602251	8163808	1499917	362981	15671176	5719224	10714455	2569711	11084425
05	93597	504.9	320689967	92091987	958984	12997608	2116739	613738	26726601	9745664	16885626	4524937	17502639
06	61319	264.6	150237656	56494143	660342	7860776	708197	302867	18163507	5236098	11546032	1949204	11466653
07	66099	306.8	176839867	64617605	720502	9004418	1949226	359940	20006630	5716665	12822666	2400115	12360513
08	159786	730.3	457375754	121613239	1565386	20001936	3811744	913801	45419170	15024955	28555328	6187357	29879982
09	2153	13.8	9012213	2561373	24084	355873	42463	16852	634849	209049	414178	120472	402611
10	32274	186.7	119910082	36066347	351286	4911709	469959	212881	8152108	3002650	6019595	1539929	6035238
11	24796	138.9	85983422	27821549	273559	3499320	274190	167502	8156813	2167817	4751026	1152089	4636852
12	44830	294.6	192748899	55830229	521352	7103013	240380	330190	13863585	4867957	8190924	2519786	8383210
13	145578	865.2	551454888	164687365	1668542	21722596	2795761	944201	44765416	15543128	27033073	7385604	27223086
14	40832	224.0	138141523	46107846	411260	6001934	554139	255676	12115964	3773943	7168177	1872508	7635584
15	19351	102.0	61982961	20972034	204029	2633155	162329	123469	6060670	1690147	3791546	809105	3618637
16	34369	177.6	109501849	35019683	375964	4848894	548159	214343	9932929	3367004	5907106	1462720	6427003
17	7932	46.5	29990835	8585162	83111	1189761	141204	53189	2260272	869842	1449070	393629	1483284
18	38249	197.3	121452502	38736792	414014	5121315	1112388	226925	10807569	3628852	7015904	1635633	7152563
19	156144	772.7	457336462	160288647	1763198	20663462	2977893	931901	49110968	13557942	30792604	6062727	29198928
20	23579	131.0	81694679	25755576	254098	3486800	427222	163168	6954324	2462879	4330277	1108321	4409273
21	88492	476.6	299943658	89330405	924419	12670497	2264906	544762	25791267	8169010	16056947	4316234	16548004
22	155355	865.6	537038605	164652034	1585086	23567140	11920994	1100471	47592148	13928452	27809645	7365013	29051385
23	66513	380.7	245679450	69571059	702326	10067667	1673331	441811	18250157	6237400	12497153	3185323	12437931

Table 21 (cont'd)

Province Code	Household	Total demand ($X10^6$ kWh)	Electricity Demand (kWh)										
			AC	Refrigerator	Radio	Color TV	Black and White TV	VCR	Iron	Rice Cooker	Fan	Computer	Light
24	513913	2076.3	1090650893	470064114	6168910	62151899	13924541	2608535	176062831	42631244	101522389	14417904	96101731
25	73386	384.3	240942980	71181708	790363	10496226	1086351	505211	22197257	7345518	12622800	3364701	13723182
26	15782	103.6	68251525	18925767	170971	2498469	292311	122919	4706875	1874884	2866777	907457	2951234
27	46163	250.3	161620486	45501680	432794	6358759	349064	323326	12341880	4533578	8008469	2165105	8632481
28	252913	1004.6	605621765	149394254	2889800	31816296	5423310	1242206	80308254	21200370	49395360	10062736	47294731
29	53967	270.7	162410486	55580041	607625	7682211	613841	342770	16259268	4915170	9947114	2287083	10091829
30	22186	116.3	71006021	23207517	236915	3183310	440855	138987	6751517	1991231	4201155	961387	4148782
31	82454	433.4	275201755	78200038	865141	11842039	812745	487843	24982028	7585952	14456901	3546686	15418898
32	2091453	12647.9	8305943370	2079239823	24714501	270003639	202390607	11863033	700268254	178364686	411719129	72295714	391101711
33	44436	215.5	126656994	44523062	492010	6223132	1194227	261141	13527913	3947411	8594201	1725845	8309532
34	40201	195.6	115096270	40850714	422508	5667938	435819	238341	12846619	3604623	7248509	1622917	7517587
35	48806	280.5	179514784	52913615	495494	7353082	957218	354976	14176128	4553388	8543020	2461776	9126722
36	25999	155.3	102661558	27860941	271083	3267401	594366	182989	6886649	2428084	4903650	1354291	4861813
37	61691	359.6	233098816	65057453	673353	9475362	1384541	422711	17679614	5962041	11310612	2984683	11536217
38	43116	242.8	152574305	47582884	474286	6620817	660516	295543	12505014	4119115	7833015	2104389	8062692
39	46493	241.9	151194668	45543462	480804	6522437	1065395	284532	13359835	4375023	8340657	2004171	8694191
40	21955	138.4	89728098	26265305	252408	3504319	501090	153808	6791140	1823691	4163038	1154523	4105585
41	73232	322.3	184889309	67802667	761975	9559202	1023871	389213	22112867	6339159	13306755	2446919	13694384
42	33829	199.3	128091730	36544080	365486	5001590	877274	250428	10226536	3663641	6244774	1729697	6326023
43	4972	33.7	23523947	5300313	56286	795598	16854	33888	1435680	511976	843551	255557	929764
44	39862	268.0	177636443	49271508	439929	6896370	506647	325773	12056788	3940527	7082390	2433705	7454194
45	22401	135.7	87713254	24977567	242817	3438637	419678	154514	6803560	2479683	4107556	1153519	4188987
46	39652	171.6	94786035	38345571	424268	5060603	441133	203977	12889741	3342394	7425067	1276479	7414924
47	70086	318.8	185364472	66217444	724803	9406232	1461227	362697	20345767	6058351	13308400	2485423	13106082
48	78080	437.5	273874919	85466451	863526	11428904	1449630	504300	23568862	7148690	15050004	3523545	14600960
49	70590	418.1	265190660	81315264	808429	10683957	1114633	467995	21782462	6447474	13669229	3445177	13200330

Table 21 (cont'd)

Pro-vince Code	House-hold	Total demand ($X10^6$ kWh)	Electricity Demand (kWh) AC	Refrigerator	Radio	Color TV	Black and White TV	VCR	Iron	Rice Cooker	Fan	Computer	Light
50	34954	205.9	130151269	39854784	401904	5231737	822032	222790	10818877	3588566	6581171	1658305	6536398
51	36700	225.4	143450071	43548898	402686	5889337	1029464	267127	11228523	4103555	6677416	1968652	6862900
52	20483	114.6	72245853	21958252	214065	2980324	569220	144396	5898143	2182907	3642461	977527	3830321
53	16210	90.7	58356902	16685708	158228	2280343	369106	112954	4480490	1714679	2781537	771683	3031270
54	37158	211.5	133513855	40267187	411627	5552577	977963	258801	10939211	3960271	6879878	1750279	6948546
55	204725	1054.7	638619790	211793906	2253276	29093249	3022053	1212780	64320692	18098497	38343374	9631088	38283575
56	39935	200.2	122937840	39279844	395075	5552491	663147	259519	11384568	3692129	6879886	1700363	7467845
57	531607	2234.1	1198844104	503534709	6061588	66614643	12929866	2658087	173536198	44819654	104613917	21107972	99410509
58	15974	91.6	58044683	17395846	172291	2495924	395652	113807	4705707	1487736	3039961	780616	2987138
59	149173	580.4	339358977	127455200	1584828	18903374	3096343	708097	15613276	12562551	28750903	4501899	27895351
60	72985	293.8	190939245	51194492	779910	7741047	2437714	378692	5522873	6664584	11959368	2524910	13648195
61	8159	51.9	34147875	9420291	85554	1289218	170838	57652	2356899	796817	1564892	446925	1525733
62	55487	323.8	212202511	57792151	540430	8113067	1471861	408780	14457185	5583787	10058295	2790799	10376069
63	45580	268.2	174186608	48862847	488701	6857227	1151802	318836	12474855	4347441	8684609	2282395	8523460
64	59671	299.2	191136835	59956723	633565	8761597	1072592	520736	7342016	5320917	10691846	2568701	11158477
65	14566	80.0	50909496	14783621	154776	2096086	246083	89518	4371799	1399400	2611531	652497	2723842
66	25540	138.9	85777965	26757599	273705	3723665	1090378	160313	7761096	2593785	4851122	1125051	4775980
67	9639	54.2	34507673	10220165	99623	1417699	262944	66010	2624616	923312	1830798	467031	1802493
68	68046	366.7	224483828	74033089	753855	10323254	407206	451302	20764639	6838137	12832296	3130273	12724602
69	8079	44.0	27426499	8577900	88534	1172860	188580	53593	2394679	749767	1513972	357600	1510773
70	8644	51.8	33414526	9729713	93278	1358738	125358	62860	2479068	839631	1648579	446498	1616428
71	67351	376.8	235164300	72053751	717630	9727704	1958428	429352	20230350	7163966	13579619	3159775	12594637
72	27358	162.7	103258667	31886263	282779	4006625	947228	207344	7835637	2951894	4816934	1398633	5115946
73	18957	102.8	66834733	18510912	186826	2541635	392265	134326	4727892	1879162	3085468	919671	3544959
74	3853	19.6	11815199	3951888	41145	542352	76562	23384	1172523	343179	729607	160222	720511
75	4092	21.1	12731064	4318475	45333	603112	24488	25859	1248698	401795	771680	176776	765204
76*	0	0.0	0	0	0	0	0	0	0	0	0	0	0

(*No urban area in province 76)

Table 22: Projected Residential Electricity Consumption in Non-Urban Areas of Provinces in Thailand by Types of Appliance, 2019

Province Code	Household	Total demand ($X10^6$ kWh)	Electricity Demand (kWh)										
			AC	Refrigerator	Radio	Color TV	Black and White TV	VCR	Iron	Rice Cooker	Fan	Computer	Light
01	43744	172.5	80277190	57822057	458467	7262423	1454968	170863	6533406	5184156	4481133	1041355	7771113
02	98945	389.4	180952084	120369809	1069438	17068041	2197751	411680	20861852	11072803	15477019	2307888	17577627
03	112930	505.8	249879625	159348044	1090807	22613867	3599139	504492	14674028	15835311	14918090	3243047	20061987
04	94212	372.4	179029770	117455343	979041	16788383	4264604	375989	11078954	11794262	11562204	2311248	16736755
05	231556	933.6	448744628	291765503	2236987	42118758	8438710	917999	32933769	26613723	32843107	5819164	41135975
06	62580	259.5	123001249	81724903	693137	11102477	1521651	268674	13021981	6905058	8575873	1577649	11117258
07	62990	280.3	134427438	86174901	719929	12217999	2487378	298585	14122172	6746530	10237768	1725816	11190139
08	104595	367.3	173036681	113481398	1010298	16389600	3333499	353702	13590984	11474017	13817034	2241242	18581261
09	40725	227.8	111434828	75850801	458446	9570658	1222391	238099	8671306	4772412	6903484	1445649	7234809
10	154449	653.0	321782471	204669870	1523883	29377968	4543077	659681	20881580	20181036	17747157	4171943	27437864
11	53077	227.3	107584852	75827260	675861	9623210	2229299	233345	8454573	6729683	5134515	1386417	9429098
12	107141	553.6	269251139	185770403	1123462	23097160	3127571	570086	18334830	15248670	14613666	3476625	19033608
13	137467	606.7	299801119	186450667	1383126	26749913	2658690	655147	24130137	17975436	18663030	3836469	24421032
14	54808	225.5	109020722	73539615	526622	9365812	1504871	227472	8102287	6777601	5298351	1409259	9736608
15	27807	111.1	50423873	36148028	293063	4492167	395661	118405	6533007	2767210	4318039	643547	4939973
16	50602	203.0	96637098	67738288	492537	8186581	807791	209181	7151320	6268052	5273346	1240541	8989438
17	69004	315.7	155007672	99904015	766070	14076588	2615926	315343	9113284	10174139	9421124	2014831	12258518
18	17295	69.8	32583864	21200396	188400	2898579	797619	69920	3931446	1710633	2947760	419874	3072450
19	29484	117.2	52575943	36088796	339594	4457243	903823	120403	8242260	2589699	5974677	653441	5237810
20	80706	337.4	166239833	108014118	866610	15509954	2124286	341072	8158006	10595876	9086044	2152106	14337455
21	348671	1431.6	695153171	452222553	1248980	65144511	12729409	1459540	48853164	42391537	41439624	8966742	61941348
22	92674	406.1	192570418	133622709	912283	17331638	2956548	409230	17389077	10369012	11584759	2493679	16463552
23	126842	565.1	272640318	183349624	1331114	23304358	4948126	575326	19607039	15222549	18115462	3509090	22533528
24	144921	486.7	212380844	135493089	1722825	17961666	4945854	500446	45821147	12110611	27922479	2119747	25745046
25	36203	156.9	73663888	50926868	390111	6585116	733944	158046	7621518	4319417	5149039	951808	6431437

Table 22 (cont'd)

Province Code	Household	Total Demand ($X10^6$ kWh)	Electricity Demand (kWh)										
			AC	Refrigerator	Radio	Color TV	Black and White TV	VCR	Iron	Rice Cooker	Fan	Computer	Light
26	46398	229.3	114524984	75314429	473704	10273575	450049	232916	5664224	7065284	5631004	1471158	8242604
27	174160	757.0	363968730	261519119	1606760	32402062	5042831	741145	15983809	22338615	17753690	4721866	30939463
28	63840	216.2	91303779	64468885	738731	8384448	1995900	220473	19044994	5402228	12288027	1048006	11341241
29	43861	177.1	81960854	56928285	500289	7347288	863731	188068	9625146	4540597	6274150	1051225	7791876
30	66233	266.1	124536276	86349230	701647	10824261	2035008	269519	11352095	7289660	9404622	1607999	11766310
31	29841	121.0	56553586	38875122	306212	4874755	453131	121250	6227629	3484338	4069053	731132	5301271
32**	0	0.0	0	0	0	0	0	0	0	0	0	0	0
33	64054	333.5	162789766	104345493	736523	13363679	2695617	359329	17448950	6249801	12043148	2099772	11379183
34	18076	68.3	32267934	21016850	164407	3038470	285192	74659	3701695	1951216	2184814	415186	3211217
35	30405	130.5	62380575	42871627	299567	5393267	1129345	127568	4951771	3365248	3746161	810785	5401455
36	64852	301.4	146102318	97036636	697138	12435425	2737649	304975	11167167	7082179	10403711	1884829	11520999
37	83910	379.9	183724113	124019349	905781	15463601	2847765	385036	13192258	10214642	11868236	2353478	14906647
38	27380	121.9	58554964	37593096	315793	5109016	585780	132611	6580579	2878106	4560966	753633	4864061
39	149470	593.7	282424645	188330909	1579149	23876044	5856634	596994	23538694	17722258	19584913	3633487	26553284
40	60002	281.5	137684394	87539791	671955	11521450	1570725	296824	12350552	8143181	9290221	1777211	10659343
41	4937	17.3	7496393	5188371	59094	637303	48282	18236	1557560	424621	895221	91062	877078
42	102039	478.5	226104352	164497458	1010096	20327140	3211557	455229	13233000	14797487	13785637	2929839	18127185
43	22022	101.1	51483730	33251988	199498	4540318	23060	109656	2049405	3360560	1528159	661689	3912222
44	5555	29.3	14447779	9715876	59098	1153104	127282	30227	1069587	825016	688688	187541	986847
45	159914	728.9	360997827	227522850	1697054	32324843	5144303	731854	21239833	23721790	22387393	4674220	28408702
46	37651	115.7	51474223	35909427	359237	5166307	597392	130220	6795633	3639837	4293374	651290	6688763
47	51864	211.4	95572597	67949374	545629	8672164	1944267	220998	12567420	4951569	8557683	1222141	9213589
48	65947	280.8	130337995	88564491	719705	11348005	2013494	292598	16295102	6275261	11556533	1666408	11715532
49	63098	274.5	130265933	84894637	721375	11749451	1903451	304850	14892412	6380660	10510868	1672988	11209390
50	115795	530.6	250771287	175118491	1208285	22655801	3047118	551955	21321379	15011607	17124364	3216045	20570919

(**No non-urban area in province 32)

Table 22 (cont'd)

Province Code	Household	Total Demand ($X10^6$ kWh)	Electricity Demand (kWh)										
			AC	Refrigerator	Radio	Color TV	Black and White TV	VCR	Iron	Rice Cooker	Fan	Computer	Light
51	31833	149.2	73478289	46495762	324848	6506601	816146	153856	5741445	4318385	4744884	947226	5655135
52	79952	337.5	163674947	108848659	857401	15357846	2004151	334419	10521478	10538660	9065074	2127255	14203480
53	182900	821.2	396304250	283660743	1662470	34125941	6471798	794671	15494439	26501955	18519822	5154255	32492193
54	134046	557.3	272856896	176428855	1440098	24864653	5217101	554547	15977079	17254613	15368755	3538442	23813300
55	45486	183.9	85275134	62123453	412715	7517060	1508071	183266	7005235	4597750	6104058	1098425	8080600
56	14922	57.3	27131737	18645539	134543	2369955	308101	56289	2320978	1699986	1635806	351842	2650904
57	4427	15.7	6635159	4466678	53349	574740	327241	16511	1486168	371730	867199	77221	786453
58	13577	64.1	30887698	19539184	159401	2357343	469258	69832	3936007	1258185	2580963	400287	2411988
59	75235	251.0	101596464	78066572	879284	9949281	1943207	249299	22888596	6338630	14442356	1258154	13365515
60	64914	293.9	147250974	83824236	669966	10761594	1367616	301128	18342884	6031642	12051191	1750785	11531943
61	23348	115.2	56646259	36558262	269180	3052898	641638	128730	6331062	2290871	4387792	732342	4147757
62	45986	209.8	101976007	67666931	494070	9559870	1611862	212130	6808630	6091876	5928109	1316058	8169393
63	82160	373.1	182037885	127946240	893396	16323036	2918220	394221	3145261	8207962	14253946	2344712	14595714
64	108715	424.3	200244320	131040944	1153440	18698606	3302968	448050	21918125	11520133	14117422	2567762	19313190
65	201801	870.9	426269904	303886746	1801065	36851904	502828	856054	15225481	25457142	18706960	5527517	35849963
66	128567	506.8	244256360	161832554	1334384	22914699	3322311	506472	15386640	16061520	15174069	3155662	22839944
67	39146	181.3	86757358	55378065	441339	7756345	1449506	191653	10130902	3879733	7202251	1122524	6954316
68	170280	704.9	341033522	224731444	1732656	28583552	5164327	706880	23671500	22602862	22068960	4378061	30250289
69	71197	335.0	162321618	109888433	780566	13579776	1782224	338401	12158033	9261555	10188829	2089056	12648125
70	42424	196.9	96279795	65889906	457699	8723287	1767453	199774	4998868	5970740	3864848	1248096	7536593
71	198068	804.4	401810191	257228762	1981705	35592275	7681744	813019	20551823	25549771	12804920	5213815	35186804
72	63253	288.8	138907991	93601126	621178	12037608	1849361	288615	10723697	9132304	8609222	1786423	11236936
73	28163	118.5	58884287	37923390	296518	5238214	639686	119251	3216111	3676407	2756963	765912	5003203
74	112034	435.7	202135110	141085390	1186845	17755604	3442244	439329	19202220	12081418	15908045	2608723	19902871
75	73804	305.0	147513138	97229484	750981	12369386	2238361	305797	10259874	9780292	9565289	1893653	13111301
76	53352	220.7	110577139	70656984	533796	9770097	2069171	223556	5535881	7010317	3449160	1435015	9477989

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