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Examination of Energy Supply-Demand Balance and Measures for Energy Efficiency and Conservation in Household Sector of Ho Chi Minh City - Impact on Spatial Development

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Abstract

All global comparative country studies list Vietnam as a country which will be extremely vulnerable to climate change in the future because of its topography. The metropolis and economic center Ho Chi Minh City (HCMC) north of the Mekong Delta is particularly affected. Even today, HCMC has to struggle with climate-related problems whose impacts are brought about or intensified by shortcomings in managing rapid urban growth, spatial urban planning and urban infrastructure management. The city had a population of 7.1 million persons in 2009 with an average annual increase of 3.3% in the last ten years. As the biggest city in Vietnam, electricity consumption in HCMC accounts for more than 18% of total electricity use in the whole country in 2008. Electricity consumption in residential sector accounted for more than 38% of total electricity consumption of the city. Severe power shortages during summer in the whole country as well as in HCMC have been observed recently. Supplying energy reliably and stably is one of main challenges for economic development in future.

Potential for energy efficiency and conservation in household sector is possibly very significant due to low progress of energy efficiency programs in Vietnam. Energy efficiency options have been long proved as cost effective as compared to supply side options. In general, promotion of energy efficient and conservation measures in household sector is relatively more difficult than in other business sectors due to its small scale and dispersal. Energy efficiency measures in household sector may vary from market based programs to regulatory measures and voluntary measures. The PhD study has strong motivation and focuses mainly on energy demand pattern and potential energy efficiency measures for household sector in HCMC. Bearing in mind that energy efficiency will play an important role for households not only to conserve resources but also to mitigate climate change; the PhD study has the following objectives:

(1) Investigation of energy demand pattern changes and making decomposition analysis of energy consumption in Vietnam and HCM;

(2) Estimation of elasticities for energy demands of households in Vietnam;

(3) Analysis of energy use and energy saving potential of households in HCMC in its relation to dwelling type, income and appliance stock; and

(4) Assessment of energy efficiency options and supporting measures in households by using a long-term energy system model.

In term of research method, the study firstly examined household energy consumption in HCMC by analyzing data from household living standard surveys. Fuel mix and main determinants for the changes in energy consumption of households were found out by employing index decomposition index analysis. Secondly, the PhD study estimated elasticities for electricity and liquefied petroleum gas (LPG) demands by employing a panel estimation. In the current context of energy price vitality, it is useful to get understand on how energy demand reacts to changes in prices, income and other related things. Thirdly, the household questionnaire survey in HCMC brought about in-depth understanding on energy consumption of households in relations to dwelling type, income and appliance stock. Energy saving potential for each dwelling type is also estimated. Finally, the study deals with energy supply and demand balance. MARKAL model was used to analysis impacts of energy efficiency options on cost, resource, emission and spatial development.

The PhD study has achieved its four research objectives by linking these mentioned above analyses.

Firstly, analysis of data from the living standard survey shows that fuel mixes for households in HCMC between 2002-1010 were characterized with large shares of electricity, gasoline and LPG. Kerosene and other biomass energies made up small parts of total energy consumption. The shares for electricity, gasoline and LPG for households in HCMC are some 40, 40 and 20 percent respectively. That contrasts with households in the rest of Vietnam, which still consumed much non-commercial energy for cooking. Fuel mix for households in HCMC did not change much during 2002-2010 thanks to the better living standard of households of the City as compared to other regions. Gasoline demand rose quickly in the meantime to meet increased transport demand.

By applying index decomposition analysis, determinants for the increase in energy consumption of households in HCMC were activity effect during 2002-2008 and intensity effect in 2008-2010. These effects mainly represented the variations in household income and energy prices. In households of HCMC, structure effect had negative impact on energy consumption indicating that households switching to efficient energies. In the current context of energy price volatility, it is useful to see price impacts on household energy consumption. Variations of income and fuel prices are possibly the main determinants for the changes of energy consumption pattern in households.

Secondly, fixed-effects, random-effects and Hausman-Taylor models were used to estimate elasticities for electricity and LPG demands. Hausman-Taylor was recommended due to its capability in dealing with endogenous and time-invariant variables. According to the panel data estimation, elasticities for electric demand are estimated at -0.611, 0.470, and 0.221 with respect to electric price, household income and LPG price. Elasticities for LPG demand are -0.533 and 0.452 with respect to LPG price and household income. Own-price elasticities for both demands are less than unity indicating both products are inelastic demands. The estimation show also significant differences for different regions, including Ho Chi Minh City.

Thirdly, data from the self-conducted household questionnaire survey allowed analysis of energy consumption in relations to dwelling type, income, appliance stock etc… In all five types of dwelling (i.e. rudimental, shop house, row house, apartment and villa), electricity and gasoline contribute the two largest shares followed by LPG uses for cooking. Coal and firewood are being used for cooking and heating in some low-income level dwelling types. Results from statistical analysis show that energy consumptions for household purposes are significantly different in dwelling type. Monthly electricity use intensity from the survey are 4.63 kWh/m2 for rudimental houses, 3.41 for shop houses, 2.40 for row houses, 4.14 for apartments and 2.14 for villas. Monthly energy density from the survey are 26.33 MJ/m2 for rudimental houses, 18.20 for shop houses, 13.45 for row houses, 22.74 for apartments and 11.27 for villas. The intensities are almost significantly different in group means according to analysis of variance (ANOVA) results. Income and having air conditioner have significant impacts on electricity and energy consumptions. Electricity and energy consumption are different significantly for three income groups. Households with air conditioner consumed significantly 1.6 times higher households without air conditioner.

Options for energy saving were built for four main energy uses, such as lighting, air conditioner, refrigerator, and water heating. The four main energy uses make up from 30 percent to 70 percent of total energy use in different dwelling types. Electric use for cooling purpose is quite high in shop houses and villas. Lighting and refrigerator account for about 10 percent while water heating small share of total electricity use. In the energy efficiency case, the current appliances will be replaced with best available appliance in the market in order to examine energy saving potential.

Finally, results from energy system model show that by promoting energy efficient devices in household sector in HCMC, cost can be saved by more than EUR 1.32 billion. CO_2 emissions can be reduced also by about 425 million tons in 2010-2030. SO_2 emission, the main cause for acid rain, reduces by 1.4 million tons in the same period. In term of energy consumption, a large amount of coal can be avoided in energy efficiency scenarios. Coal consumption would reduce by 54 MTOE in the study horizon. All five energy efficiency options included are cost effective without support measures. These options are lighting, air conditioner, window, refrigerator, and water heater. Efficient air conditioner contributes the largest energy saving amount. The second largest is contributed by efficient lamps. Efficient appliances in households are economic viable. To promote these efficient appliances, it needs to overcome the two main barriers, which are availability and quality of efficient appliances.

About 1.2 GW can be reduced by 2020 and more than 6.6 GW by 2030 if energy efficient devices would be highly penetrated in households of HCMC. Avoided capacity is mainly coal fired power plants in the South of the country. It is estimated that about 3 big coal fired power stations with total capacity of 6GW can be avoided in the energy efficiency scenario. Moreover, one gas fired station with capacity of 630 MW would be avoided in the Central, which consumed expensive imported gas from abroad. In the output of the model, the largest impact of energy efficiency of household is coal power development, especially coal power plant in the South of the country, where energy efficiency options would take place. Reductions in coal power capacity also help country enhance its energy security by reducing coal import from abroad.

Energy efficiency activities reduce the land use for power development by 103 ha by 2020 and up to 467 ha by 2030. In the energy efficiency scenario, quantity of resettled people reduces by 315 persons by 2020 and 2,055 persons by 2030. CO_2 and SO_2 emissions can be saved in the energy efficiency scenario. Energy efficiency activities are able to reduce 7 million tons of CO_2 in 2020 and up to 78 million tons in 2030. Further expansion of energy efficiency in households may help the country reduce lots of its energy consumption and power capacity building, especially removing potentially harmful nuclear power plants in future (more than 6.6 GW avoided by energy efficiency options as compared to total nuclear power capacity of 10.7 GW by 2030). Moreover, energy efficiency mitigate issues associated with the development of power plants such as land occupied, displaced communities, emissions which raise social disparities throughout the country.

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List of Abbreviations

AAGR	Average annual growth rate
ADB	Asian Development Bank
ANOVA	Analysis of variance
BAT	Best available technologies
BAU	Business-as-usual
BTU	British thermal unit
CCGT	Combined cycled gas turbine
CFL	Compact fluorescent lamp
CHP	Combined heat and power
CO_2	Carbon dioxide
DHW	Domestic hot water
DSM	Demand side management
EE&C	Energy efficiency and conservation
EUR	Euro
EVN	Electricity of Vietnam
FE	Fixed-effects
GDP	Gross Domestic Product
GEF	Global Environment Facility
GJ	Giga Joules = 10^{12} Joules
GLS	Generalized Least Squares
GOV	Government of Vietnam
GSO	General Statistical Office
GW	Gigawatt hour
GWh	Gigawatt hour
GWh	Gigawatt
HCMC	Ho Chi Minh City
HPP	Hydro power plant
IDA	Index decomposition analysis
IE	Institute of Energy
IGCC	Integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IV	Instrumental variable
kcal	Kilo calorie
kW	Kilowatt
kWh	Kilowatt hour
LM	Lagrange Multiplier
Lm.hr	Lumen hour

LMDI	Logarithmic Mean Divisia Index
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MARKAL	Market Allocation
MEPS	Minimum energy performance standard
MOIT	Ministry of Industry and Trade
MW	Megawatt
MWh	Megawatt hour
MWh	Megawatt hour
NEEP	National Energy Efficiency Program
NPP	Nuclear power plant
NPV	Net present value
OLS	Ordinary Least Squares
PJ	Petajoule = 10^{15} Joules
PV	Photovoltaic
RE	Random-effects
SIDA	Swedish International Development Agency
SO_2	Sulfur dioxide
SWH	Solar water heater
TFEC	Total final energy consumption
TFL	Tube fluorescent lamp
TOE	Ton of oil equivalent
TPES	Total primary energy supply
TPP	Thermal power plant
USD	United States Dollar
VHLSS	Vietnam household living standard survey
VND	Vietnamese Dong
WB	World Bank

Chapter 1. Introduction

1.1 Background

Vietnam has been experiencing relatively high economic growth rate recently after performing the reform program in the late 1990s. The economy turned from a central planning to a market-based economy by reducing the role of ineffective state owned enterprises, emphasizing private sector, decollectivisation of agricultural land, enlarging exports and international trade etc... As results of the reform program, the economy had expanded five times in size during 1986-2010 with growth rate in a range of 6 to 7 percent per year. The country belonged to mid-income class based on World Bank's classification in 2009. The economy's structure has changed significantly by reducing agricultural share in total Gross Domestic Product (GDP) and increasing the share of industrial sector.

All global comparative country studies list Vietnam as a country which will be extremely vulnerable to climate change in the future because of its topography. The metropolis and economic center Ho Chi Minh City (HCMC) north of the Mekong Delta is particularly affected. Even today, HCMC has to struggle with climate-related problems whose impacts are brought about or intensified by shortcomings in managing rapid urban growth, spatial urban planning and urban infrastructure management. The city had a population of 7.1 million persons in 2009 with an average annual increase of 3.3% in the last ten years.

Vietnamese economy had grown quickly with average growth rate of 7.31% annually during 2000-2009. Electricity consumption consequently had been increasing rapidly in the same period at the rate 14.5% per year, which is two times higher than that of economy. Residential sector accounts for some 40% of total electricity consumption in Vietnam. This share had reduced in recent years from 48.9% to 38.2% due to a significant increase in industrial consumption. Residential consumption has been mainly occurring in the evening peak period of the power system (i.e. 6PM-10PM) that requires more expensive peaking capacity. In recent years, residential electricity demand has been increasing at averagely 12% per year. This very high increase rate has created strong pressure on electricity development in the country.

In recent years, boom quantity of household energy appliances has been observed. This evolution along with climate change effects, which created extreme hot summer and long increased space cooling demand, especially in big cities of Hanoi and Ho Chi Minh City. Due to lack of generating capacity to meet electric demand, Electricity of Vietnam (EVN), the Vietnamese power utility, had implemented load shedding to guarantee supply security of the system. Load shedding was heavily implemented during the hot summer when water availability of hydropower stations was critically low. EVN's rolling blackout was filled with deep concern by electricity consumers, especially rural consumers who suffer from the EVN's scheme on giving priority to supply electricity stably in industrial, commercial and urban areas. The actual value of residential consumption, therefore, would be higher than that recorded by the load dispatching center.

The growing economy with orientation for industrialization put very strong pressure on energy infrastructure development. GDP had grown at 7.4%, while electricity consumption at 14.4% in 2000-2008. Severe power shortages during summer in the whole country as well as in the megacities (HCMC and Hanoi) have been recently observed. Supplying energy reliably and stably is one of the main challenges for economic development in future. Potential for energy efficiency and conservation (EE&C) in household sector is possibly very significant due to low progress of energy efficiency programs in Vietnam. Energy efficiency options have been long proved as cost effective as compared to supply side options. In general, promotion of EE&C measures in household sector is relatively more difficult than in other business sectors due to its small scale and dispersal. EE&C measures in household sector may vary from market based programs to regulatory measures and voluntary measures.

The PhD study, therefore, has strong motivation and focuses mainly on energy demand pattern and potential energy efficiency measures for household sector in Ho Chi Minh City. The PhD study is funded by Deutscher Akademischer Austauschdienst (DAAD) under the BMBF (Bundesministerium für Bildung und Forschung) Megacity Project of HCMC.

1.1.1 Overview

Vietnam is located in the South-East Asia ranging over from 102°09’ to 109°30’ east longitude and 8°10’ to 23°24’ north latitude. The country shares borders with China in the North, Laos and Cambodia in the West and the South China Sea in the East and the South with an area of 331,698 km^2. Country’s population as 1st April 2009 is of 85,789,573 people. Vietnam consists of 64 cities and provinces. The two biggest cities are Ho Chi Minh City and Hanoi, where economic development and living standard are remarkably higher than the rest of the country.

Mountainous area accounts for 75% of total land area. Mountainous and highland areas are located in the north and the west, while plains in the east. There two large and important river deltas, they are Red River delta in the North and Mekong River delta in the South, with areas of 15,000 km^2 and 40,000 km^2 respectively. Vietnam has long coastal line more than 3000km with many famous beaches.

Vietnam’s climate is featured with monsoon tropical with hot and wet weather, high and seasonal precipitation. Annual rainfall levels in Hanoi are of 1,763mm, Hue of 2867mm, and Ho Chi Minh City of 1910mm.

Vietnam is divided into six economic regions due to their different characteristics of geographic, weather, climate, demography and economic condition. These regions are: North Mountain, Red River Delta, Northern and Coastal Central, Central Highland, Eastern South, and Mekong River Delta.

Hanoi and HCMC are the two biggest cities of the country, which are located in Red River Delta and South Eastern regions respectively. Therefore, average income and electricity consumption in the two regions were remarkably higher than in other region. The areas surrounding the two cities are two most dynamic regions for economic development.

Ho Chi Minh City located in the center of the Southeast of Vietnam. It shares the border with provinces: Binh Duong in the North, Tay Ninh in the Northwest, Dong Nai in the East and Northeast, Ba Ria-Vung Tau in the Southeast, Long An in the West and Southwest, and the East sea in the East. HCMC’s area is 209,554 ha (0.6% of total area of the country).

HCMC has the biggest population in Vietnam with very high urbanization rate of 80%. Its population in 2009 was more than 7.1 million persons, which accounts for 7.9% of total population. HCMC is now facing with high population growth rate, that even increasing higher and higher. The main reason was the migration from other provinces to HCMC. During 2001-2008 the rate was 3.3% per year.

1.1.2 Energy Consumption and Supply

Vietnam has various types of indigenous energy resources such as crude oil, coal, natural gas and hydropower, which played an important role in boosting economic development in the last two decades. Export of crude oil and coal are major sources for the state budget. The country is currently a net energy exporter, however, it is expected that the country will turn to net energy importer from 2014-2015 onwards.

Coal is an important energy source in Vietnam which has been used in various sectors including industrial, power, commercial and residential. Coal types consist of anthracite, sub bituminous, and peat coals; among which anthracite is the most important resource. Anthracite coals have been also exported abroad. There have been subsidies for coal domestic user, which are expected to be removed in future. The country has abundant coal resources, however, it located geographically mainly in the North of the country. Coal, therefore, is considered to be imported for power plants in the Central and the South from 2015 onwards.

The country has offshore crude oil deposits in the South. Almost crude oil extraction had been exported until the coming of the first refinery in late 2009. Before this, Vietnam hade imported all petroleum products to meet its domestic demands. The first refinery which located in the Central consumes about 30 per cent of total indigenous crude oil supply. In future, more refinery capacity will be built in some other places, which consumed not only domestic crude but imported crude.

Natural gas was first exploited in 1990s in the form of associated gas in the oil fields. Associated gas was then pipelined to onshore gas thermal power plants in the South. Natural gas fields right now fuel important power centers featuring combined cycle gas turbine in the South. In coming years, power plants and industrial are two major natural gas users.

Renewable energy development has not been paid adequate attention in Vietnam with small amount of renewable energy employment. Renewable energy applications so far have been limited mainly in small hydro power; other renewable energy type such as wind, solar, biomass, bio fuel are all featured with small scale and pilot. Vietnamese Government has had some commitments to promote renewable energy uses. However, it takes time and needs stronger efforts to make it all viable technically and economically.

Energy consumption has increased rapidly to meet the growing demands, especially industrial and residential sectors. The growth rate of 11.5 per cent per annum of total commercial energy consumption was observed in 2000-2009. Share of industrial energy consumption had increased quickly. Energy use intensity had increased from 387 kgoe per 1000 USD to 545 kgoe per 1000 USD (Institue of Energy, 2009). This indicates that the country is consuming more and more energy to generate one unit of Gross Domestic Product (GDP). In the same time, elasticities with respect to GDP were 1.39 for total energy and 1.8 for electricity.

The increasing trend of energy consumption has made strong pressures on energy infrastructure developments in recent years, especially in the context of increased international energy prices and the economic recession. Financial difficulties and severe delays of power plant development were the reasons for the recent power shortages in summer months.

After a slowdown in economic growth during global economic recession in the late 2000s, Vietnam is going to recover its high economic growth (Institue of Energy, 2009). Under this scenario, the economy will grow at 7.5 percent per year in 2011-2015, 8 percent in 2016-2020, and reduce to 7.83 percent in 2021-2030. Agriculture’s share will be reduced to 14.33 percent in total GDP and less than 10 percent in 2030. Industry and services meanwhile have a share about 42-43 percent. Per capita GDP was projected to increase sharply from more than USD 1,000 currently to more than USD 2,000 in 2015 and more than USD 3,000 in 2020. This economic projection shows an optimistic view on the bounce back of the economy after recovering from the hit of the global recession.

Although the economy has grown quickly for the last two decades, it was said to face very tough challenges in medium and long terms. Improvement of legal and institutional framework for monetary policy, raising the efficiency of the economy, easing supply-side constraints, restructuring state-owned enterprises were considered as most important tasks for the Government of Vietnam to maintain high economic growth (Asian Development Bank, 2010). From energy planner's point of view, reliance on capital formation of GDP growth, low total factor productivity, environmental degradation, out-of-date technologies, and lack of skilled labor force are among the main challenges for Vietnam in the years to come (Institue of Energy, 2009).

1.1.3 Energy Efficiency in Residential Sector

Energy efficiency is commonly defined as a reduction of energy consumption per unit of service supplied. The definition simply means meeting service demands in such ways that reduce energy requirements. After energy crisis in 1970s, energy efficiency and conservation were carefully considered by industrialized countries. With the rise of global warming concerns, in which energy consumers contribute a major part of greenhouse gases, promotion of energy efficiency and renewable energy is highly regarded as one of the most cost-effective measures in tackling climate issues. In developing countries, energy efficiency can enable in addition to alleviate the financial burden of oil imports5, reduce energy investment requirement, and make the best use of existing supply capacities to improve the access to energy (World Energy Council, 2010). Generally speaking, achieving energy efficiency in residential sector may include four different paths as follows:

- Increasing energy efficiency of energy using appliances (purchasing high energy efficiency appliances etc…)
- Reducing wasted and unnecessary energy uses by changing consumption behavior (setting appropriate temporary for air conditioner, automatic control for lamps etc…)
- Reducing energy uses by improving building design (ecological house design, improving air leakages through windows etc…)
- Increasing uses of household renewable energy (solar applications etc…)

Residential sector in Vietnam is the second largest electricity user, just behind industrial sector. In contrast to industrial sector, residential loads mainly occur in evening time (day time in the case of industrial sector) and cause the evening peak of the system (i.e. from 6 to 10 P.M.). Therefore, promoting energy efficiency measures in residential sector (including demand side management options) not only conserve energy but also avoid building expensive peaking generating capacity (i.e. oil and gas turbines). The Government of Vietnam has implemented a number of efforts to formulate energy efficiency strategies. The most important programs relating to energy efficiency in residential sector are:

- Vietnam Demand Side Management (DSM) and Energy Efficiency was sponsored by World Bank and Swedish International Development Agency (SIDA); and implemented by Ministry of Industry including two phases in 2000-2007. The program focused on education and building capacity with the introduction of financial support to energy user.
- Compact Fluorescent Lamp Promotion Campaign was implemented by Electricity of Vietnam (EVN) and funded by Global Environment Facility (GEF). The Campaign delivered about 1 million CFLs to household with at subsidized price (which was 10 per cent lower than market price).

- The National Energy Efficiency Program (NEEP) was implemented by Ministry of Industry. The Program is comprehensive energy efficiency program at national level covering various sectors and energy efficiency fields (i.e. legal framework, capacity building, energy audit, financial support etc…)
- The Labeling Program was implemented by Ministry of Industry. The Program regulated compulsory labeling requirements for some major household appliances which started in 2013. Within the program, the country adopted its first mandatory fuel consumption standards for several appliances and equipment.

The later and most recent program is expected to help promote energy efficiency in household sector. With increased electricity tariff, households are paying more attention on energy efficiency to cut their energy bills. Labeling program has been proved one of the most successful measures around the world. In general, energy efficiency efforts have been initiated in Vietnam; however, the in-depth researches for residential sector have been limited due to lack of adequate data and systematic methods. Regards to promotion of energy efficiency in household sector, supporting measures for appliances and equipment are really needed (Asia Pacific Energy Research Centre, 2009). Measures needed are: enforcing MEPS; strengthening plans and implementation of labeling program; monitoring and evaluating efficient appliances; providing incentives; and developing human capacity. One interesting recommendation for promotion of energy saving behavior in households is that the role of social interactions must be emphasized. People often communicate with neighbors, trust each other, and expect to return to their communities after time away. Taking into account the fact that social interaction is the basis of community, community-based activities may be an effective way to promote energy-saving behaviors in Asian cities (Hori, Kondo, Nogata, & Ben, 2013).

1.1.4 Implications of Energy Efficiency on Resources, Spatial Development, and Climate

In the context of global warming and vulnerable world fuel prices, energy efficiency emerges as one of important policy in achieving sustainable development for every country. Energy efficiency should be incorporated in development policy as important pathway to low carbon community. In the context of the PhD study, implications of energy efficiency in residential sector on resources, spatial development and climate will be investigated.

Energy efficiency shall be regarded as a mean to achieve overall efficient resource allocation rather than the goal in itself (Dennis, 2006). As a consequence of improved energy efficiency, other public policy goals will be achieved as well, the most important of which are the goals of economic development and climate change mitigation (Morvaj & Bukarica, 2010). Energy efficiency initially helps reduce energy consumptions; therefore it reduces the energy cost, avoids building generating, and saves energy exploitations or imports (coal, oil, gas etc…). Promoting energy efficiency has therefore positive implications on conserving energy and other resources of the economy.

In the context of urbanization and industrialization in Vietnam, energy efficiency in residential sector has two important impacts on spatial development, Firstly it change urban forms of the city by employing house ecological designs, new modal shift, changing built-up densities etc… (World Energy Council, 2010) Secondly, by reducing energy requirements, energy efficiency affects structures of energy supply side, which cover energy facilities (power plants, transmission lines, oil refineries, gas processing plants etc…). Changes on energy facilities obviously have impacts on land occupation, population surrounded, emissions, and bio integrity etc… Slow down the electricity demand growth, and reduce the investment needed for the expansion of the electricity sector; this is especially important in countries with high growth of the electricity demand, such as China and many South East Asian countries (World Energy Council, 2010).

Power development, such as building power plants and power lines, has a number of negative impacts on spatial development. Land occupied, people resettled, surrounding environment degraded, climate change are some of major impacts can be mentioned. Energy efficiency helps reduce energy consumption and avoid energy production, therefore, influence energy facility developments. Promotion of energy efficiency consequently has obvious impacts on spatial development by solving issues related to these impacts.

In households, improving the efficiency of energy use resulting in reduced energy requirement to provide a given amount of lighting, cooking, heating and other services is equivalent to an increase in income on account of reduced expenditure. In the long run, households enjoy the benefit of lower expenditures on energy, while increasing their comfort and well-being (Reddy, Assenza, Assenza, & Hasselmann, 2009). However, in practice, families prefer cheap energy and appliances to clean energy and high efficient appliances, which feature with high initial price. Supporting policy measures, therefore, are needed to promote energy efficiency. Examples of policies for households that are used extensively internationally include (Chandler, 2005):

- Appliance efficiency standards
- Appliance labeling programs
- Loans and tax incentives
- Demand side management utility programs
- Building efficiency standards.

Nowadays, energy efficiency plays an important role in tackling of global warming issues. Energy efficiency is globally considered to be the most readily available and rapid way to achieve desired greenhouse gases reductions in the short to medium term (Morvaj & Bukarica, 2010). Moreover, energy efficiency is considered as one of the five pillars of the low carbon society (Morvaj, Lugarić, & Morvaj, 2012). These five pillars are: energy efficiency, renewable energy sources, and buildings as active consumers, electro mobility, and developing smart energy cities.

1.2 Research Questions and Objectives

Vietnam is hunger for energy to fuel its economy’s development. It’s expected that the country may turn to net energy importer in 2014-2015 after long period as a net energy exporting country. Household sector currently accounts for more than 40 percent of total electricity consumption. Moreover residential consumption activities mainly take place at the evening peak hours of the system. Households consume large part of non-commercial energy types such as firewood, agricultural residues, bio energy etc… As the biggest city in Vietnam, electricity consumption in HCMC accounts for more than 18% of total electricity use in the whole country in 2008. Electricity consumption in residential sector accounted for more than 38% of total electricity consumption of the city. Main problems in energy development of the city are as follows:

- High economic growth rate creating pressure on energy/electricity supply
- Large and rapid growing population
- HCMC is barely above sea level
- Poor urban development

- Power shortage especially in dry season
- Inefficient use of energy

These issues make the city vulnerable to climate change effects. Bearing in mind that energy efficiency will play an important role for households not only to conserve resources but also to abate and to adapt to climate change; this research work has the following objectives:

(1) Investigation of energy demand pattern changes and making decomposition analysis of energy consumption in Vietnam and HCM;

(2) Estimation of elasticities for energy demands of households in Vietnam;

(3) Analysis of energy use and energy saving potential of households in HCMC in its relation to dwelling type, income and appliance stock; and

(4) Assessment of energy efficiency options and supporting measures in households by using a long-term energy system model.

Research on energy end-use in Vietnam has suffered from the lack of consistent and detailed data. During March to June 2011, the author therefore carried out the household energy survey in HCMC, which included about 500 households. This questionnaire survey was designed to get detailed information related to energy consumption of households in the City. The survey was completed successfully. Summary and analysis of the survey are presented in Chapter 1. These steps help build energy system model, in which energy supply and demand balance is allowed. Based on the results from the model, most appropriate energy efficiency measures for households can be formulated.

1.3 Dissertation Structure

The dissertation starts with Chapter 1, which gives background, research questions and objectives as well as overview of the study flow. Structure of the dissertation is also presented here making readers easy to follow.

Chapter 2 continues with an overall picture on energy and economic development of Vietnam in the last two decades. The chapter also highlights development challenges and outlook for economic and energy development in coming years.

Data and research methodology are presented in Chapter 3. Data mainly consists of (1) general social, economic and energy data, (2) series of household living standard survey, (3) household questionnaire survey in Ho Chi Minh City, and (4) other related data. This chapter also explains analytical methods, which were used in different parts of the study. The methods cover a wide range of statistical models, econometric models, index decomposition analysis, and energy system modeling.

Chapter 4 deals with the first objective. This part shows results and findings from calculation of fuel mix and index decomposition analysis of energy consumption of households in Ho Chi Minh City and Vietnam. Analyses in this part employ data from the series of household living standard during 2000-2010 in Vietnam. A proper design for questionnaire household survey was considered here to get useful information for further analysis.

The results for the second objective are shown in Chapter 5. This part analyzed residential electricity and LPG demands to find out elasticities by employing panel data estimation. Demand equations were regressed with own price, income, substitutes' prices, regional and sectoral factors. Analysis was made based on data for households in 64 provinces of Vietnam.

Chapter 6 presents summary and analysis of the household questionnaire survey. The survey was designed to get in-depth understanding of energy consumption of households in Ho Chi Minh City. This part of the study employs analysis of variance to distinguish energy use intensity of different dwelling types. Energy consumption and energy saving potential for major end-uses were estimated.

Chapter 7 presents energy system model by employing outputs from the previous parts of the study such as fuel mix, appliance stock, appliance utilization, elasticities etc… MARKAL model was used for this purpose. This chapter firstly comes up with the construction of the model by presenting database and assumptions. Different scenarios are then built to model different pathways of development in future. Energy efficiency measures were finally assessed in comparisons to the business-as-usual scenario. Results from model allowed accessing impacts of energy efficiency on economic, resource, environmental and spatial development.

Chapter 8 comes with main conclusions and contributions from the different parts of the study. Discussions here mention important findings and the linkages between them from the PhD study.

Chapter 9 presents references and finally appendix in Chapter 10.

Chapter 2. Overview of Economic and Energy Developments in Vietnam and Ho Chi Minh City

2.1 Overview of Socio-economic Development in Vietnam

2.1.1 Status of Socio-economic Development

Vietnam economy has achieved a remarkable economic growth after implementing the reform program (widely known as Doi moi) in 1986 by turning from the central planning to market-based economy. Before that the social-economic status was in crisis in the mid-1980s, which was mainly caused by the deficiencies inherent in the former economic model itself. The reform program focused on reducing state owned enterprises, emphasizing private role, decollectivisation of agricultural land, increasing export, and attracting foreign direct investment inflow etc… As a result, high and sustainable growth rate had been achieved since the late 1980s. In the first two years of reform program, measures had been implemented in gradual basis. However, the early improvement in economic performance along with the collapse of the former Soviet Union in 1989 and the loss of traditional exporting market from Eastern European countries, the Government of Vietnam were forced to reform in a comprehensive basis (Phan, 2008). The past trends of GDP growth with a number of major historical events are shown in Figure 2-1 and Table 2-1.

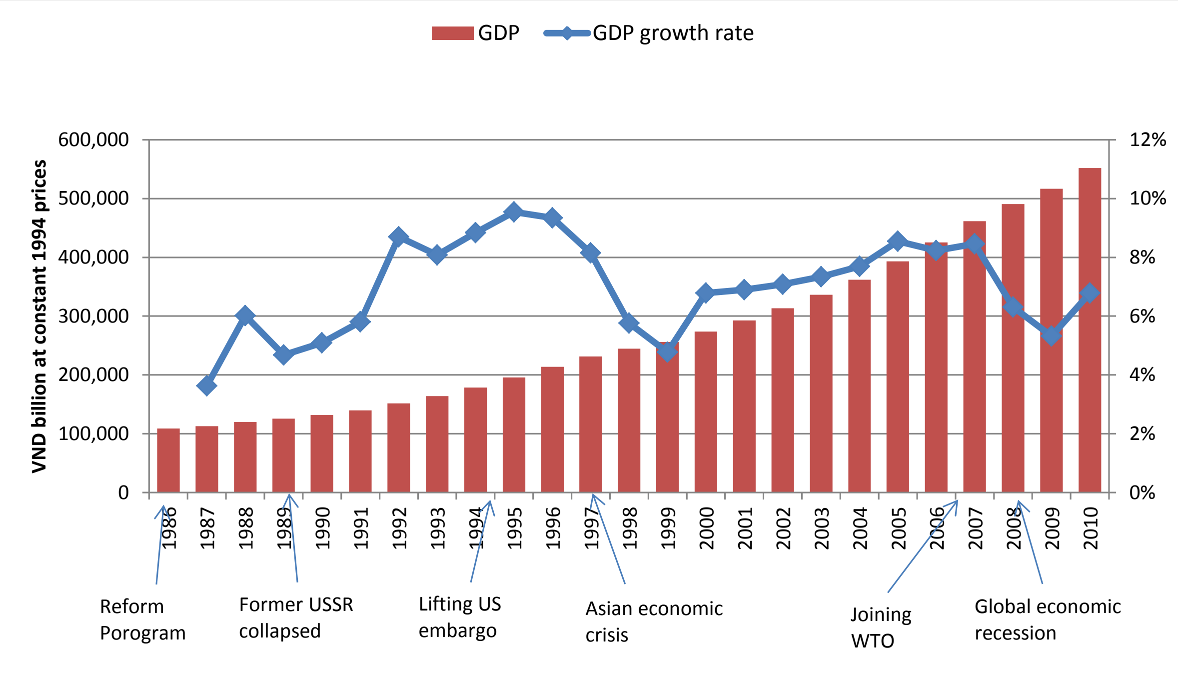

Figure 2-1: GDP growth and annual growth rate during 1986-2010

With increased FDI inflow in 1990s, the economy grew at the rate 7 percent per year in 1991-1995 and 6.5 percent per year in 1996-2000 (in comparison with the growth rate of 3.7 percent per year during 1975-1986). This decade was marked with the lifting of US embargo in 1995. Among sectors, industrial sectors had the highest growth rate in 1990s with the significant expansion of mining industries for export such as coal and crude oil. The economy enjoyed the high growth rate until 1997, when the regional economic crisis took place. Significant slowdown in GDP growth rate was observed in the two latest years of 1990s. Economic growth rate declined from 9.3 percent and 8.2 percent in 1996 and 1997 to 5.8 percent and 4.8 percent in 1998 and 1999. Many argued that regional economic crisis was the main reason for the slowdown due to the high share of regional trade in the overall export market of the country. After reforming, foreign trade and investment played important role in economic growth.

Table 2-1: GDP trends during 1986-2010 (VND billion at constant prices 1994)

	1986	1990	1995	2000	2005	2006	2007	2008	2009	2010
Total	***109,189***	***131,968***	***195,568***	***273,666***	***393,031***	***425,373***	***461,344***	***490,458***	***516,566***	***551,609***
Agriculture	37,932	42,003	51,319	63,717	76,888	79,723	82,717	86,587	88,166	90,613
Industry	29,284	33,221	58,550	96,913	157,867	174,259	192,065	203,554	214,799	231,336
Service	41,973	56,744	85,698	113,036	158,276	171,391	186,562	200,317	213,601	229,660

Source: (General Statistics Office, 2010)

It took two years for countries to back on the right track. Growth rates were more or less 8 percent per years in 2000s. Vietnam became an official World Trade Organization's (WTO) member in 2007. The country was once expected to benefit from enlarging its export by joining WTO. However, the country then was hit by the recent global economic recession that took place in 2008. The economic growth rate was 6.3 percent in 2008 and 5.3 percent in 2009 as compared to the rate of 8.5 percent in 2007. Substantial and timely policy responses helped the economy weather the global recession, allowing for reasonably high economic growth in 2009 (Asian Development Bank, 2010). GDP is forecasted to accelerate in the early 2010s, although not to the rapid seen in the early 2000s.

Table 2-2: GDP growth rate by economic sector in 1986-2010

	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010
GDP growth rate	**3.9%**	**7.0%**	**6.5%**	**6.1%**	**5.0%**
Agriculture	2.1%	3.6%	4.1%	3.2%	2.6%
Industry	2.6%	10.3%	9.8%	8.1%	5.8%
Service	6.2%	7.1%	5.2%	5.7%	6.0%

Source: (General Statistics Office, 2010)

A quick check on sector growth rate reveals different accelerations by different sectors during 1986-2010. Table 2-2 presents GDP growth rate by three economic sectors and Table 2-3 shows their shares during 1986-2010. Agriculture (including forestry and fisheries) expanded by less than 4 percent per year. Industry grew quickly in 1990s with the rate more or less 10 percent per year as a result of increased output of crude oil and coal mining, utilities and construction activities. Services rose stably at the rate 5-7 percent per year in the last two decades. The differences in growth rate led to significant changes in economic structure. Agriculture's share declined from 35 percent in total GDP in 1986 to 23 percent in 2000 and 16 percent in 2010. The share of agriculture in GDP was on a steadily decreasing trend. In some contrast, industry meanwhile increased its share from 27 percent to more than 40 percent since 2005 and stable at 42 percent in 2010. This is result of giving priorities for developing light industries towards export such as textile and garment and food processing. Services' contribution to GDP was stable at about 40 percent in total GDP.

Table 2-3: GDP shares by economic sector during 1986-2010

	1986	1990	1995	2000	2005	2006	2007	2008	2009	2010
Agriculture	35%	32%	26%	23%	20%	19%	18%	18%	17%	16%
Industry	27%	25%	30%	35%	40%	41%	42%	42%	42%	42%
Service	38%	43%	44%	41%	40%	40%	40%	41%	41%	42%

Source: (General Statistics Office, 2010)

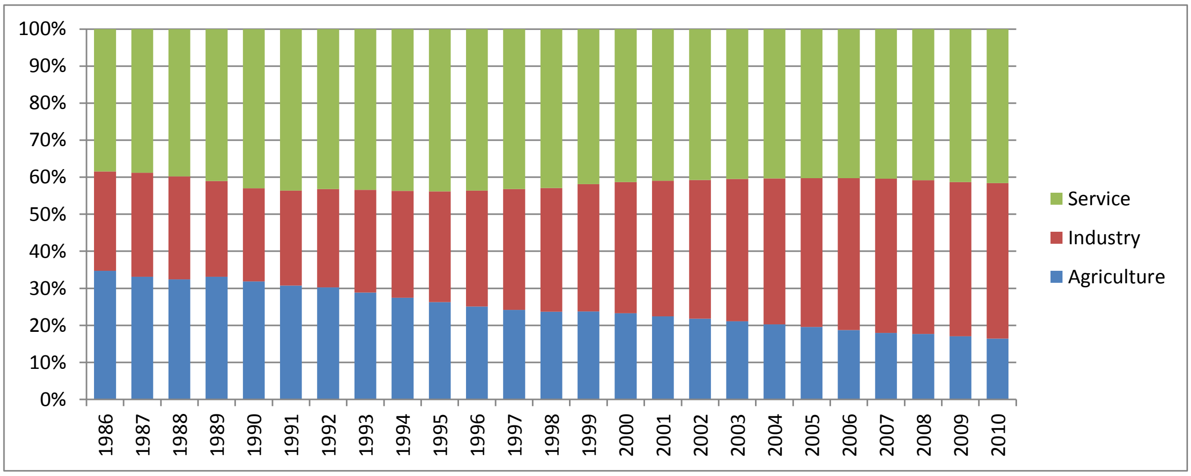

Figure 2-2: Economy structure during 1986-2010

In the last two decades, significant changes in urban/rural population share were also seen. Urban share increased from 19.3 percent in 1986 to 30.2 percent in total population in 2010. The urbanization improved the accessibility to the electricity grid, therefore, increased remarkably rural electrification rate. Along with the high economic growth, in which the economy grew five times in size in the last two decades, per capita GDP had been much improved. Per capita GDP increased ten times from USD 114 per person per year in 1990 to USD 1,169 in 2010 (conversion to USD using annual average market exchange rate). The country belonged to mid-income class in 2008 (timing may vary from source to source due to different method for conversions to USD). Per capita GDP and urban population trends in the last two decades are shown in Figure 2-3.

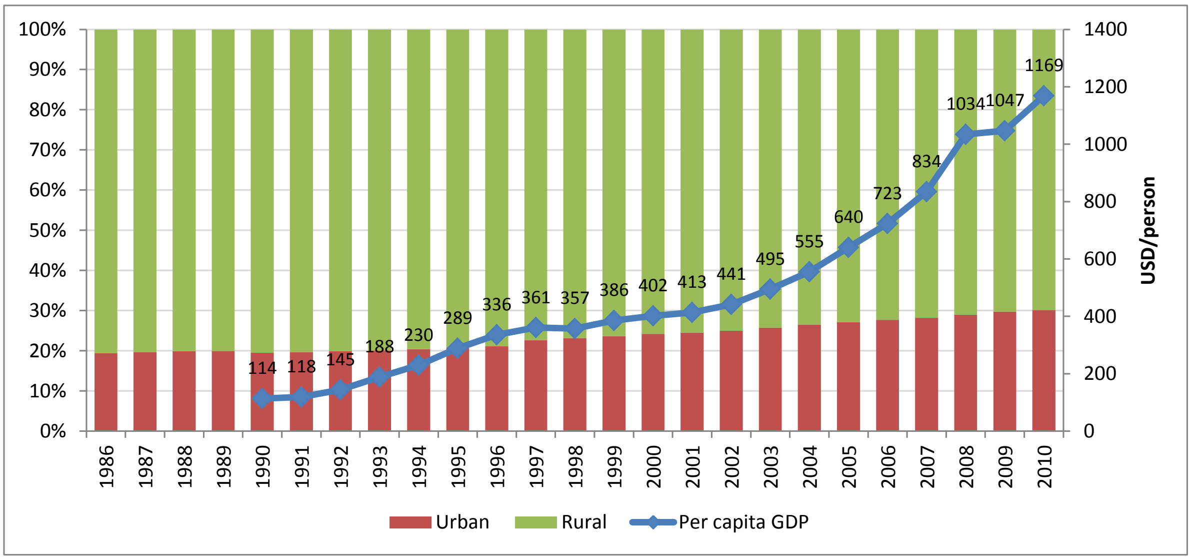

Figure 2-3: Urban/rural population share and per capita GDP during 1986-2010

The economic achievements have been quite positive. There were large improvements in policies, acceleration in growth and a dramatic decline in poverty (Dollar, 2002). A quick look at income per capita shows an increase of 19 percent per year during 2002-2010, from 356 thousand VND monthly in 2002 to 1.387 million VND in 2010. This should be reminded that, these values are in current prices and does not take into account the relatively high inflation rates meanwhile. Income increases took place in all sectors (i.e. urban and rural), all parts and all groups of the country. However, the increased gaps can be seen between urban and rural areas. South East region, where Ho Chi Minh City located, is characterized with the highest income, which followed by Red River Delta (where Hanoi located). This shows the far superior development of the two megacities as compared to other parts of the country. The gap between the poorest one fifth and the richest one fifth also increased from 8.1 times in 2002 to 2010. Evolution of household income is shown in Table 2-4.

Table 2-4: Monthly income per person during 2002-2010 (thousand VND at current prices)

Year	2002	2004	2006	2008	2010
Nationwide	356	484	637	995	1,387
By sector					
Urban	622	815	1,058	1,605	2,130
Rural	275	378	506	762	1,071
By five quintiles					
Group 1	108	142	184	275	369
Group 2	178	241	319	477	669
Group 3	251	347	459	700	1,000
Group 4	371	514	679	1,067	1,490
Group 5	873	1,182	1,542	2,458	3,411

Source: (General Statistical Office, 2010)

Although the economy has grown quickly for the last two decades, it was said to face very tough challenges in medium and long terms. Improvement of legal and institutional framework for monetary policy, raising the efficiency of the economy, easing supply-side constraints, restructuring state-owned enterprises were considered as most important tasks for the Government of Vietnam to maintain high economic growth (Asian Development Bank, 2010). From energy planner's point of view, reliance on capital formation of GDP growth, low total factor productivity, environmental degradation, out-of-date technologies, and lack of skilled labor force are among the main challenges for Vietnam in the years to come (Institue of Energy, 2009).

2.1.2 Economic Outlooks

Economy grew 6.8 percent in 2010, an increase as compared to the slowdown of 5.5 percent in 2009. Based on the assumptions of tightening fiscal policies and maintaining of the banking system, GDP growth was projected to accelerate in the early 2010s (Asian Development Bank, 2010). This is somewhat lower than the economic forecast by (Institue of Energy, 2009), which was based on to formulate the power development plan. This forecast was based on the flowing assumptions:

- World economy will start to recovery in 2010
- World crude oil price will be stable
- Vietnam economy grow back in 2010
- Government keeps implementing current restructure reform
- Hi-tech industries and other industries toward export will be given priority to develop

Table 2-5: Economic outlook up to 2030

Item	2010	2015	2020	2030
Population (thousand persons)	86.9	91.3	96.0	102.4
GDP structure (%)				
Agriculture	19.9	16.93	14.33	9.26
Industry	40.3	41.68	42.62	42.22
Service	39.8	41.39	43.07	48.53
GDP growth rate (%/year)	**2011-2015**	**2016-2020**	**2021-2030**	**2031-2040**
Total GDP	7.5	8	7.83	7.57
Agriculture	3	2.2	2.2	2.2
Industry	8.4	8.6	8.05	7.45
Service	8.2	8.95	8.59	8.19
Per capita GDP				
Current prices (VND million/person)	22.2	45.4	92.7	351.6
Current prices (USD/person)	1,221	2,023	3,350	9,891

Source: (Institue of Energy, 2009)

The results from economic projection are presented in Table 2-5. Under this scenario, the economy will grow at 7.5 percent per year in 2011-2015, 8 percent in 2016-2020, and reduce to 7.83 percent in 2021-2030. Agriculture's share will be reduced to 14.33 percent in total GDP and less than 10 percent in 2030. Industry and services meanwhile have a share about 42-43 percent. Per capita GDP was projected to increase sharply from more than USD 1000 currently to more than USD 2000 in 2015 and more than USD 3000 in 2020. This economic projection shows an optimistic view on the bounce back of the economy after recovering from the hit of the global recession.

Under energy economic point of view, the development towards industrialization and increase in urban share of population makes the country hunger for energy. This will increase energy intensity and energy elasticity with respect to GDP if there is no appropriate policy measures would be taken place. Besides expanding energy system to meet domestic demand, in order to maintain high economic growth, sustain energy security and follow sustainable development, commitments for energy efficiency and conservation activities are really needed. More discussions on the linkages between economic and energy will be discussed in the next section.

2.1.3 Household Living Standard

Household living standard has been improved significantly in Vietnam backed by economic growth. Living standard is depicted in the series of household living standard survey, which is carried out by GSO biannually for the whole country. Living standard is reflected through income, education, shelter, expenditure, healthcare service etc… In relation to energy consumption, living standard improvements are presented in terms of income, expenditure, energy consumption amount, electrification rate, living area, dwelling type etc... Trends for living standard improvement for households in Vietnam are shown in Table 2-6.

Table 2-6: Selected indicators for living standard in 2002-2010

Item	Sector	2002	2004	2006	2008	2010
Household size (persons)	***Whole country***	***4.44***	***4.36***	***4.24***	***4.12***	***3.89***
	Urban	4.27	4.2	4.13	4.07	3.82
	Rural	4.49	4.41	4.28	4.14	3.92
Income (thousand VND)	***Whole country***	***356***	***484***	***637***	***995***	***1387***
	Urban	622	815	1058	1605	2130
	Rural	275	378	506	762	1071
Expenditure (thousand VND)	***Whole country***	***294***	***397***	***511***	***793***	***1211***
	Urban	498	652	812	1245	1828
	Rural	232	314	402	620	950
Access to grid (%)	***Whole country***	***86.5***	***93.4***	***96.0***	***97.6***	***97.2***
	Urban	98.2	99.0	99.1	99.6	99.6
	Rural	82.7	91.6	94.9	96.8	96.2
Poverty rate (%)	***Whole country***	***18.1***	***15.5***	***13.4***	***10.7***	***14.2***
	Urban	8.6	7.7	6.7	5.1	6.9
	Rural	21.2	18	16.1	13.2	17.4
Living area (m^2/person)	***Whole country***		***13.5***	***14.7***	***16.3***	***20.2***
	Urban		15.8	16.9	18.7	23.9
	Rural		12.8	13.9	15.4	18.8

Source: (General Statistical Office, 2010)

A quick check on data reveals relative improvement on household living standard, especially in income, access to grid, poverty rate and living area. Rural electrification in Vietnam was quite high as compared to level of development of the country. Almost urban household have access to the electricity grid while the rate for rural areas is of 96.2 percent. Income and living area during 2002-2010 (five surveys on living standard) also increased significantly. Percentage of household having durables is shown next:

Table 2-7: Quantity of household durables (pieces per 100 households)

Durable	2004	2006	2008	2010
Car	0.1	0.2	0.4	1.3
Motorbike	55.3	68.6	89.4	96.1
Telephone	28.5	51.4	107.2	128.4
Refrigerator	16.6	23.0	32.1	39.7
Video player	32.8	44.5	53.4	54.2
Television	69.8	82.0	92.1	85.9
Stereo set	1.0	12.8	14.9	12.6
Computer	5.1	7.7	11.5	17.0
Air conditioner	2.2	3.7	5.5	9.4
Washing machine	6.2	9.3	13.3	17.6
Water heater	5.4	7.6	10.1	13.3

Source: (General Statistical Office, 2010)

Table 2-7 describes evolution of quantity of household appliances between 2002 and 2010. All of main household appliances rose quickly in their saturation level in these years, especially some major energy consuming devices such as motorbike, air conditioner, washing machine, refrigerator etc… Motorbike quantity rose remarkably from 55.3 percent of total households to 96.1 percent, quite impressive figure. That explains rapidly increased oil product demands of the country. Quantity of some large household appliances also grew quickly such as air conditioner, washing machine, water heater, and refrigerator. The improvements in living standard of household means increased energy demand will be required for comfortable life.

2.2 Overview of Socio-Economic and Energy Development in Ho Chi Minh City

Ho Chi Minh City located in the center of the Southeast of Vietnam. It shares the border with provinces: Binh Duong in the North, Tay Ninh in the Northwest, Dong Nai in the East and Northeast, Ba Ria-Vung Tau in the Southeast, Long An in the West and Southwest, and the East sea in the East. HCM's area is 209,554 ha (0.6% of total area of the country). The City's administration map with its district border is presented in Figure 2-4.

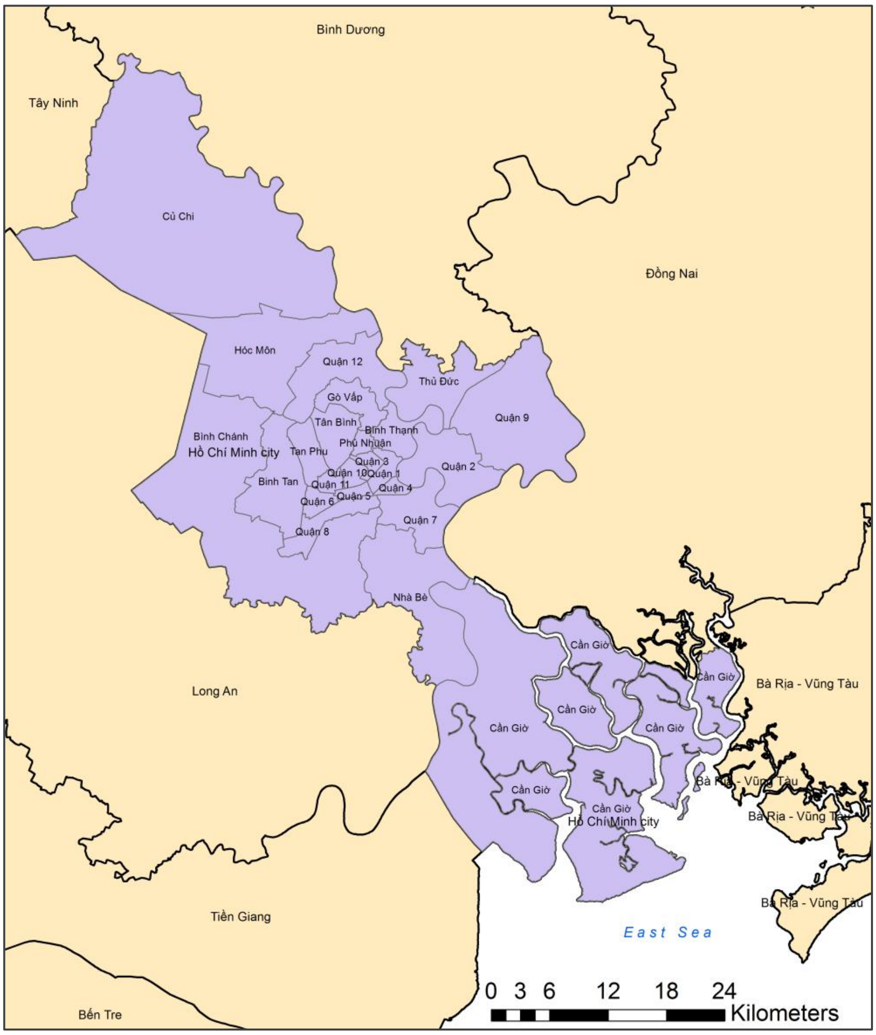

Figure 2-4: Administration map of Ho Chi Minh City

In comparison with other cities and provinces in Vietnam, HCMC has the biggest population with very high urbanization rate of 80% (Table 2-8). Its population in 2009 was more than 7.1 million persons, which accounts for 7.9% of total country's population. HCMC is now facing with high population growth rate, that even increasing higher and higher. The main reason is the migration from other provinces to HCMC. During 2004-2009, migration from other provinces increased the City's population by 780 thousand persons. In 2009, migrated peoples accounted for 15.7 percent of total population of the City (General Statistic Office, 2010). During 2001-2008 the growth rate of population was 3.3% per year (Table 2-9).

Table 2-8: Urbanization trend of HCMC

Year	Population (persons)	Population in urban (persons)	Urban share (%)
1979	3,293,146	2,700,849	82.0
1989	3,924,435	2,899,753	73.9
1999	5,037,151	4,204,662	83.5
2009	7,123,340	5,929,479	83.2

Source: (General Statistic Office, 2010)

Table 2-9: Population trend of HCMC

Item	Unit	2000	2005	2006	2007	2008
Population	Thousand persons	5,248	6,240	6,425	6,651	6,810
Urban share	%	83.0	85.2	85.0	84.8	85.0
GDP @ constant price 1994	VND billion	52,754	88,866	99,662	112,258	124,220

Source: (General Statistic Office, 2010)

HCMC was organized into 19 urban and 5 rural districts. Population density in HCMC has increased year by year. Population density was 2,505 in 2000 and 3,419 persons per km^2 in 2009. However population distribution varies much by district. The highest population density of 44,135 person/km2 was recorded in District 11 while the lowest of 97.8 person/km2 in Can Gio District (Table 2-10). Urban population of HCMC accounted for 23.3 percent of total urban population of the country.

In the last ten years, HCMC has developed significantly and become an attraction destination for domestic and foreign investments. The economic growth rate is high and contributing more and more to the whole country GDP. The HCMC's share in the national GDP was 17.53% in 2005, 19.1% in 2005 and 25.34% in 2008. During 2001-2008 GDP of HCMC had increased at 11.3% annually (1.5 times higher than the average of the country) which was higher than that during 1996-2000 (10.3% per year).

Table 2-10: Population by district

District	Population (persons in 1st April 2009)	Area (km^2)	Population density (persons/km^2)
Bình Chánh	420,109	252.7	1,662.5
Bình Tân	572,132	51.9	11,025.9
Bình Thạnh	457,362	20.8	22,030.9
Cần Giờ	68,846	704.2	97.8
Củ Chi	343,155	434.5	789.8
Gò Vấp	522,690	19.7	26,478.7
Hóc Môn	349,065	109.2	3,197.2
Nhà Bè	101,074	100.4	1,006.6
Phú Nhuận	174,535	4.9	35,765.4
Quận 1	180,225	7.7	23,315.0
Quận 2	147,490	49.7	2,965.2
Quận 3	190,553	4.9	38,730.3
Quận 4	180,980	4.2	43,296.7
Quận 5	171,452	4.3	40,152.7
Quận 6	249,329	7.2	34,677.2
Quận 7	244,276	35.7	6,844.4
Quận 8	408,772	19.2	21,312.4
Quận 9	256,257	114.0	2,247.7
Quận 10	230,345	5.7	40,270.1
Quận 11	226,854	5.1	44,135.0
Quận 12	405,360	52.8	7,680.2
Tân Bình	421,724	22.4	18,843.8
Tân Phú	398,102	16.1	24,757.6
Thủ Đức	442,177	47.8	9,258.3
Total	**7,162,864**	**2,095**	**3,419.0**

Source: (General Statistic Office, 2010)

With high economic development level and urbanization rate, households in HCMC have advantages to improving living standard such as access to electric grid and clean water; better education conditions, good infrastructure; and favorable jobs. These factors attract people from other areas migrating to HCMC. This trend will put a strong pressure on energy and electricity supply for the City.

HCMC's economy grew more than 10 percent per annum during 2000-2008, which was some 1.5 times higher than the growth rate of the country in the same period. The comparison of GDP and its growth rate of HCMC and the country is presented in Figure 2-5. HCMC's GDP had contributed some 20 percent of total national GDP. The city's and the national GDP had the same trend during 2000-2008, increasing trend up to 2007, and slowdown in 2008. The City's GDP growth rate was still quite high despite of the slowdown; it was more than 10 percent in 2008.

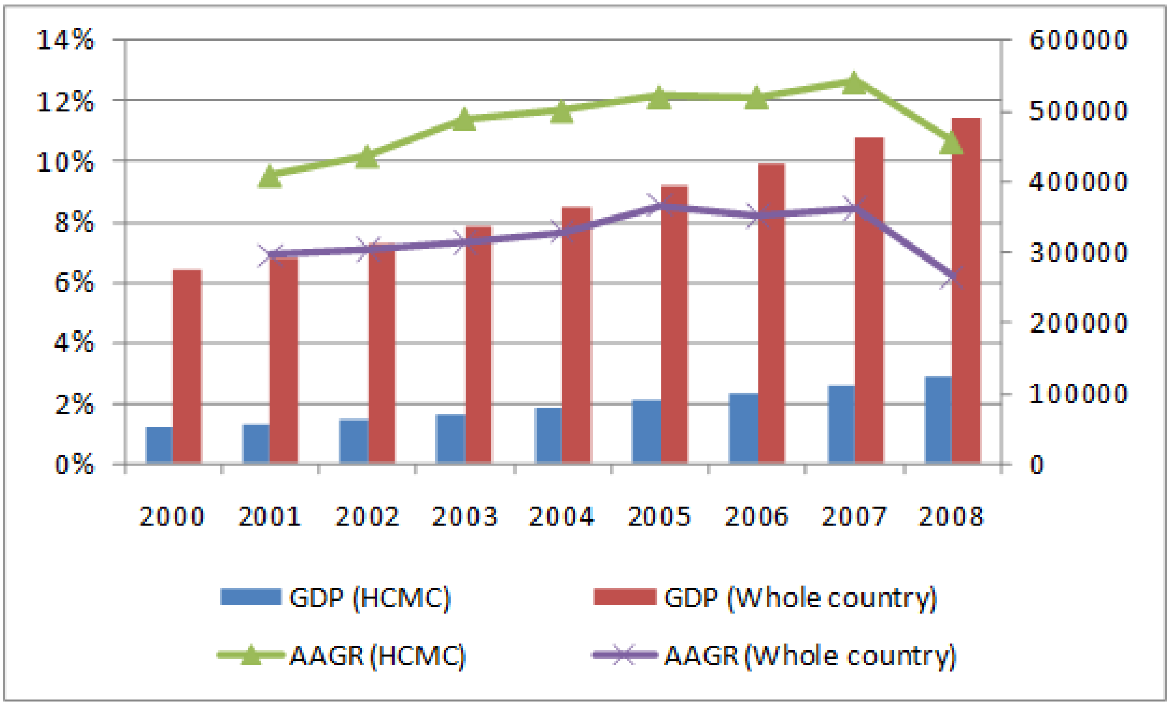

Figure 2-5: Economic growth of Vietnam and HCMC

Figure 2-6 depicts economic structures of HCMC and the country from 2000 to 2008. Economic structure of HCMC has not changed much in the last ten years. Service sector keeps contributing for more than 50% of total GDP of the city followed by industrial sector with the share more than 40%, while agriculture has a negligible contribution (less than 2% in 2008). Average GDP growth rate during 2000-2008 was of 11.3% per year. Industry had the highest growth rate of 11.6% during this period, service sector 11.3 and agriculture 4.6% annually. As compared to the current economic structure of Vietnam, service sector plays more important role in GDP in HCMC while agricultural less significant. This is an advantage of HCMC as a major economic and business center in the country. That allows the city an easier pathway to low carbon economy as a megacity in the future.

Figure 2-6: Economic structures of Vietnam and HCMC

Electricity sale by HCMC Power Company (HCMCPC) in 2008 was 12,365 GWh accounting for 18.74% of total sale by Electricity of Vietnam (EVN). Electricity consumption increased averagely at 10.9% per year during 2000-2008 (less than that by the country 14.4% annually). In 2008, industry made up 446.42%, residential 36.80% and service 11.63%. The residential share has reduced from 39.62% in 2000 to 36.80% 2008 due to rapid increase in demand for service sector. Industrial sector is the largest consumer for electricity although its contribution to GDP is less than that by service sector as mentioned before.

Table 2-11: Electricity consumption in HCMC

No.	Sector	2000	2005	2007	2008
1	Industry	2,806.46	4,976.54	5,843.79	5,983.72
2	Agriculture	10.40	11.90	11.78	17.76
3	Service	541.62	1,112.24	1,359.15	1,499.74
4	Residential and management	2,228.83	3,616.97	4,366.26	4,743.96
5	Others	163.41	487.76	462.28	645.08
	Total sale	5,750.7	10,205.4	12,043.3	12,890.3
	Losses	709.90	775.12	887.15	822.49
	Total supply	6,460.6	10,980.5	12,930.4	13,712.7
	Peak demand (MW)	1,126	1,760	2,140	2,270

Source: (Institute of Energy, 2010)

Table 2-11 depicts trend of electricity supply and consumption in HCMC. Electric losses in HCMC had been reduced remarkably from 10.99% in 2000 to 6.86% in 2007 and 6.5% in 2008. This is due to an enhanced network management, improvement in power network and additional installation of reactive capacitor. Peaking demand in 2007 was 2,140MW with load factor about 6100 hours. Due to power shortage throughout the country, a number of measures for reducing consumption was implemented in 2007 by power saving 105GWh, consumers' standby generator 18GWh and load-shedding 92GWh (total reducing amount of 215GWh). Power saving was contributed by public lighting 37.9%, administration offices 33.8%, advertisement lighting 7.4% and others 6.7%. Peaking demand could be about 2,106MW in case of having enough capacity to keep supplying. The reducing amount in 2008 was 345GWh.

Average growth rate of electricity consumption for industrial sector has decreased from 12.1% per year during 2001-2005 to 6.3% during 2006-2008. Service sector reduced its growth rate at the same time from 15.5% to 10.6%.

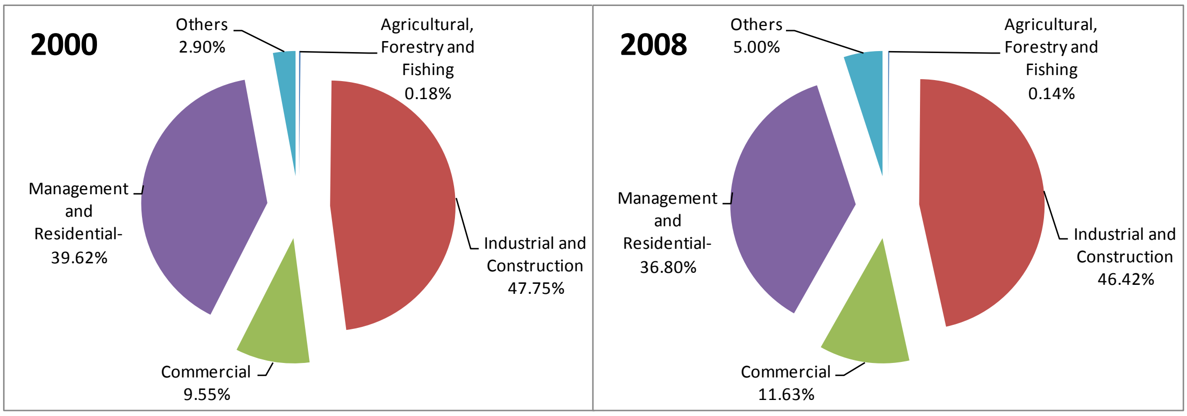

Figure 2-7: Structure of economy in 2000 and 2008

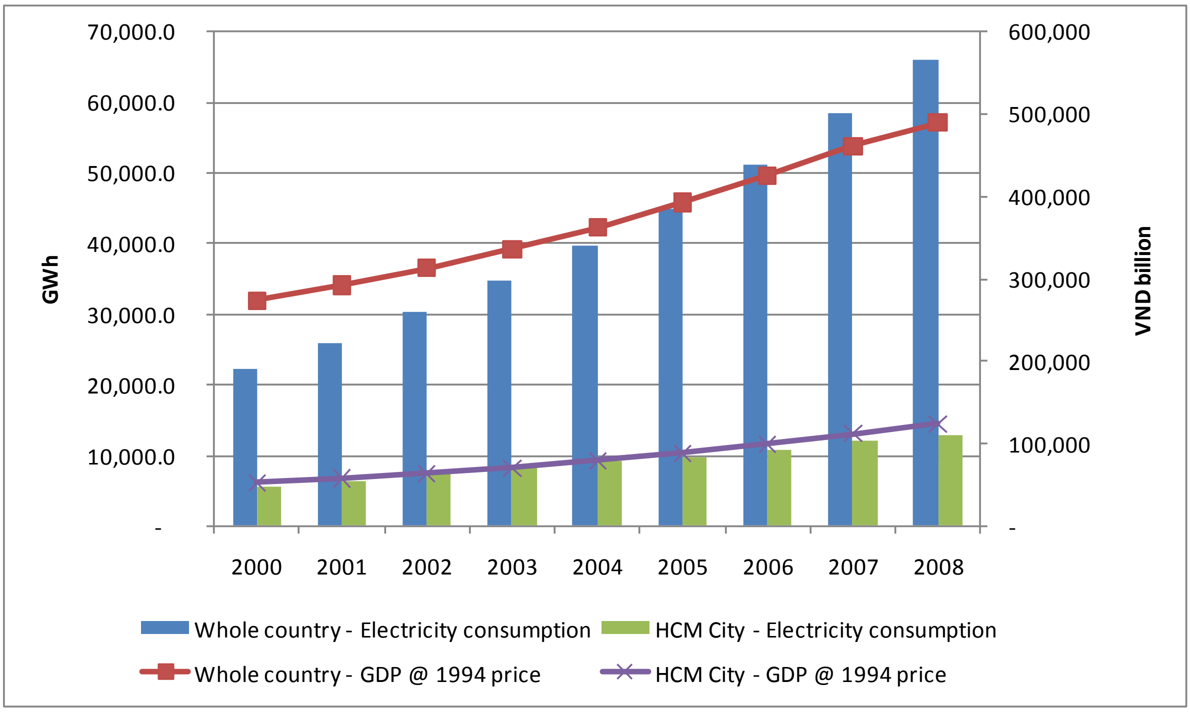

Figure 2-8: Growth for economic and electricity consumption of HCMC and Vietnam

Elasticity of electricity consumption with respect to GDP tends to increase in recent years. This trend may remain in future due to the country's development orientation toward to industrialization with the expansion of energy intensive industrial sectors like cement, steel, paper, chemical etc... The elasticity was 2.23 times in 2001, decreased to 1.55 in 2005, but then increased to 2.03 in 2008. Changes in economic structure (increasing contribution from industrial sector to total GDP, i.e. 35.4% in 2001 to 41.6% in 2008) and low energy efficiency are two main reasons for this increasing trend. Therefore, energy efficiency improvement should be considered adequately in energy development in the country.

In comparison to the whole country, electricity consumption in HCMC has increased slower than that for nationwide but GDP of HCMC increased at higher rate than GDP of the whole country. This can be explained by the economic structure of HCMC. Service sector accounts for more than 50% of total GDP while this figure for the whole country is more than 30% (i.e. more GDP contribution by industrial and agricultural sectors). Moreover, service sector normally consumes less energy to produce a unit of GDP. Consequently, during 2000-2008, elasticity of electricity consumption with respect to GDP of HCMC is much lower than for the whole country (0.66 versus 2.07 in 2008).

The elasticity of HCMC had been decreasing during 2000-2008 from 1.6 times to 0.66 times. This may reflect partly the improvement in productivity and energy efficiency by economic sectors of the city in recent years.

Table 2-12: Comparison of economic and energy growths between HCMC and Vietnam

	Item	2001	2002	2003	2004	2005	2006	2007	2008
HCMC	Electricity growth	15.3%	15.7%	11.5%	9.6%	7.5%	8.9%	12.3%	7.0%
	GDP growth	9.5%	10.2%	11.4%	11.7%	12.2%	12.1%	12.6%	10.7%
	Elasticity of electricity with respect to GDP	1.60	1.54	1.01	0.82	0.61	0.73	0.97	0.66
Nationwide	Electricity growth	15.4%	17.0%	15.4%	13.5%	13.2%	14.4%	13.9%	12.8%
	GDP growth	6.9%	7.1%	7.3%	7.7%	8.6%	8.2%	8.4%	6.2%
	Elasticity of electricity with respect to GDP	2.23	2.40	2.10	1.76	1.55	1.75	1.65	2.07

Electric load curve for HCMC was relative flat with two peaks occurring at 8-9 AM and 14-15PM. The maximum demand was at 14PM. The two daytime peaks are mainly contributed by industrial sector and partly by service sector. This is different from the national load curve, which is characterized by the evening peak mostly by household sector (lighting and cooking loads). Electricity consumption per capita in 2008 in HCMC reached to 1,893 kWh per person, which is 2.48 times higher than the average for the whole country.

Table 2-13: Trends of living area, income and electricity in households in HCMC

	Unit	2002	2004	2006	2008	2010
Living area	m2/household	71.42	72.50	73.28	79.13	72.05
Nominal annual Income	thousand VND/household	47,303.12	63,724.92	75,529.77	109,204.7	133,109.7
Electricity consumption	kWh/household.month	125.66	137.30	172.71	208.69	242.91
Electricity use intensity	kWh/m2	1.76	1.89	2.36	2.64	3.37

Source: author's calculation from the living standard surveys

It is estimated that a household in HCMC consumed 1866.9 MJ per month in 2010, which was 1.43 times higher than the average of the country (1304.5 MJ). Total energy consumption increased at the growth rate of 2.69 percent per annum during 2002-2010. In 2002-2010, household income increased at 13.81 percent per annum while electricity 8.59 percent. Living area per household increased from 71.42 m^2 in 2002 to 79.13 m^2 in 2008, and then reduced to 72.05 m^2 in 2010. Electricity use intensity rose from 1.76 $kWh.m^{-2}$ in 2002 to 3.37 $kWh.m^{-2}$ in 2010 at the rate of 8.47 percent per annum.

2.3 Overview of Energy Supply and Demand

2.3.1 Status of Energy Supply and Demand

Vietnam has various types of indigenous energy resources such as crude oil, coal, natural gas and hydropower, which played an important role in boosting economic development in the last two decades. Export of crude oil and coal are major revenue sources for the state budget. The country is currently a net energy exporter, however, it is expected that the country will turn to net energy importer from 2014-2015 onwards. Keeping crude oil for domestic oil refineries, reducing import of anthracite coal and increasing import of sub bituminous coal for power generation are among the main reasons. Table 2-14 presents past trends of coal, oil and natural gas extraction.

Table 2-14: Coal, crude oil and natural gas extraction trends

Year	1990	1995	2000	2005	2006	2007	2008	2009
Total production (million tons)	4,6	8,4	11,6	34,09	38,9	43,2	39,8	43,7
Total production (million tons)	2.7	7.67	16.3	18.5	16.8	15.9	14.85	16.3
Total production (million m^3)	-	183	1,580	6,890	7,520	6,860	7,944	8,100
In which, for power generation	-	182	1,224	4,460	4,950	5,050	5,410	7,180

Source: (Institue of Energy, 2009)

Coal

Vietnam has important anthracite coal deposits in the North of the country. Vietnam anthracite coal is hard, difficult to burn and has high heating value. Anthracite coal has been used for power generation, industries (including cement, fertilizer, and steel) and export.

During 1976-1992, coal production was always below 5 million tons per annum. Coal production had been improved much since 1993, when coal export was promoted. Coal output rose 9.6 percent per year during 1991-2000 and 16.7 percent during 2001-2008.

Beside high-value anthracite coal deposits in the North, Vietnam has also potential sub bituminous coal in the Red River Delta and peat coal dispersed in all parts of the country.

Crude Oil

Crude oil extraction had grown quickly from 40 thousand tons in 1986 to 2.7 million tons in 1990 and 7.6 million tons in 1995. Growth rate during this period was 23 percent per annum. Crude oil production reached to its peak of 18.5 million tons in 2005 and then reduced to 16.3 million tons in 2009. No significant new exploration has reduced oil extraction amount. All of crude oil amount was exported before the coming of the first oil refinery in 2009, which was designed for refining local sweet crude oil. The first refinery with output capacity of 6 million tons of oil products per annum aims to supply one third of domestic oil demand.

Natural Gas

Associated gas was first exploited in offshore oil fields in the South of the country and transmitted to onshore gas power plants. New explorations of natural gas fields and construction of gas pipelines has boosted the building of gas power plants in the South and develop the downstream market for natural gas.

Hydropower

Hydropower once accounted for more than half of total power generation. During 1990-2002, the highest share was 75 percent in 1994 and the lowest 51 percent in 1998. In recent years, new thermal power plants have been built. As a result, hydropower share reduced from 51.9 percent to 32.8 percent in 2008

Energy Import and Export

By the boosted export of crude oil and coal since 199, Vietnam turned to a net energy importer, although the country had to import its entire domestic oil product demand. Vietnam is exporting its anthracite coal while importing sub bituminous coal for power plants in the Central and the South. Electricity import was started in 2005 by purchasing power from China, which increases in volume year by year. Energy import and export trends are shown below:

Table 2-15: Energy import and export trends

Year	1990	1995	2000	2005	2006	2007	2008	2009
Import of oil products (KTOE)	2,888	5,004	8,748	9,636	11,894	13,651	13,665	12,680
Export of crude oil (KTOE)	2,617	7,652	15,423	17,967	16,442	15,062	13,908	13,373
Export of coal (KTOE)	789	2,821	3,251	17,987	29,308	31,948	19,699	24,992
Import of coal (KTOE)	-	-	-	-	-	-	-	908
Import of electricity (GWh)	-	-	-	383	966	2,630	3,220	4,102
Export of electricity (GWh)	-	-	-	-	-	-	-	373

Sources: (Institue of Energy, 2009); (General Statistics Office, 2010)

In 2009, the first refinery start supplying oil products for domestic demand, then it reduced import of oil products as well as export of domestic crude oil. Some amount of coal was also imported for coal power plant in the Central of the country.

Total Primary Energy Supply

In 2009 total primary energy supply (TPES) for Vietnam was of 56,398 KTOE, in which commercial accounts for 73.9 percent of total and non-commercial 26.1 percent. During 2000-2009 total non-commercial energy grew at 9.7 percent per annum, which was higher than the GDP growth rate of 7.3 percent in the same period. Therefore, elasticity of energy with respect to GDP during 2000-2009 was of 1.33 indicating that the economy consumed more energy to generate a unit of GDP. Among kinds of energy, gas had the highest growth rate of 19.7 percent per year in 2000-2009. The growth rates for coal, oil products, and hydropower are 12.5, 7.1 and 5.2 percent per annum respectively.

Table 2-16: Total primary energy supply (KTOE)

Year	1990	1995	2000	2005	2006	2007	2008	2009
Coal	2,212	3,314	4,372	8,341	9,030	9,681	11,888	12,645
Oil products	2,860	4,617	7,917	12,336	12,022	14,149	14,058	14,635
Gas	8	186	1,441	4,908	5,360	5,653	6,533	7,290
Hydropower	2,063	3,237	4,314	3,835	4,619	5,213	5,881	6,785
Electricity import				33	83	226	277	321
Total without non-commercial	***7,143***	***11,354***	***18,044***	***29,453***	***31,114***	***34,922***	***38,637***	***41,676***
Non-commercial	12,421	12,872	14,191	14,794	14,767	14,748	14,725	14,722
Total	**19,564**	**24,226**	**32,235**	**44,247**	**45,881**	**49,670**	**53,362**	**56,398**

Source: (Institue of Energy, 2009)

Figure 2-9 presents fuel mix of primary energy consumption. Oil products (including gasoline, diesel oil, fuel oil, kerosene, jet fuel, LPG) account for the largest share in total non-commercial energy, which was 35.1 percent in 2009. Coal was ranked second with the share of 30.3 percent of total. Natural gas and hydropower contribute similar share about 17 percent of the total. Non-commercial energy (including firewood, agricultural residues, peat coal, household bio fuel etc…) still accounts for large share in TPES due to a large part of population living in rural areas and having variety of agricultural works. Coal share in the total noncommercial energy increased much in 2000-2009 due to new coal generating capacity came into the power system. In this period, a number of coal and gas thermal power plants had been built making hydropower share steadily smaller.

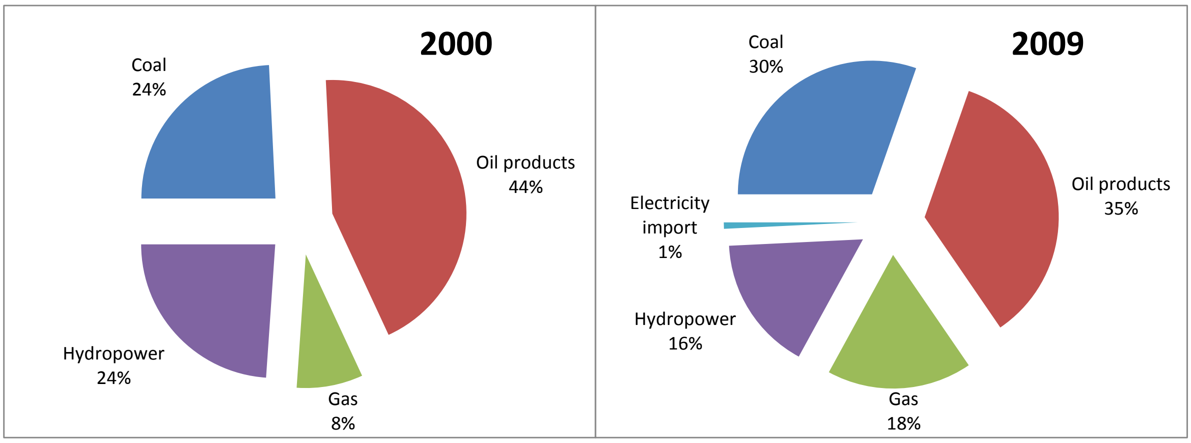

Figure 2-9: Total non-commercial primary energy shares

Total Final Energy Consumption

In 2000-2009, total final energy consumption (TFEC) grew at 6.6 percent per annum and reached to 46,774 KTOE in 2009. In the total final energy consumption, oil products still play an important role and accounts for significant share in the total. Oil products are mainly used for transport activities. Oil products account for 33.9 percent in the total final energy consumption, which includes also non-commercial energy types. The shares for coal, electricity and gas are 19.2, 14.7 and 1.4 percent in the total. Gas had the highest growth rate among all kinds of energy, which was 47.4 percent per year during 2000-2009. Natural gas downstream market was created in the South including fertilizer and heating other industries. Electricity had relatively high growth rate of 14.7 percent per annum in 2000-2009. The elasticity of electricity with respect to GDP hence was 2.01 times that was really high. It indicates that growth rate of electricity consumption was double that of GDP in the same time. This reflects the development orientation toward industry of the country, in which a number of energy intensive industries have been accelerated such as steel, cement, shipping etc… This also raises the challenge for the economy to reduce energy elasticity and energy intensity in future development pathway.

Table 2-17: Total final energy consumption (KTOE)

Year	1990	1995	2000	2005	2006	2007	2008	2009
Coal	1,324	2,603	3,223	5,351	5,562	6,089	8,271	8,966
Oil products	2,479	4,247	6,920	12,122	12,023	13,713	13,797	15,851
Gas	5	21	19	537	485	542	666	639
Electricity	532	963	1,927	4,051	4,630	5,275	5,834	6,615
Non-commercial	12,421	12,872	14,191	14,780	14,748	14,726	14,710	14,704
Total	**16,760**	**20,707**	**26,280**	**36,841**	**37,449**	**40,345**	**43,277**	**46,774**

Source: (Institue of Energy, 2009)

A quick look at the share changes between 2000 and 2009 in Figure 2-10 reveals a significant reduction of non-commercial. Its share decreased from 54 percent in 2000 to 32 percent in 2009. Non-commercial energy was steadily replaced by the other commercial energy types. This replacement was possibly took place in household sector due to the popular use of non-commercial energy kinds in rural areas. This trend in household fuel mix pattern will be investigated deeply in the later chapters. All kinds of commercial energy had increasing shares in the total. Among them, oil had the biggest share in 2009, followed by coal, electricity and gas.

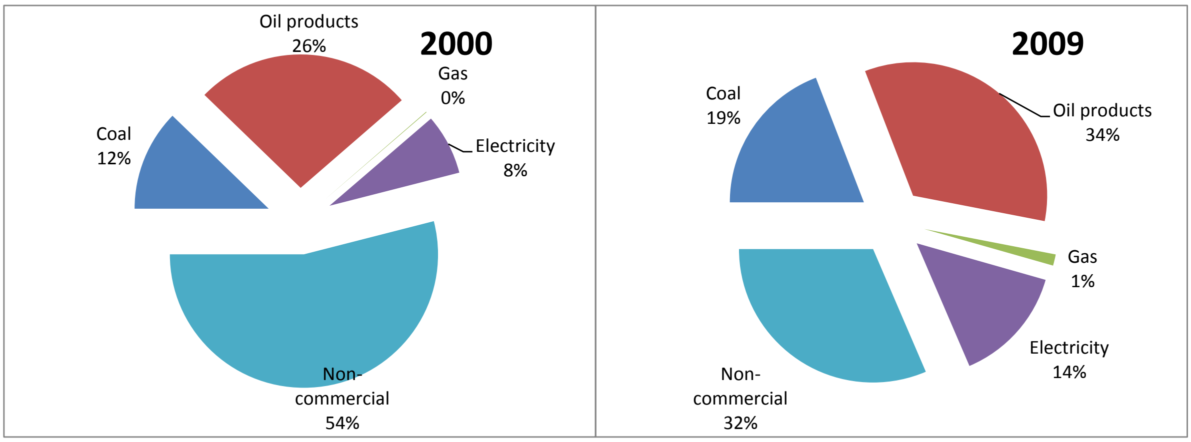

Figure 2-10: Shares of total energy final consumption

In 2008, urban population was less than half of rural population (24 million persons in urban areas as compared to 62 million in rural areas). However, electricity consumption by urban and its contribution to systems load curve was 1.5 times higher than that by rural. During peak period, the difference was reduced due to an increase in lighting use, the main purpose of use in rural areas. The higher load factor of urban areas indicates urban load curve was much flatter as compared to the one of rural. Table 2-18 presents contribution of residential electricity consumption to system load.

Table 2-18: Contribution of residential electricity consumption to system load

Sector	Share of electricity consumption	Load factor		Contribution to residential load		Contribution to system load	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Urban	23.36%	0.7147	0.7553	53.72%	56.29%	24.20%	29.04%
Rural	13.96%	0.5084	0.5249	46.28%	43.71%	20.84%	22.55%
Total	37.32%	0.6192	0.6626	100.00%	100.00%	45.04%	51.58%

Source: (Institute of Energy, 2010)

Due to large contribution to the peak capacity (45% in weekday and more than 51% weekend), energy efficiency activities in households will have significant impact on system peak clipping, that helps reduce much marginal cost of supply during evening peak period. This is very important option for Vietnam to shortly solve the problem of lacking generating capacity and reduce economic burden on electricity tariff.

2.3.2 Energy Outlook

This section presents results for energy demand forecast by (Institue of Energy, 2009) for the purpose of reference. It gives readers an imagination on energy development outlook in Vietnam and emphasizes the need for promotion of energy efficiency measures. Total final energy consumption was projected to 2020 and 2030, which are 92,824 KTOE and 164,877 KTOE respectively. In 2020, oil share will be 37 percent of the total, coal share 19.4 percent, electricity share 26.9 percent, gas 1.5 percent and non-commercial energy 15.1 percent. Total final energy consumption will grow 6.8 percent per annum in 2010-2020 and 5.9 percent in 2020-2030. These growth rates are lower than the projected rate for GDP during the same period. This indicates somewhat more efficient use of energy of the economy. Energy production plans are shown in Table 2-19.

Table 2-19: Energy production plan

Year	2010	2015	2020	2025	2030
Coal production (million tons)	44 - 46	55 - 58	60.5 - 63.5	64.5 - 66.5	75
Oil extraction (million tons)	19,9	20,0	20,7	21,7	22
In which, domestic production	15,0	17,0	12,4	9,3	6,3
Gas extraction (million cubic meters)	7.98	12.4-12.6	14.2-19.6	11.1-18.2	9.6-13.4

Source: (Vinacomin, 2011); (Petroleum Vietnam Institute, 2010)

Coal

Coal will be mainly exploited from the coal deposits in the North East region of the country, which accounts for 90 percent of total coal output. Sub bituminous coal in the Red River delta will be exploited in a gradual basis after 2015. Coal deposits here are very deep underground and located in richly agricultural land. Its exploitation should be carefully implemented to avoid negative impacts on food security. Coal production plan was built as below:

Crude Oil

Crude oil production will increase to 20 million tons in 2012 and 22 million tons in 2030. However, domestic production will be reduced. Total crude oil production will be made up by oil fields abroad.

Natural Gas

Investigation of natural gas reserves is being accelerated. Gas production may reach to its peak of 19.6 billion cubic meters in 2020 and then reduce to 13.4 billion cubic meters in 2030.

Hydropower

Hydropower potential is located in all parts of Vietnam including large and small hydropower potentials. Total hydropower potential is of 75-80 billion kWh per annum corresponding to capacity of 18-20 GW, in which 85.9 percent of the total is contributed by ten main river basins. Geographically, capacity in the North is of 9.49 GW (36.4 billion kWh per annum), in the Central 5.655 GW (22 billion kWh), and in the South 3 GW (12 billion kWh).

Renewable Energy

Vietnam is well endowed with various types of renewable energy resources. However, except small hydropower and some bagasse power, current exploitation of renewable energy sources in Vietnam is rather limited. Hydropower potential for small-scale generation has been estimated at more than 4000 MW, located mainly in the north and central regions. Solar radiation is good in the southern and central regions. Wind energy potential for large-scale generation in the coastal area has been estimated at some 9,000 MW. While wind energy brings about ecological, economic and social benefits, it is only modestly exploited in Vietnam, where the main barrier is the lack of political impetus and a proper framework for promoting renewable energy (Nguyen, 2007). Opportunities also exist for power generation using cogeneration from biomass (bagasse and rice husks), geothermal, and tidal power. Potential for renewable power is presented in Table 2-20.

Table 2-20: Renewable energy potential

Renewable energy type	Capacity (MW)	Gross electricity generation (GWh)
Small hydropower	4,015	
Biomass[1]	698-781	3,066-3,422
Wind	8,748[2]	
Geothermal	50-200	

Sources: (Institute of Energy, 2009); (Meier, 2008)

Vietnam is formulating policy measures to support renewable energy development, which include subsidy and incentive schemes. Renewable energy may contribute from 4.0 to 5.4 percent of total electricity generation in different development scenarios. The main barriers for renewable energy development in Vietnam are realized as below:

Table 2-21: Main barriers for renewable energy development in Vietnam

Main barriers	Items
Policies	Environment and social benefits are not assessed. Price subsidy for rural electrification is less than that for conventional power grid.
Engineering	Equipment and operation skills are not that of the best international practice. Not sufficient number of skilled persons for large scale
Business	No business on RE Government's approval procedure is complicated and difficult
Information	Lack of awareness, data on power network and villages, communities un-electrified by EVN
Resources	Lack of measurement and sufficient assessment, no general data base
Financing	Lack of long term financing and finance of customers

Sources: (Institute of Energy, 2009)

[1] Biomass includes rice husk, bagasse, landfill gas, and biogas

[2] Sites with annual average wind speed equal or greater than 8-9 m/s

Chapter 3. Data and Methodology

3.1 Data

3.1.1 Vietnam Household Living Standard Survey

Vietnam household living standard survey (VHLSS) is series of living standard survey, which have been carried out for every two years in the whole countries. The questionnaire covers all fields of living standards including demography, income, expenditure, education, healthcare, shelter, appliances, and others. The surveys were carried out by General Statistical Office and published by Statistical Publish House. The surveys cover some 9000 households in all parts and from all groups of the country with some were interviewed repeatedly. It hence formed an unbalanced panel data. Core modules included in VHLSS are:

- Expenditure
- Income
- Employment and labor force participation
- Education
- Health
- Housing
- Assets and durable goods
- Participation in poverty programs

Surveys' sample sizes cover some 75,000 households in 2002 (of which 30,000 with expenditure) about 46,000HHs in 2004, 2006, 2008 and 2010 (of which 9,300 with expenditure). Questionnaire was designed with the exact questions asked households, these questionnaire forms were printed out. Implementations of VHLSS were four rounds (four quarters) in 2002 and two rounds (May and September) in 2004, 2006, 2008, and 2010.

The PhD study used raw data, which were stored in original Stata format, from the surveys for its analyses. Unfortunately the surveys did not ask information about physical amounts of energy consumption by households. Only information about energy expenditure for each energy type was surveyed instead. Consequently, energy consumption had to be calculated from corresponding expenditures by using average fuel prices in each year. Summary on household living standard survey is as below:

Table 3-1: Brief view on VHLSS data

Dataset	Year	Number of household with expenditure
VHLSS 2002	2002	29,532
VHLSS 2004	2004	9,188
VHLSS 2006	2006	9,189
VHLSS 2008	2008	9,189
VHLSS 2010	2010	9,402

Living standard data is served as a basis for calculation of energy consumption in household sector due to lack of official statistical data sources for energy consumption in residential sector. Modeling energy system in Vietnam so far has neglected the breaking down into end users, especially in residential sector. Therefore, data from living standard surveys were used for the following purposes:

- Calculation of main indicators that related to energy consumption including household size, sector, income, expenditure, living area, appliance stock, dwelling type
- Calculation of energy consumption based on yearly average energy price for each of energy type such as electricity, coal, LPG, kerosene, gasoline, firewood and other agricultural residues
- Analysis of changes in fuel mix by households during 2002-2010
- Index decomposition analysis to reveal main driving factors for energy consumption in households
- Estimation of elasticity for electricity demand by using a panel econometric model
- Forming a basis, which is time-series data, for energy consumption forecast by relating energy consumption of households with income, living area or appliance tock
- Building detailed end use data for household to incorporate into the energy system model

3.1.2 Household Questionnaire Survey

A survey in household sector of HCMC is needed for the research work due to a number of reasons:

- There is no official statistical data on energy use in household in Vietnam (even in other sectors of the economy).
- Lack of information to break down energy use in household into different purposes of use (i.e. lighting, water heating, space cooling etc...).
- A number of household surveys in the past did not include much information on house type and income (mainly focus on energy consumption and appliances).
- These data are required for the HCMC Project to quantify the energy indicators for different urban structure types.
- Importance of this information in assessing potential for energy efficiency options as well as proposing appropriate supporting measures.

Therefore, the household survey on energy situation in household sector of HCMC is an indispensable part of the PhD Research.

Objectives of the Survey

The household survey aims to collect necessary data and information, which are needed to analysis energy demand pattern as well as potential for energy efficiency in household sector. A number of household energy surveys have been done so far in Vietnam with different scales and targeted groups. However, information from these surveys is not enough for the required research issues raised by the PhD research as well as the Work Package 4. Therefore, the household survey has the following objectives:

1. Breaking down energy consumption in household by different purposes of use (i.e. cooling, lighting, cooking, water heating etc…)

2. Situation of appliance stock in household in term of quantity and capacity (i.e. air conditioner, fan, cooking device, refrigerator, water heater etc…)
3. Situation of building, roof, window, floor materials in household
4. Information on income and/or economic activity in linking with energy consumption, house type, and others
5. Classification of energy indicators by house type

Design of Questionnaire Survey

The household survey includes main steps such as: size, sample, questionnaire, data summary etc… The work flow for the household survey is designed as follows:

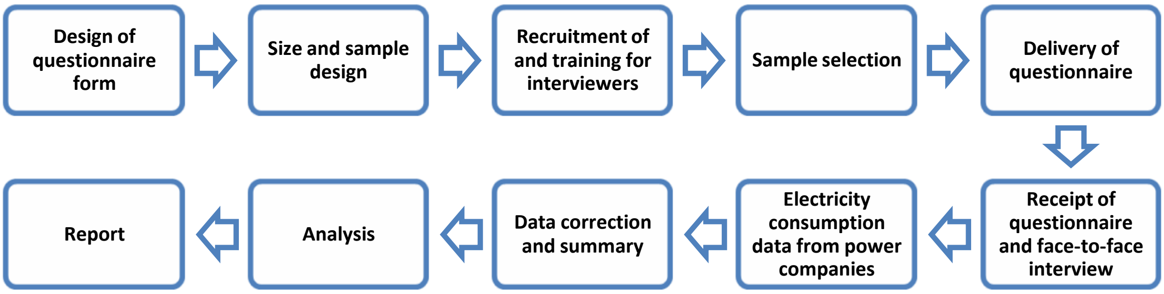

Figure 3-1: Work flow for the household questionnaire survey

Firstly, a questionnaire form is constructed to collect necessary data and information. The size and the sample design will be carried out next. These two steps are the necessary preparation for the implementation of the survey. According to the work plan, I will go back to Vietnam in March 2011 to do the survey. Thirdly, interviewers for the survey will be recruited and given necessary instructions. Sample selection will be then decided based on the sample design in such a way appropriate for interviewers. Questionnaire form will be delivered to households, which are qualified for sample criteria. After one week, interviewers will go to these houses to do direct face-to-face interview and check the answer by the respondents. After that, electricity consumption data will be bought from HCMC Power Company based on the list of respondent. Data correction and summary will be made to develop a database for household energy. Finally, a summary report for the survey will be produced.

Size of the Survey

According to the classification of urban structure type and building type by the Work Package 1 of the BMBF Project, residential households in HCMC include five groups with 25 building types. The urban structure types are presented in Table 3-2.

Table 3-2: Urban structure types in HCMC

Urban structure type	Grouping, typologies	No. of blocks	Area in km2
Residential Use	5 groups, 25 Types	6717	445,9
Shop house based	(3 sub-groups) 12 types	6346	424,8
Villa based	4 types	107	8,4
Apartments	5 types	103	5,0
Central Business District	2 types	160	7,4

Based on the above classification and expected data for analysis, the survey size needed is 500 households (about averagely 100 HHs for each group and 20 HHs for each house type) in the area of the city. As compared to the total household of 1.8 million in HCMC, the proposed sample size accounts for 0.028% of the total. This share is rather small. However, due to feasibility to implement the survey under time and financial constraints, the proposed size is acceptable. Sizes of a number of household energy surveys in the past are as follows:

- Demand side management (DSM) Project, implemented by Electricity of Vietnam (EVN): 3,000 households for the whole country (including HCMC, Hanoi as well as other provinces). This survey focused on energy consumption and stock of energy-consuming appliances in household sector of Vietnam.
- A Study on Energy Master Plan for Vietnam (EMP), by Japan International Cooperation Agency (JICA): more than 600 households in Hanoi, HCMC and Da Nang (three major cities of Vietnam). This survey concentrated on energy consumption and stock of energy-consuming appliances in household sector with some additional questions on house type and attitude toward energy efficiency.
- A household energy survey, by Tohoku University, Japan: about 400 households in Hanoi and HCMC. This survey aimed to gather information on energy consumption, energy efficiency by house design, consumer behavior and income.

Based on review of these surveys in the past, the size of 500 HHs in HCMC is proposed to implement for the household survey under the PhD research.

Sampling Method

Sample selection plays a very important role in survey implementation. The sample should meet following criteria:

- To represent all house types in different urban structure forms in HCMC (rudimental, shop house, villa, apartment, etc…).
- To cover all kinds of districts of HCMC with the focus on central districts

Contents of Questionnaire

Due to the wide scope of data and information, the household survey employs a questionnaire form for interviewing work, which is designed specially to obtain required data. Therefore, the questionnaire form includes the main contents as follows:

- Household characteristics: name, address, population profile, profession, age, number of person, business activity etc…
- House characteristics: dwelling type, area, number of room, number of floor, building material, roof material, insulation method, shading method, number of window, etc…

- Energy consumption amount and purpose of use: electricity, coal, LPG, oil, biomass, biogas, solar, etc…
- Energy consuming appliances: lighting, cooking, water heating, space cooling, refrigerator, etc…
- Income, movement in the past, plan in future
- Attitude towards energy efficient use

Detailed questionnaire form is presented in Section 10.3 in the Appendix.

Implementation

The household questionnaire survey was successfully carried out from March-June 2011. The questionnaires were randomly distributed by interviewers to some 520 households in eight districts of Ho Chi Minh City. The interviewers helped household owner to get information and answer the questions in the questionnaire form. The number questionnaire forms with completed and useful information were of 498. Number of respondents by house type and districts are as follows:

Table 3-3: Number of respondents by dwelling type and district

Dwelling type	District							
	2	4	6	7	8	9	Binh Thanh	Thu Duc
Rudimental	17	1	26	22	16	0	26	6
Shop house	32	0	67	18	14	1	47	17
Row house	7	0	13	8	2	0	5	10
Apartment	3	0	28	11	29	0	10	1
Villa	37	0	5	7	1	2	3	6

Source: author's survey

From the distribution of respondents, rudimental and shop house are located in six main districts of the survey. Row houses are mainly from Districts 6 and Thu Duc. Apartments were mainly taken from Districts 6 and 8, while villa mainly in District 2, which is one of new quarter of the City.

Information on consumption of energy types, which are other than electricity, will be gathered through the survey. Moreover, electricity consumption data for each household are expected to be obtained from HCMC Power Company. By purchasing electricity consumption data from the company, the accuracy of data will be guaranteed. The electricity consumption data will include monthly consumption for one-year long. This data will serve to the examination of monthly change in electricity consumption of household sector as well. Other energy consumption data were obtained based on information filled by the respondents. Energy for private transport was calculated based on gasoline/diesel consumption by households. Almost households are using liquefied petroleum gas (LPG) for cooking along with electricity, coal, and fired wood. Results from household survey are presented in details in Chapter 1 of the dissertation.

3.1.3 MARKAL Database

General energy economic database was collected from various sources. These are mainly from plans and strategies for energy subsector development such as electricity, coal, oil and gas, and renewable energy. Building energy system model require intensive data covering supply side, transformation and ultimately to end users. MARKAL is used for that purpose due to its wide comprehension and flexibility for doing the task. The current MARKAL database for Vietnam have been developed by the author since 2002 and used as analytical tool for a number of policy studies. The main features of the MARKAL database for Vietnam are:

- Time frame: 30 years with discount rate of 10%
- Energy carriers: electricity, coal, crude oil and oil products, natural gas, CNG, nuclear, hydropower, biomass, solar, wind, geothermal etc…
- Resource: extraction and mining, import, export and storage
- Conversion: oil refineries, gas pipelines, power plants, gas processing plants, etc…
- Sector: agriculture, service, industry, residential, transport
- Emission: CO2, SO2

The current database **will be developed with a strong focus and detailed disaggregate on the household sector of HCMC** to allow a thoroughly and comprehensive examination of energy efficiency options in the sector (See Chapter 1 for detailed data of the model).

3.2 Methodology

3.2.1 Analysis Framework

The PhD study focused on energy consumption of households in HCMC by investigating energy consumption behavior in relations to other factors, such as dwelling type, income, living area, energy prices expenditure, household size, and appliance stock. The study therefore starts with the past and current status of energy consumption by households, calculation of energy use intensity, elasticity for electricity demand, effect of dwelling type on energy use, energy demand forecast and modeling energy system. The ultimate goal of the PhD study is to propose the best energy efficiency measures for household sector and its implications on energy, environment and climate. The PhD study therefore proposed a research flow as in Figure 3-2.

The PhD has investigated energy consumption of household in Vietnam for the first time in a systematic and comprehensive manner. The study starts with an analysis of past trends of energy consumption in households by decomposing energy consumption into different indexes. It aims to investigate the main determinants for the changes in energy consumption pattern and fuel mix of households in the past. In the next step, the PhD study estimates elasticity for electricity demand by employing an econometric analysis. In the current context of energy price vitality, it is useful to get understand on how energy demand reacts to changes in prices, income and other related things. The household questionnaire survey then evolves in-depth analysis of energy and electricity consumption in the relation to dwelling type, income and appliance stock. Output from this analysis will form a good basis for future energy demand forecast and energy-saving potential for households. The last part of the study deals with energy supply and demand balance. MARKAL model will be used to analysis the balance in long term taking into account of wide range of energy efficiency options, which can be applied for households. The outputs from the model suggest the best energy efficiency options and their implications on energy resources, economics, environment and climate. Core analytical methods for each part above are presented in the next sections.

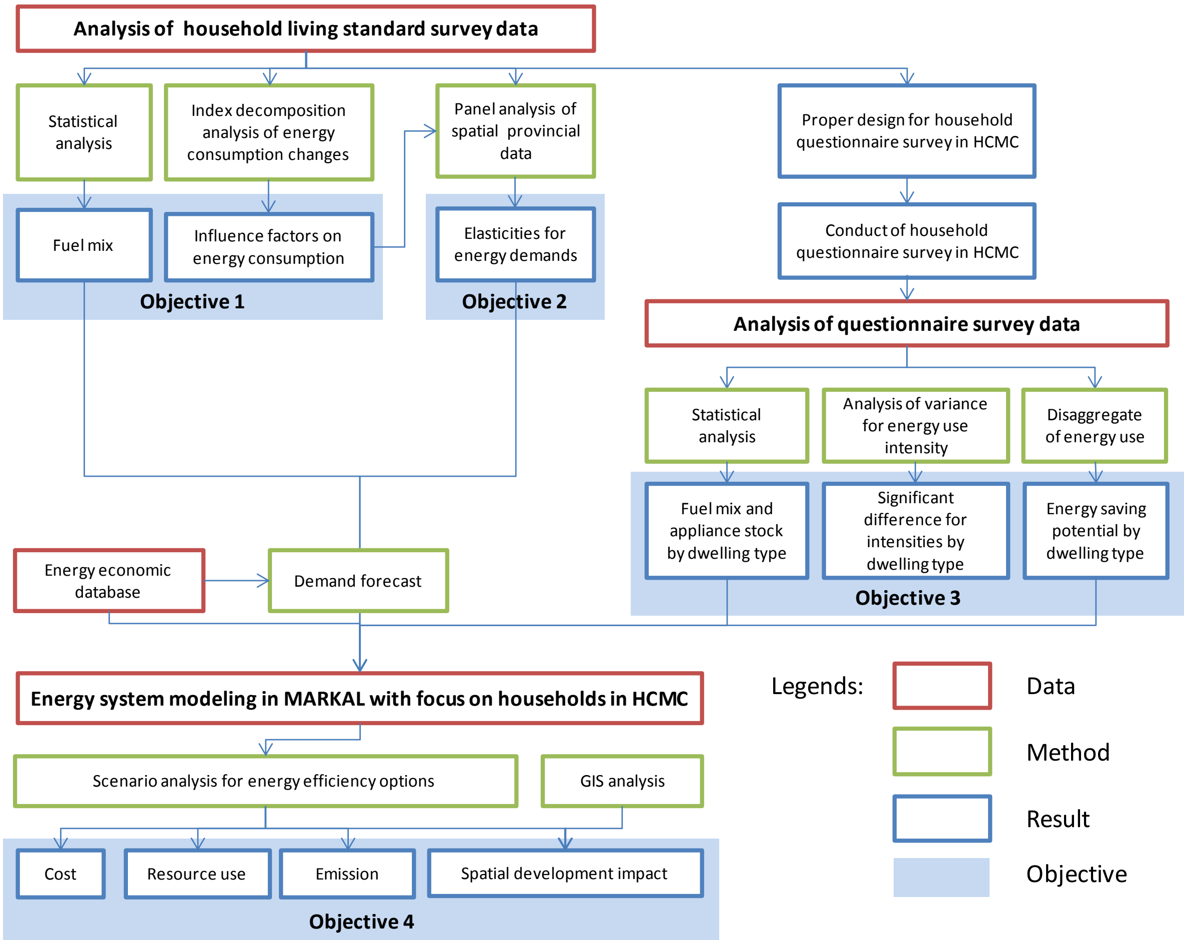

Figure 3-2: Research flowchart

3.2.2 Index Decomposition Analysis of Energy Consumption

Introduced at the end of the 1970s, index decomposition analysis (IDA) methods have been developed and applied in various different areas (Ang & Zhang, 2000). Its application in energy helps remarkably understand the determinants of changes in energy consumptions as well as emissions. Due to its simplicity but strength in analyzing, the method has been used as main analytical tool for formulation of energy and environmental policies. It has been applied extensively to understand historical changes in energy and emission by exploring the driving forces or determinants underlying the changes. IDA uses aggregate data at the sector level to decompose the changes in main variable into determinants such as intensity, structural, fuel mix effects (Hoekstra & Van den Bergh, 2003). IDA consists of two mainstreams such as methods linked to Divisia and Laspeyres indices. Fatherly, decomposition can be performed multiplicatively or additively. The former represents the rate of change while the later the difference of change of an aggregate. Overview of index decomposition methods can be described in Figure 3-3 (Ang, 2004).

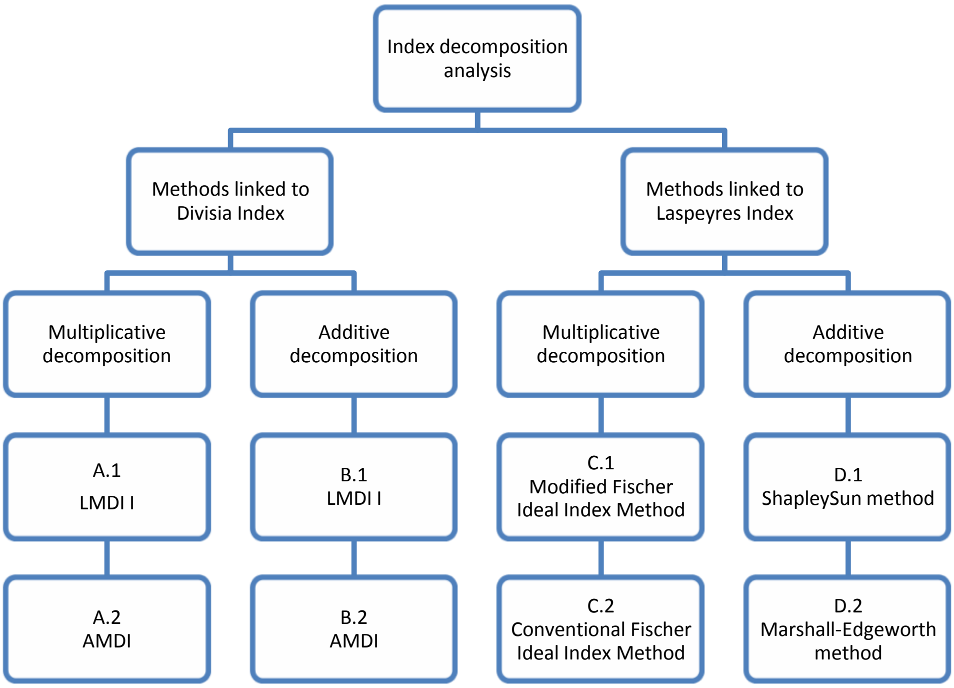

Figure 3-3: Overview of index decomposition methods

In this PhD study, the Logarithmic Mean Divisia Index method I (LMDI I) method was employed. LDMI I was recommended for general use by (Ang, Decomposition analysis for policy making in energy: which is the preferred method?, 2004) due to its capability to perform perfect decomposition thanks to no unobserved residual term exists in the outputs. Moreover, the formula for decomposition takes a simple form that eases the use as well as the ease of result interpretation. By applying IDA, effects underlying electricity and energy consumption changes in households of HCMC will be investigated. These are intensity, structure, activity. In Vietnam, the use of LDMI in energy field has been rather limited due to the availability of energy consumption data, especially in residential sector. This is so far the first attempt in employing the technique to explore the driving forces behind the rapidly increased household energy sector in Vietnam.

3.2.3 Panel Data Analysis of Energy Demand

Analysis framework

Econometric analysis was carried out to estimate elasticities for electricity demand based on the survey data on household living standard. Electricity demand was built in relation own price, income, other substitutes' prices, household size, cooling degree days, and other factors. General process for implementing econometric analysis is as follow:

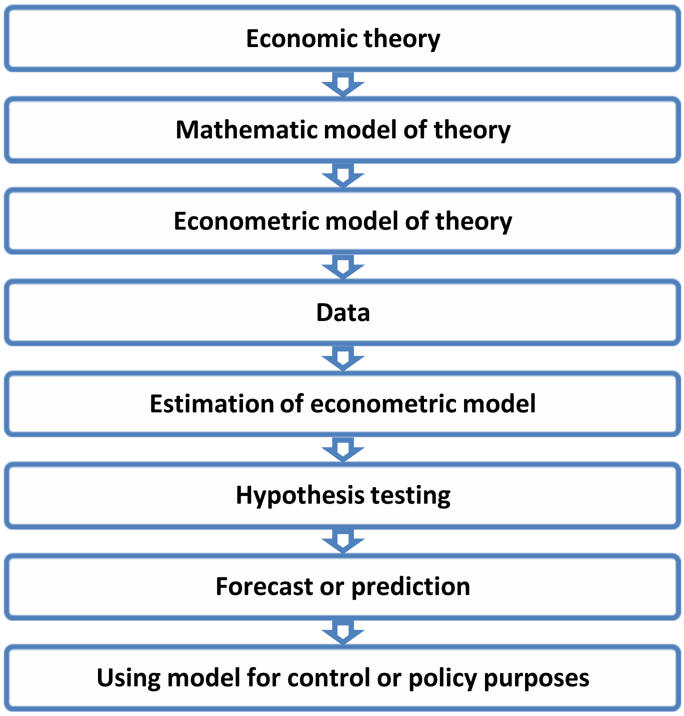

Figure 3-4: Anatomy of econometric modeling

Source: (Gujarati, 2003)

The panel estimation starts with the economic theory for demand of goods and service. The service here is electricity and LPG demands for households. These demands therefore depend on income level, own price, prices of substitute goods, and other factors related (such as household size, living area, geographic location etc…).

In literature, equation with log-log form was preferred for demand estimation. This model has one attractive feature, which is that the slope β_1 measures the elasticity of the demand with respect to its own price (in the equation below). In another word, this model has constant elasticity, which made it popular in applied works, especially for demand equation. The model in double log form, based on the Cobb–Douglas type of demand function, was chosen for household electricity demand as follows:

$$\ln(E_{it}) = \beta_0 + \beta_1 \ln(P_{eit}) + \beta_2 \ln(Y_{it}) + \beta_3 \ln(X_{it}) + \beta_z \ln(Z_{it}) + \varepsilon_{it}$$

In the above equation, β_1, β_2, β_3, β_z are parameters to be estimated and ε is random error term. According to economic theory the income elasticity and the cross-price elasticity for a competitive product (say LPG), are expected to be positive, while the own-price elasticity of electricity demand is expected to be negative. Data used for demand estimation is panel data on average electricity demand of households in provinces and cities of Vietnam in 2002, 2004, 2006, 2008 and 2010. This hence formed a balanced panel data with the average values of each province in each of these years.

Ordinary Least Squares (OLS)

In a simple linear regression:

$$\boldsymbol{y = \beta_1 + \beta_2 x + \varepsilon}$$

Based on the least squares principle, we want find the estimates b_1 and b_2 of $\boldsymbol{\beta_1}$ and $\boldsymbol{\beta_2}$ that minimizes the "sum of squares" function

$$S(\boldsymbol{\beta_1}, \boldsymbol{\beta_2}) = \sum_{i=1}^{N} (\boldsymbol{y_i} - \boldsymbol{\beta_1} - \boldsymbol{\beta_2 x_i})^2$$

Partial derivatives of S with respect to $\boldsymbol{\beta_1}$ and $\boldsymbol{\beta_2}$ are:

$$\frac{\partial \boldsymbol{S}}{\partial \boldsymbol{\beta_1}} = \boldsymbol{2N\beta_1} - \boldsymbol{2}\sum \boldsymbol{y_i} + \boldsymbol{2}\left(\sum \boldsymbol{x_i}\right)\boldsymbol{\beta_2}$$

$$\frac{\partial \boldsymbol{S}}{\partial \boldsymbol{\beta_2}} = \boldsymbol{2}\left(\sum \boldsymbol{x_i^2}\right)\boldsymbol{\beta_2} - \boldsymbol{2}\sum \boldsymbol{x_i y_i} + \boldsymbol{2}\left(\sum \boldsymbol{x_i}\right)\boldsymbol{\beta_1}$$

The sum of squares S was minimized where $\boldsymbol{\partial S/\partial \beta_1}$and $\boldsymbol{\partial S/\partial \beta_2}$ are zero. Setting two derivatives to zero and replacing $\boldsymbol{\beta_1}$ and $\boldsymbol{\beta_2}$ by b_1 and b_2, we obtain:

$$\boldsymbol{Nb_1} + \left(\sum \boldsymbol{x_i}\right)\boldsymbol{b_2} = \sum \boldsymbol{y_i}$$

$$\left(\sum \boldsymbol{x_i}\right)\boldsymbol{b_1} + \left(\sum \boldsymbol{x_i^2}\right)\boldsymbol{b_2} = \sum \boldsymbol{x_i y_i}$$

These two equations have two unknowns b_1 and b_2. We can find the least squares estimates by solving these two linear equations for b_1 and b_2.

$$\boldsymbol{b_2} = \frac{\boldsymbol{N}\sum \boldsymbol{x_i y_i} - \sum \boldsymbol{x_i} \sum \boldsymbol{y_i}}{\boldsymbol{N}\sum \boldsymbol{x_i^2} - \left(\sum \boldsymbol{x_i^2}\right)}$$

Assumptions for error term $\boldsymbol{\varepsilon}$ of linear regression are:

- Expected value of the random error $\boldsymbol{\varepsilon}$ is: $\boldsymbol{E(\varepsilon) = 0}$
- Homoscedasticity (no heteroscedasticity): $\boldsymbol{var(\varepsilon) = \sigma^2 = var(y)}$
- No autocorrelation: $\boldsymbol{cov(\varepsilon_i, \varepsilon_j) = 0 = cov(y_i, y_j)}$

Individual-effects model

In a panel data including N individuals and T periods, individual-effects model can be specified as:

$$y_{it} = x_{it}\beta + u_{it} \text{ where } u_{it} = \alpha_i + \varepsilon_{it}$$

In the above equation, i is individual index $i = 1, N$, t is period index $t = 1, T$, y_{it} is dependent variable, x_{it} regressor, β is coefficient to be estimated, u_{it} is the error term for observation i since it contains all factors affecting y_{it} other than x_{it}, α_i random individual-specific effects, and ε_{it} an idiosyncratic error.

Table 3-4: Models for panel analysis

No.	Model	Equation
1	Fixed effect (FE) estimator	$(y_{it} - \overline{y_{it}}) = (x_{it} - \overline{x_{it}})\beta + (\varepsilon_{it} - \overline{\varepsilon_{it}})$
2	Random effect (RE) estimator	$y_{it} = x_{it}\beta + (\alpha_i + \varepsilon_{it})$
3	Hausman-Taylor estimator	$y_{it} = x_{1it}\beta_1 + x_{2it}\beta_2 + w_{1i}\gamma_1 + w_{2i}\gamma_2 + \alpha_i + \varepsilon_{it}$

Source: (Cameron & Trivedi, 2010)

Fixed-effects model

In Fixe-effects (FE) model, α_i is permitted to be correlated with the regressorx_{it}. The composite error in the individual-effects model becomes $u_i = \alpha_i + \varepsilon_{it}$ and we permit x_{it} to be correlated with time-invariant component of error α_i while uncorrelated with ε_{it}. FE model can be estimated using within groups estimator following these steps:

Computing averages of x_{it} and y_{it} within each group of cross-sectional unit $\bar{x}_{i.}$ and $\bar{y}_{i.}$

$$\begin{cases} y_{it} = x'_{it}\beta + \alpha_i + \varepsilon_{it} \\ \bar{y}_{i.} = \bar{x}'_{i.}\beta + \alpha_i + \bar{\varepsilon}_{i.} \end{cases}$$

$$\Rightarrow (y_{it} - \bar{y}_{i.}) = (x'_{it} - \bar{x}'_{i.})\beta + (\varepsilon_{it} - \bar{\varepsilon}_{i.})$$

Applying OLS regression the centered y_{it} by the centered x_{it} by OLS, by centering the individual fixed effects α_i are eliminated.

Random-effects model

The random effects (RE) model is based on the assumption that the unobserved person specific effects, α_i, are uncorrelated with the included variables, x_{it}. This assumption is a major shortcoming of the model. However, the random effects treatment does allow the model to contain observed time-invariant characteristics, such as demographic characteristics, while the fixed effects model does not—if present, they are simply absorbed into the fixed effects. when we had heteroscedasticity or autocorrelation, we can obtain the generalized least squares (GLS) estimator in the random effects model by applying least squares to a transformed model (Hill, William, & Lim, 2011). The transformed model is:

$$\boldsymbol{y}^*_{it} = \boldsymbol{\beta x}^*_{it} + \boldsymbol{u}^*_{it}$$

Where the transformed variables are $y^*_{it} = y_{it} - a\bar{y}_i$, $x^*_{it} = x_{it} - a\bar{x}_i$. The variables $\bar{y}_i$ and $\bar{x}_i$ are the individual means. The transformed error term is $u^*_{it} = u_{it} - a\bar{u}_i$. The key transformation parameter a is defined as:

$$a = 1 - \frac{\sigma_\varepsilon}{\sqrt{T\sigma^2_\alpha + \sigma^2_\varepsilon}}$$

It can be shown that the u^*_{it} have constant variance σ^2_ε and are uncorrelated. The variances σ^2_α and σ^2_εneed to be estimated before using fixed effects estimator. Then, OLS regression is applied to the transformed model.

Breusch-Pagan Lagrange specification test

The Breusch-Pagan Lagrange multiplier (LM) test helps you decide between a random effects regression and a simple OLS regression (Breusch & Pagan, 1980). The null hypothesis in the LM test is that variance across entities is zero. This is, no significant difference across units (i.e. no panel effect). If $\hat{u}_{it}$ is the itth residual from the OLS regression, then the Breusch-Pagan (BP) test for one-way random effects is:

$$BP = \frac{NT}{2(T-1)}\left[\frac{\sum_{i=1}^{N}[\sum_{t=1}^{T}\hat{u}_{it}]^2}{\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{u}^2_{it}} - 1\right]^2 \sim\chi^2$$

If the null hypothesis is rejected, one can conclude that there is a significant random effect in the panel data, and that the random effect model is able to deal with heterogeneity better than does the pooled OLS.

Hausman test

The Hausman test is often used to compare RE and FE estimators (Hausman, 1978). Under the null hypothesis that individual effects are random, these estimators should be similar because both are consistent. If the null hypothesis is not rejected, it suggests adoption of random-effects estimator due to its higher efficiency (Frondel, Peters, & Vance, 2009).

$$LM = (\beta_{fixed} - \beta_{random})' \widehat{W}^{-1} (\beta_{fixed} - \beta_{random}) \sim \chi^2(k)$$

where $\widehat{W} = Var[\beta_{fixed} - \beta_{random}] = Var(\beta_{fixed}) - Var(\beta_{random})$ is the difference in the estimated covariance matrices of within estimator (robust model) and GLS (efficient model). This test statistic follows the chi-squared distribution with k degrees of freedom. If the null hypothesis of no correlation is rejected, you may conclude that individual effects u_i are significantly correlated with at least one regressors in the model and thus the random effect model is problematic. Therefore, you need to go for a fixed effect model rather than the random effect counterpart (Park, 2011).

Hausman-Taylor estimator

The Hausman-Taylor estimator is an instrumental variables (IV) estimator that additionally enables the coefficients of time-invariant regressors to be estimated (Hausman & Taylor, 1981). Variables known as instruments, which are correlated with the endogenous variables but uncorrelated with the equation error, were introduced, leading to an instrumental variables estimator that has the desirable property of consistency. The values of the regressors in periods other than the current period can be used as instruments.

In the demand equations for electricity and LPG, there are time-invariant variables representing regional and sectoral characteristics of households. The presence of these variables and possibly endogenous regressor (e.g. rural urban) would make it impossible to estimate their associated parameters when a time or mean differencing approach. Additionally, the probable correlation between these time-invariant regressors and the unobserved individual effects causes random effects to be inconsistent (García-Mainar & Montuenga-Gómez, 2011).

Model for Hausman-Taylor estimator includes four categories of explanatory variables:

$$y_{it} = x_{1it}\beta_1 + x_{2it}\beta_2 + w_{1i}\gamma_1 + w_{2i}\gamma_2 + u_{it}$$

- x_{1it}: exogenous variables that vary over time and individuals
- x_{2it}: endogenous variables that vary over time and individuals
- w_{1it}: time-invariant exogenous variables
- w_{2it}: time-invariant endogenous variables

Fixed effects transformation $\tilde{x}_{2it} = x_{2it} - \overline{x}_{2i}$, which eliminates correlation with α_i can be used as instrument for x_{2it}. $\overline{x}_{1i}$ is suitable instrument for w_{2i}. x_{1it} and w_{1it} are used as instruments for themselves, making the complete instrument set x_{1it}, $\tilde{x}_{2it}$, w_{1it}, and $\overline{x}_{1i}$ (Hill, William, & Lim, 2011). Hausman-Taylor estimator is applied to the transformed generalized least squares model:

$$y_{it}^* = x_{1it}^*\beta_1 + x_{2it}^*\beta_2 + w_{1i}^*\gamma_1 + w_{2i}^*\gamma_2 + u_{it}$$

Where, for example, $y_{it}^* = y_{it} - \hat{a}\bar{y}_i$, and $\hat{a} = 1 - \hat{\sigma}_\varepsilon / \sqrt{T\hat{\sigma}_\alpha^2 + \hat{\sigma}_\varepsilon^2}$.

3.2.4 Analysis of Variance for Energy Use Intensity and Energy Consumption

Energy consumption levels in households are characterized by a number of factors, which may be household size, dwelling type, income, living area, appliance stock, and others. From the outputs of the household questionnaire survey, it is necessary to get understand the effects of these factors on energy consumption in households. The whole procedure involves calculate energy and electricity consumption and then compare these consumptions for different groups of household. Households are classified into different groups with different dwelling types, income levels, living areas and appliance stocks. Analysis of variance (ANOVA) was designed to compare means for different groups.

One way ANOVA of energy and electricity use intensity in different dwelling types was employed to substantiate the impacts of dwelling types on energy consumption. ANOVA is designed to access the main and the interaction effects of several independent variables on single dependent variables. The independent variables here are different dwelling types, income, demography, and appliance stock while dependent variables are energy consumption, electricity consumption of households. Analysis of variance method was developed by R. A. Fisher in the 1920s which is a significance test, using F distribution, to distinguish differences among different group means. Because different levels of the categorical independent variable (i.e. dwelling type, income level) involved different households, we use a one-way between groups ANOVA. Necessary steps involved in ANOVA are discussed as below:

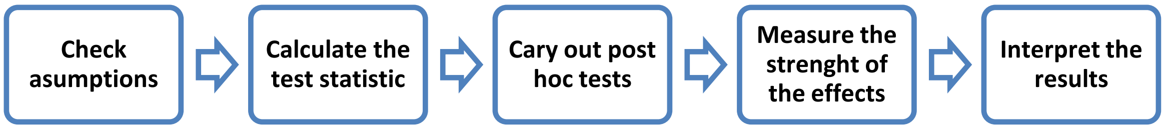

Figure 3-5: Steps in ANOVA

Source: (Mooi & Sarstedt, 2011)

Checking assumptions involves the test of homogeneity of variances. Violation of this assumption can have serious consequences, especially when group sizes are unequal. Therefore it is necessary to perform Levene's test. If Levene's test shows that population variances are different, modified F test such as Brown and Forsythe test or Welch test are recommended to use. These tests make adjustments if the variances are not homogenous, in which the Welch test has been proved to exhibit greater statistical power (Mooi & Sarstedt, 2011).

In the PhD study, we focused on energy use intensity of different dwelling types and energy consumption of different income levels. Hence, in the first analysis, dependent variables are electricity use intensity (kWh.m^{-2}) and energy use intensity (MJ.m^{-2}). Independent variables are dwelling type for which we want to compare the means of energy use intensity by different dwelling type. Because we want to test the significant differences among dwelling groups, the null and the alternative hypotheses for the significant test are as follows:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 \text{ and } H_1: \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$$

The null hypothesis simply reflects the statistical statement that the population means for each of the dwelling groups are equal. In these equations, µs are mean values of energy use intensity for each dwelling group namely rudimental, shop house, row house, apartment, and villa.

ANOVA split up the total variation (SS_T) in the data into two parts (1) the between-group variation (SS_B) and (2) the within-group variation (SS_W) according to the following formula:

$$SS_T = SS_B + SS_W$$

The total variation calculated by comparing observations' values with the overall mean $\bar{x}$:

$$SS_T = \sum_{i=1}^{n} (x_i - \bar{x})^2$$

The between-group variation derived by differencing each group means with the overall mean:

$$SS_B = \sum_{j=1}^{k} \left(\bar{x}_j - \bar{x}\right)^2$$

Finally, the within-group variation computed by comparing each observation values with its group means:

$$SS_W = \sum_{j=1}^{k} \sum_{i=1}^{n_j} \left(x_{ij} - \bar{x}_j\right)^2$$

In which:

i: observation index

j: dwelling type index

n: number of observation

k: number of dwelling type

The results for SS_B and SS_W then have to be normalized by dividing these values by their degree of freedom to obtain the true mean square values. We have:

$$MS_B = \frac{SS_B}{k-1} \text{ and } MS_W = \frac{SS_W}{n-k}$$

We use these mean squares to compute the F test statistic as follows:

$$F = \frac{MS_B}{MS_W}$$

Using an ANOVA allows us to test for statistically significant differences among multiple groups while holding significant level constant. However, to determine which of dwelling types differ, we must conduct a post hoc test. A post hoc (after the fact) test is performed after we find a significant F test, or overall difference among means. The post hoc test is a second level of analysis that allows us to test for differences between pairs of conditions.

The idea underlying post hoc test is to perform tests on each pair of groups, but to correct the level of significance for each test so that the overall type I error rate across all comparisons remains constant at a certain level such as α=0.05. There are many post hoc tests, which are based on different assumptions and designed for different purposes. In case of different group sizes and unequal variances, it is highly recommended to perform Games-Howell procedure (Mooi & Sarstedt, 2011).

The next step for performing ANOVA relates to measure the strength of the effects, which is impact of the factors on dependent variable. The ratio between-group variation to the total variation η^2 is used to measure effect size that can take values in the range of 0 to 1. High value of η^2 implies that the factor has high influence on dependent variable. However, this measure of effect size is slightly biased because it is based purely on sums of squares from the sample and no adjustment is made for the fact that we're trying to estimate the effect size in the population. Therefore, we often use a slightly more complex measure called omega squared (ω^2) (Field, 2009). It is suggested that ω^2 of 0.01, 0.06 and 0.14 represent small, medium and large effects respectively. Formula for calculation of ω^2 is as follow:

$$\omega^2 = \frac{SS_B - (dfM)MS_W}{SS_T + MS_w}$$

3.2.5 Energy System Modeling

MARKAL is a multi-time period model of the national energy system that allows technology and policy options to be analyzed in a consistent manner (Fishbone, Giesen, Goldstein, Hymmen, Stocks, & Vos, 1983). MARKAL provides a representation of the energy system by means of a Reference Energy System (RES) that tracks energy flows from primary sources through transformation, transmission and distribution processes until used in demand devices that provide the ultimate energy services required by consumers. In this research, in order to have detailed modeling of HCMC energy system, a sub system for the household sector of the City was built. This allows modeler examine thoroughly impacts of energy efficiency options in the sector. The subsystem may include disaggregated service demands of household sectors of the city as well as a number of alternative technologies.

MARKAL is a demand driven model (Fishbone & Abilock, 1981). The useful energy categories in MARKAL are chosen so that competing devices provide the same energy service. MARKAL is a linear programming model that represents the energy system by a large set of equations that governs system operation according to the technologies and data input (Kleemann & Wilde, 1990). The objective of MARKAL is to optimize a chosen objective function subject to meeting all system constraints that are defined. A variety of such objectives are available within MARKAL but the one normally used is the minimum of total system discounted cost. The MARKAL solution is obtained by using a linear programming optimizer (or other optimizer depending on different variants of MARKAL) that finds the minimum objective function value while simultaneously satisfying all constraints that have been defined. MARKAL is very strong on analyzing environment impacts and policies (Intelligent Energy Sytem, 2002). Different types of emissions can be defined and associated with each technology at the point of release. Limitations can also be placed on the level of emissions on either an annual or cumulative basis. Environmental tax can be applied to achieve predetermined emission targets.

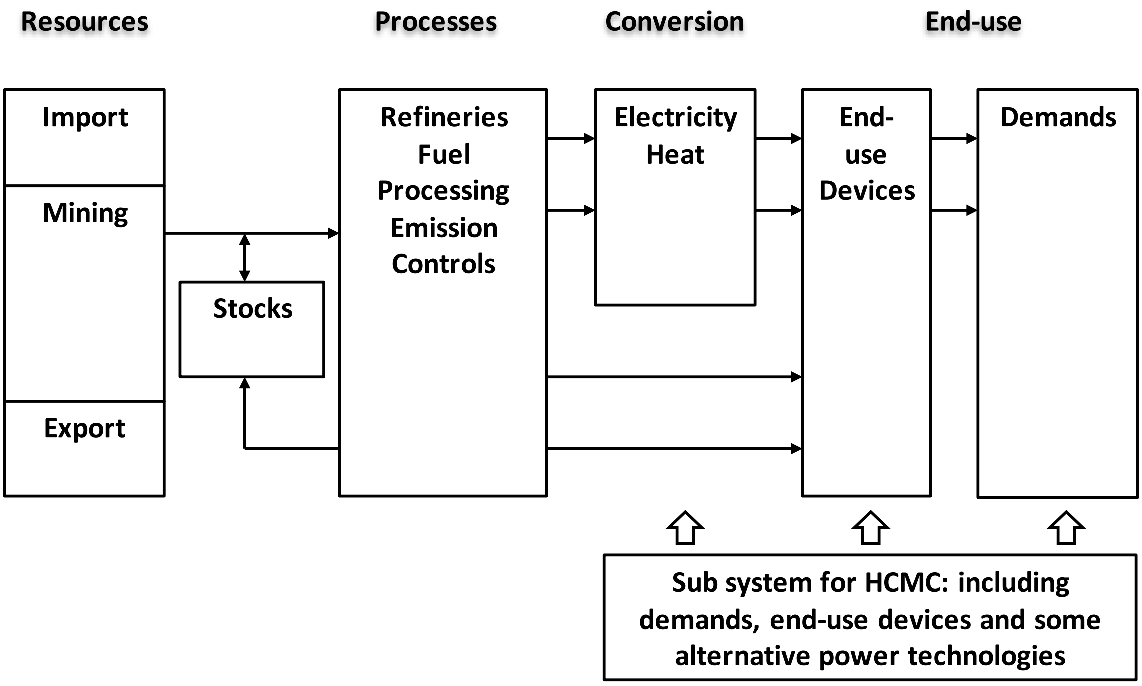

Figure 3-6: Simplified reference energy system in MARKAL

Energy demand forecast in household can be made based on two methods: engineering and econometric (Larsen & Nesbakken, 2004). Due to the importance of service demand projection in a demand-driven model, service demand in household sector of HCMC will be classified based on different purpose of use such as: lighting (lumen hour), cooking (PJ, useful energy demands are derived from energy use and devices' efficiencies), space cooling, refrigerator, water heating, television (all in quantity of appliances), etc… These demands for the base year 2010 (based on current stock) will be calculated from the household survey and then projected up to 2030. With the above features, outputs from the model possibly are: system cost, resource use, fuel mix, equipment capacity mix, emission levels, tax/subsidy levels, and others. Outputs from different scenarios suggest selecting right technologies, making plans, and proposing policy measures for developing a low-carbon economy for the City.

Chapter 4. Index Decomposition Analysis of Energy Consumption in Households

4.1 Introduction

A study for household energy in China and India pointed out that the most important drivers of the household energy transition are income, urbanization, energy access, and energy prices (Pachauri & Jiang, 2008). As a developing country with a development orientation of industrialization, Vietnam is now facing a number of severe issues in developing its energy sector to satisfy the increased demand. The most important challenges are limited domestic resources, rational energy price scheme and inefficient use of energy. These issues are strong motivations to gain in-depth understanding in energy and electricity consumptions in Vietnam. So far few studies in Vietnam have paid attention for energy consumption by households due to lack of data as well as inadequate assessment of the sector’s role. As the second largest electricity consumer and main contributor to the evening peak of power system, understanding energy consumption pattern in households helps suggest appropriate policy measures to overcome the mentioned above challenges.

Introduced at the end of the 1970s, index decomposition analysis (IDA) methods have been developed and applied in various different areas. Its application in energy sector helps remarkably understand the determinants of changes in energy consumptions as well as emissions. Due to its simplicity but strength in analyzing, the method has been used as main analytical tool for formulation of energy and environmental policies. It has been applied extensively to understand historical changes in energy and emission by exploring the driving forces or determinants underlying the changes. IDA uses aggregate data at the sector level to decompose the changes in main variable into determinants such as intensity, structural, fuel mix effects (Hoekstra & Van den Bergh, 2003). IDA consists of two mainstreams such as methods linked to Divisia and Laspeyres indices (Ang, Decomposition analysis for policy making in energy: which is the preferred method?, 2004). Fatherly, decomposition can be performed multiplicatively or additively. The former represents the rate of change while the later the difference of change of an aggregate.

The purpose of this part is to (1) understand fuel mix of households in HCMC; (2) analysis determinants for variations of energy consumption; and (3) find out what data needed for household questionnaire survey. We analyzed changes in energy consumption of households in HCMC and Vietnam during 2002-2010. We used data from the household living standard surveys by General Statistical Office of Vietnam. To the best of our knowledge, this is the first attempt to employ index decomposition analysis to investigate energy consumption changes in residential sector of Vietnam.

4.2 Data Sources and Analytic Method

4.2.1 Data Sources and Preparation

To analyze the variations of household energy and electricity consumptions of Vietnam, we used data obtained from five Vietnam Household Living Standard Survey (VHLSS). These were carried out by General Statistical Office, which had been biannually repeated to get understanding of living standard changes in household sector of Vietnam. The questionnaire surveys cover some 9889 households in 64 provinces in Vietnam, in which some of households were repeatedly interviewed in all five surveys.

Data used for the analysis in the paper were divided into primary and secondary data. The primary data were derived from the raw data on household demography, income, expenditure and energy bills of the surveys, and then summarized by provincial average values accounting for urban and rural areas. The secondary data, which are physic amounts of energy consumption by households (i.e. kWh, kg, MJ, l etc…) were obtained with the aid from additional data on energy prices in the past.

Table 4-1: Type and sources of data

Type of data	Description	Data sources
Primary	Demography Total income and expenditure Energy bills and expenditures (for electricity, coal and fired-wood, LPG, kerosene, gasoline and agricultural residues)	(General Statistical Office, 2002) (General Statistical Office, 2004) (General Statistical Office, 2006) (General Statistical Office, 2008) (General Statistical Office, 2010)
Energy prices	Average retailed energy prices in the past years	Collected from many sources, mainly in news and media
Secondary	Energy consumption amount in physical units	Calculated by the author based on the above sources

In Vietnam, electricity tariff has been applying uniformly for the whole country. Different electricity tariffs, which were used for calculation of energy consumption, were taken from different points of time in these past years. Petroleum products prices (i.e. gasoline and kerosene) had been also set uniformly throughout the country. These oil products' prices could change several times during a year depending on the world oil prices. We applied different prices of the oil products based on time of interview (i.e. month of the years). LPG prices had been set by major importers and retailers throughout the countries. LPG prices therefore were collected from quoted prices by the retailers during the past years. Other fuel prices such as coal, fired wood and agricultural residues were in fact different geographically due to their characteristics, availability, distribution system and consumers' preference. However, due to lack of detailed data, the average annual uniform prices of coal, firewood and agricultural residues were assumed for every provinces and sectors.

The physical amounts of energy consumed in households were calculated based on the below formula:

$$E_{it} = \frac{Ex_{it}}{P_{it}}$$

In which:

E_{it}: energy consumption amount for energy type i in year t

Ex_{it}: expenditure on energy type i in year t

P_{it}: price collected in different points of time for energy type i in year t (twelve monthly prices each year for electricity, gasoline, kerosene and LPG; one annual price for coal and firewood)

i: index for energy types (electricity, LPG, firewood, kerosene, gasoline)

t: index for year (2002, 2004, 2006, 2008 and 2010)

Summary on descriptive statistics of main variables form VHLSS surveys is presented in Section 10.1 in Appendix.

4.2.2 Method for Decomposition Analysis

Logarithmic Mean Divisia Index I (LMDI I) method was employed for decomposing energy consumption in households. LDMI I was recommended for general use due to its capability to perform perfect decomposition thanks to no unobserved residual term exists in the outputs (Ang, 2004). Moreover, the formula for decomposition takes a simple form that eases the use as well as the ease of result interpretation. Energy consumption in a household is represented in the following equation:

$$E = \sum_i E_i = \sum_i \frac{E_i}{X_i}\frac{X_i}{X} X = \sum_i I_i S_i X$$

In which:

- E: monthly average household energy consumption, calculated as total monthly energy requirement for a household (MJ per household)
- E_i: monthly average consumption of energy type i, calculated as monthly energy requirement for each of five energy types: electricity, LPG, kerosene, gasoline, coal and agricultural residues (MJ per household)
- X_i: monthly average expenditure for energy type i, calculated as monthly household spending on each of five energy types: electricity, LPG, kerosene, gasoline, coal and agricultural residues (VND per household)
- X: monthly average energy expenditure, calculated as total household spending on energy products (VND per household)
- i: index for five energy types in household, such as electricity, LPG, kerosene, gasoline, coal and agricultural residues.

The formula therefore includes three components:

- Intensity: $I_i = \frac{E_i}{X_i}$ represents energy intensity for energy type i,
- Structure: $S_i = \frac{X_i}{X}$ represents the shares of expenditure for energy type i in total energy expenditure, and
- Activity: X represents total energy expenditure

Employing LMDI I technique (Ang, 2005), the variation in total energy consumption of a household between year t and year 0 can be decomposed as below:

$$E^t - E^0 = \Delta E_{total} = \Delta E_{intensity} + \Delta E_{structure} + \Delta E_{activity} + \Delta R$$

$$= \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0} \ln\left(\frac{I_i^T}{I_i^0}\right) + \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0} \ln\left(\frac{S_i^T}{S_i^0}\right) + \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0} \ln\left(\frac{X^t}{X^0}\right) + \Delta R$$

In the above equation, $E_{intensity}$ explains the variation in energy consumption in terms of variation in energy intensity (i.e. MJ/VND), $E_{structure}$ in terms of variation in expenditure share by different fuel type, $E_{activity}$ in terms of variation in total spending on energy products, and the residual term which is proved to take zero value in LDMI method. Proof of perfect decomposition is as follow:

$$E^t - E^0 = \Delta E_{total} = \Delta E_{intensity} + \Delta E_{structure} + \Delta E_{activity}$$

$$= \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0}\left[\ln\left(\frac{I_i^T}{I_i^0}\right) + \ln\left(\frac{S_i^T}{S_i^0}\right) + \ln\left(\frac{X^t}{X^0}\right)\right]$$

$$= \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0}\left[\ln\frac{I_i^T S_i^T X^T}{I_i^0 S_i^0 X^0}\right]$$

$$= \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0}\left[\ln\frac{E^T}{E^0}\right]$$

$$= \sum_i \left(E_i^T - E_i^0\right) = \Delta E_{total}$$

By applying IDA, effects underlying energy consumption changes could be investigated. In Vietnam, the use of LDMI in energy field has been rather limited due to the availability of energy consumption data, especially in residential sector.

4.3 Results

4.3.1 Fuel Mix

Fuels consumed in households include electricity, coal, LPG, kerosene, gasoline and agricultural residues (that mainly include firewood, straw and rice husk). Nowadays, electricity is being consumed in various types of appliances for modern life. Coal briquette is used for cooking and heating purposes while LPG for cooking and water heating, especially in the South regions. Kerosene is used for cooking and lighting purpose whereby no access to electricity or as back-up lighting equipment in case of blackout. Agricultural residues, which are by-product from farming activities in rural areas, are mainly burned for cooking. Gasoline is used for vehicles such as motorcycle and car. According to estimation from the living standard surveys, a household in HCMC consumed averagely 1509.4 MJ in 2002 and 1,866.9 MJ monthly in 2008. This increase in total energy consumption comes from electricity and gasoline. The results show a decrease in energy consumption between 2002 and 2004, significant increases in 2004 and 2008, and a small increase between 2008 and 2010.

Table 4-2: Monthly energy consumption for households of HCMC (MJ)

Energy type	2002	2004	2006	2008	2010
Electricity	583.1	568.5	684.6	736.2	740.2
LPG	287.2	238.6	250.7	288.1	275.8
Gasoline	510.7	508.2	590.8	753.2	795.4
Kerosene	78.3	61.2	30.7	19.3	9.4
Coal+Biomass	50.0	40.8	52.6	51.2	46.1
Total	**1,509.4**	**1,417.3**	**1,609.5**	**1,848.0**	**1,866.9**

Source: author’s calculation from results of living standard surveys

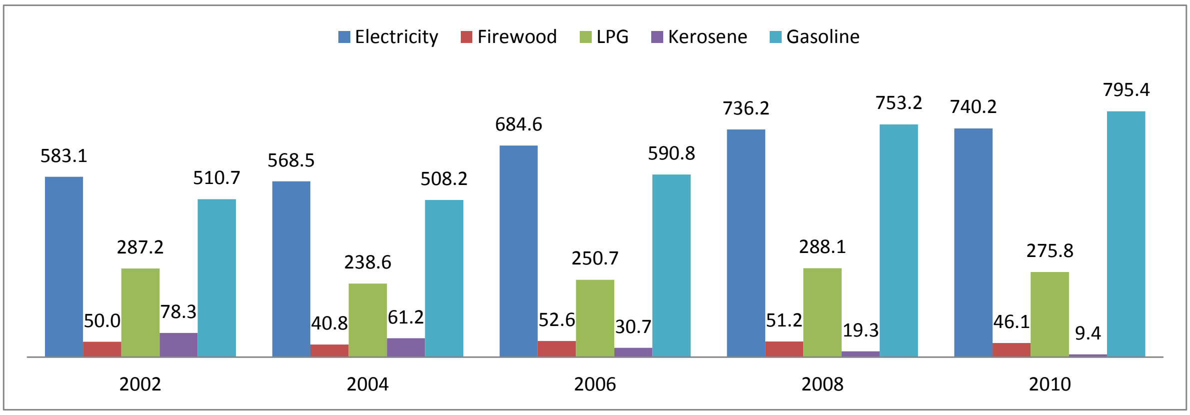

Figure 4-1: Monthly energy consumption for household of HCMC (MJ)

Table 4-3: Monthly nominal energy expenditure for household of HCMC (thousand VND)

Energy type	2002	2004	2006	2008	2010
Electricity	116.6	137.7	180.8	228.3	276.3
LPG	40.3	61.5	83.7	138.7	139.6
Gasoline	84.7	108.5	197.3	355.9	398.4
Kerosene	9.2	8.3	7.1	8.4	4.0
Coal+Biomass	3.3	3.3	4.9	5.5	6.1
Total	**254.1**	**319.2**	**473.8**	**736.7**	**824.5**

Electricity was the dominant source in total household energy consumption in HCMC. Its share almost remained the same during 2002-2010 which was some 40 percent. Average electricity consumption per household increased at 3 percent per annum. Electricity consumption changes were possibly influenced by changes in electricity tariff in 2008-2010. Due to the escalation in the world oil price, electricity tariff in Vietnam had been adjusted accordingly during this time.

Gasoline had increased quickly its share in total energy consumption, which rose from 34 percent in 2002 to 43 percent in 2010. Gasoline had the highest growth during 2002-2010, which was 5.69 percent per annum. Gasoline is the main fuel for private transport in the City due to the under-developed public transport system (only inner-city public bus, no metro and other mass transit systems).

LPG had almost remained the same physical amount during 2002-2010 which fluctuated below and above 280 MJ monthly. However, its share in total energy consumption declined from 19 percent in 2002 to 15 percent in 2010. In residential sector, there are other alternatives for cooking and water heating such as electricity, coal, firewood, and solar. People then easily switched to other energy types in case of remarkable increase in LPG price. In Vietnam, LPG is being distributed to households in gas cylinders instead of pipeline system. Large part of LPG use of Vietnam has been import from abroad, except one part is being processed in LPG plant in the South.

Firewood and other non-commercial energy types made up small share in the total, which were only 3 percent in 2002 and 2 percent in 2010. Kerosene had almost disappeared in total energy consumption in 2010. Its share was very small in 2010 indicating that few people now using kerosene for lighting and cooking. The past trend of fuel mix reveals that households in HCMC had changed significantly from non-commercial to modern and clean energy types during 2002-2010.

A quick check on rural and urban households shows that the most different on the fuel mixes are amount of firewood consumption. Households in rural districts of the City still consumed some non-commercial energy types for cooking. Urban households consumed more electricity (40 percent as compared to 30 percent in rural households).

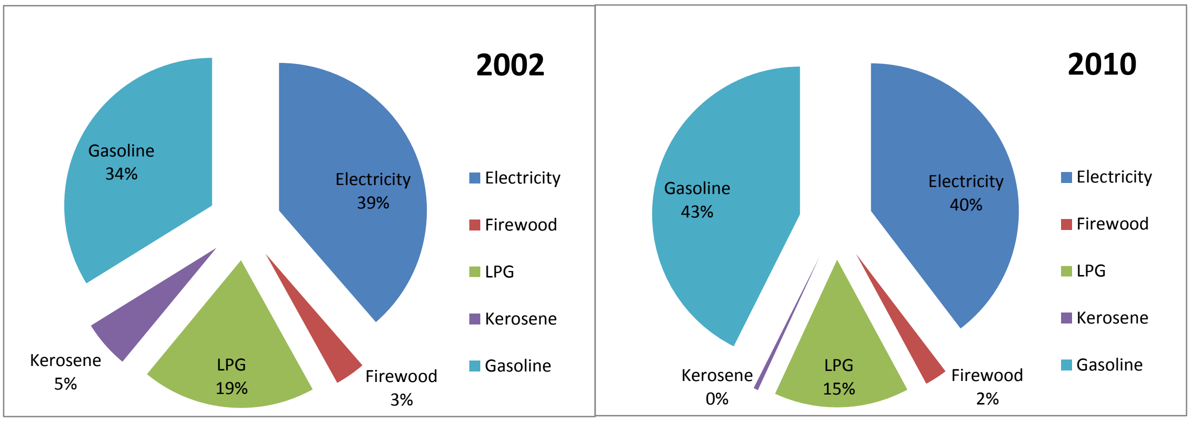

Figure 4-2: Fuel mix for household in Ho Chi Minh City in 2002 and 2010

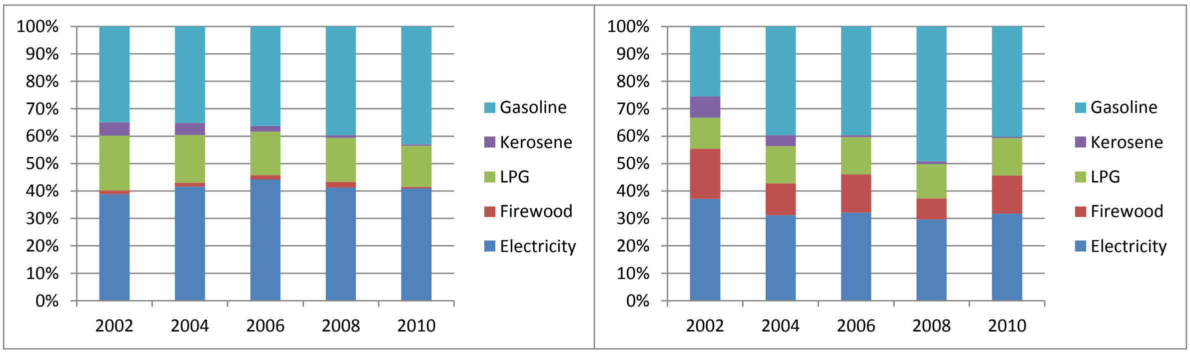

Figure 4-3: Fuel mix trend for urban (left) and rural households (right) of HCMC during 2002-2010

Consumption behavior of households in HCMC was much different from households of the country. Urban households in HCMC consumed typically gasoline, electricity and LPG (about 40, 40 and 20 percent respectively) with very small shares of firewood and kerosene. Rural households in HCMC still consumed some 10 percent of firewood. In contrary to household in HCMC, household in Vietnam consumed much agricultural residues (such as rice husk, straw, bagasse…), coal and firewood for cooking and water heating. The share of these kinds of energy accounted for 50 percent in 2002 and 35 percent in 2010. The shares had a declining trend in 2002-2010 with the replacements from oil, electricity and gas. During the same period, gasoline share rose significantly from 15 to 29 percent indicating an increased mobility demand of households. LPG share increased from 7 to 10 percent while electricity from 24 to 26 percent of total energy consumption.

Table 4-4: Monthly energy consumption for household in Vietnam (MJ)

Energy type	2002	2004	2006	2008	2010
Electricity	180.8	216.2	260.6	312.9	340.0
Firewood	372.5	326.5	324.8	370.9	451.9
LPG	51.7	64.9	71.8	84.4	127.2
Kerosene	26.2	19.2	9.5	5.8	6.8
Gasoline	113.3	163.9	184.7	241.7	378.5
Total	**744.3**	**790.7**	**851.5**	**1,015.6**	**1,304.5**

Source: author's calculation from results of living standard surveys

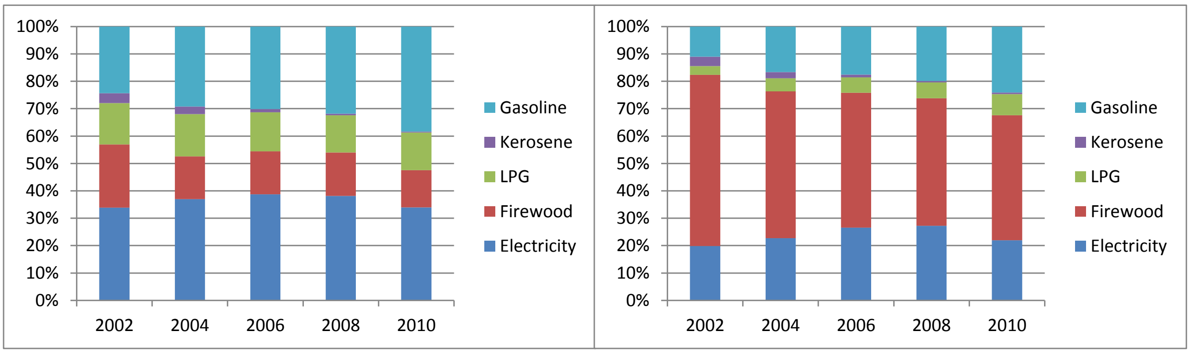

Figure 4-4: Fuel mix for urban (left) and rural households (right) in Vietnam during 2002-2010

Household fuel mix is different from urban to rural area by the amount of commercial and noncommercial energies. Households in urban areas consumed much more electricity, LPG and gasoline, while the ones in rural areas more fired wood and agricultural residues. Urban households consumed typically 40 percent from gasoline, 35 percent from electricity and more than 10 percent from LPG. Firewood share accounted for only 10 percent of total energy consumption in urban households. In contrary, in 2010, rural households consumed some 50 percent from firewood and other agricultural residues (almost 60 percent in 2002).

Electricity accounts for more than 20% in urban areas, which are especially high in HCMC (approximately 40%), Hanoi and big and developed cities in Central-South regions (i.e. Da Nang and Khanh Hoa). In rural areas, these share more or less 10% of the total energy consumption. Household in HCMC consumed averagely 234 kWh per month, while a household in Hanoi 216 kWh. Gasoline plays important role in urban areas. A household in HCMC consumed almost 40% of total energy consumption for mobility demand while this figure in Hanoi was more than 30%.

Fuel mix changes in 2002-2010 showed a significant increase in the share of gasoline and remarkable decrease in the share of coal and biomass. In 2010, gasoline contributed for the largest share in the total in almost regions. In 2002, coal and biomass accounted for more than 50 percent in almost regions except Red River Delta and Southern East. In 2010, share of biomass was highest in Northern West and lowest in Southern East (where HCMC located). The Southern East region featured with large shares of electricity, gasoline and LPG. Households in Southern East and Red River Delta consumed much more commercial energy as compared to other regions. The two regions are characterized with economic development, high urbanization rate and good infrastructure. In general, to some different extents, biomass and coal had been gradually replaced with LPG in all regions due to its healthiness and high efficiency as compared to coal and fired wood. Along with improved income, electricity and LPG shares had increased quickly over the period. The geographic variation in energy use patterns across households in different regions also suggests that climatic factors and local resource availability are of importance, which may also impact energy choices and use.

The fuel mixes in household sector represents the fact that, although living standard has been improved significantly in the last decade, households in rural areas is still relying much on noncommercial energy. Improving access to modern and affordable energy is necessary to improve living standard in these areas. Understanding the significant difference between fuel mixes of urban and rural areas in developing countries like Vietnam help design future strategies as well as appropriate tariff design to reduce regional inequalities.

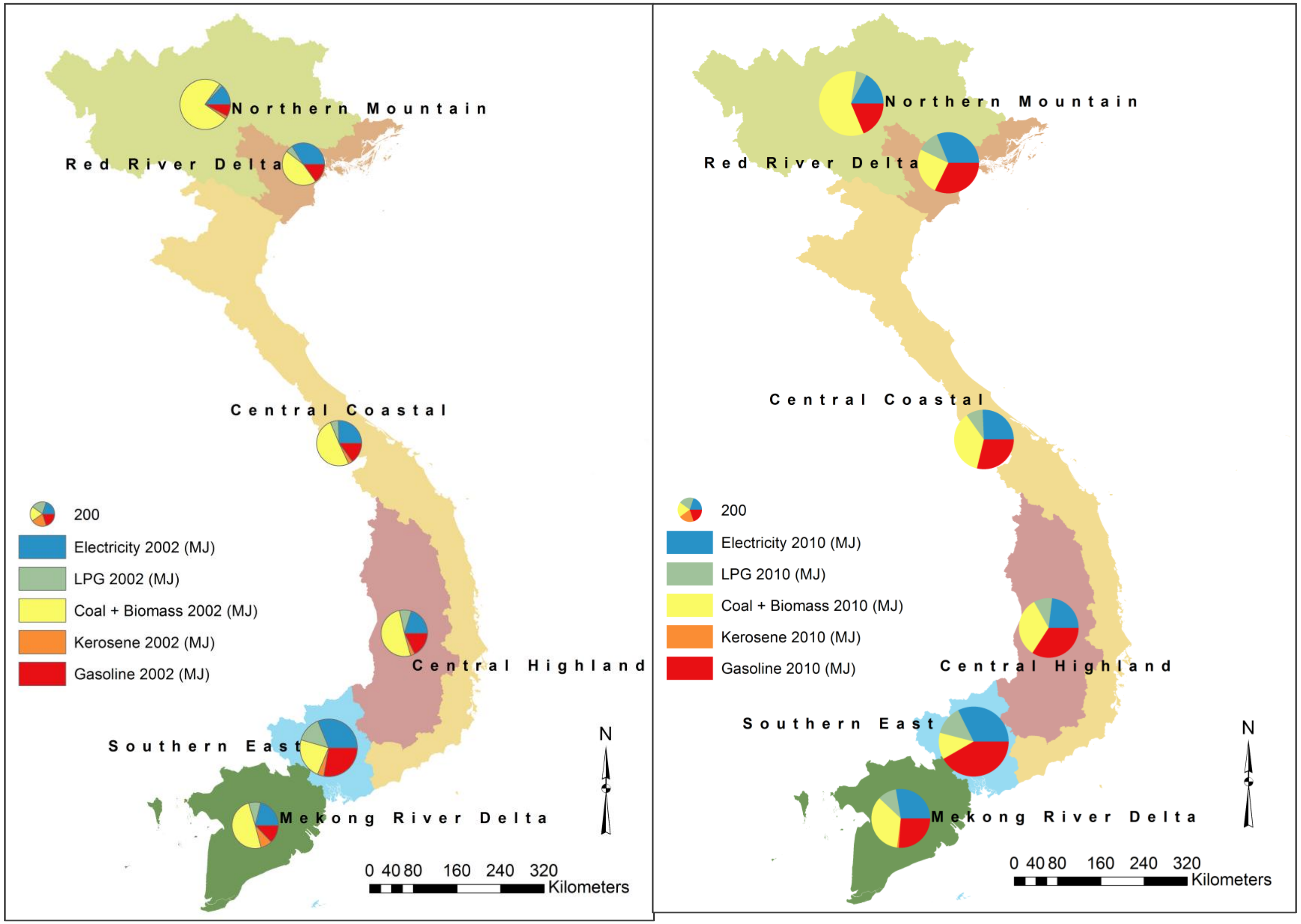

Figure 4-5: Fuel mix changes in households between 2002 (left) and 2010 (right) by region

4.3.2 Decomposition Analysis of Energy Consumption

Decomposition of variations in residential energy consumption by households in HCMC for the period 2002-2010 was carried out to find out main determinants for variations in energy consumption. Structure effect explains the increase in energy use due to changes in fuel mix when people switching among energy types. Intensity effect shows to what extent energy intensity influences energy consumption. Activity effect describes impact of spending activity on energy consumption. Results for IDA of energy consumption by household of HCMC are presented in Figure 4-6.

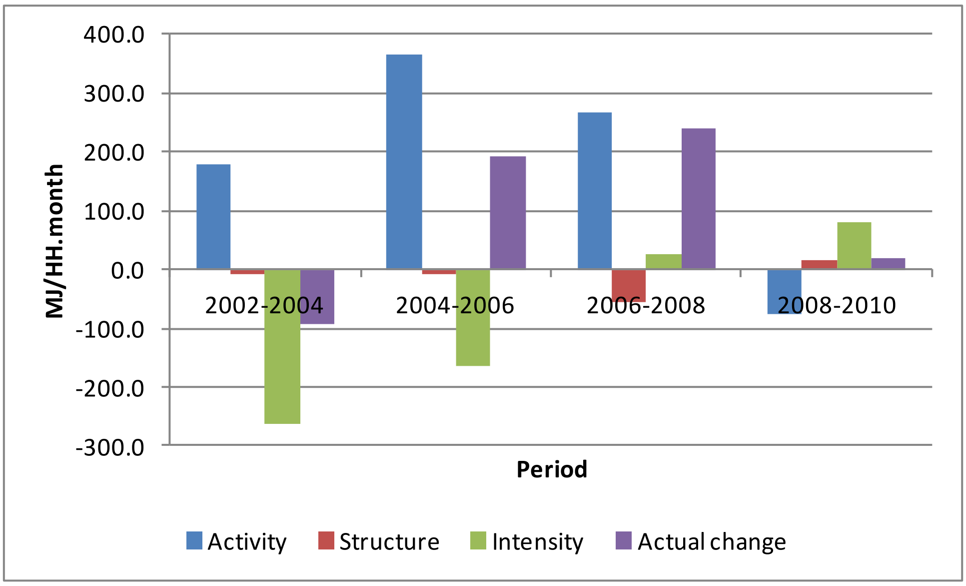

Figure 4-6: Decomposition of energy consumption for household in HCMC

Results for calculation of household energy consumption showed a decrease in energy consumption between 2002 and 2004, large increases between 2004 and 2008, and a small increase in the last period 2008 to 2010.

It is interesting to observe that there are two contrast periods during 2002-2010, the first period consists of 2002-2008 and the second 2008-2010. In the first period, activity effect was the main driver for energy increases. Activity effects were always positive during this time. Activity represents magnitude of energy expenditure by households and had obviously a strong relation to income. The higher the household income, the larger the expenditure is available for households to spend on goods and services. With the increased income during the time, households had improved budget for energy services to comfort their life. Nominal monthly income increased almost three times from VND 3.9 million in 2002 to VND 11 million in 2010. However due to country' high inflation rate, real income increased some 1.4 times in 2002-2010. Total household expenditure in the meantime had accounted for 70 to 80 percent of income. Households consequently were able to increase their spending power on energy services.

In the second period, activity effect however had a negative impact on energy consumption while intensity effect had a positive impact. Energy consumption increase between 2008 and 2010 mainly occurred through the increased intensity. Structure effect had negative impacts during 2002-2008 indicating that people switching from inefficient energy to efficient one. The switching led to changes in fuel mix and helped reduce total energy consumption. In the last period structure effect however had positive impact on energy consumption. Did people switch back to cheap and inefficient energy types from LGG and electricity? Checking variations of domestic energy prices may answer this question. Figure 4-7 presents past trends for energy consumption, prices and income of households in HCMC between 2002-2010. All monetary values were converted to the real value at 2000. Values in 2002 were normalized as one.

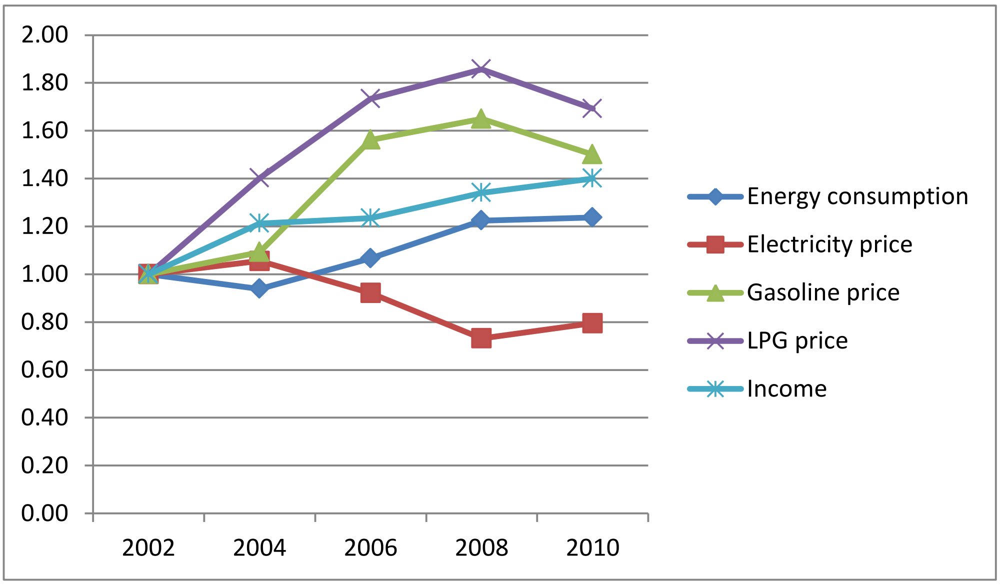

Figure 4-7: Past trends for energy consumption, prices and income of households in HCMC during 2002-2010

After the September 11th attack, fossil fuel prices increased sharply to its peak around August 2008, and then reduced thanks to the global economic recession. Electricity tariff in Vietnam however decreased in terms of real value during 2002-2008 due to the high inflation rate. Income kept increasing some 40 percent in 2002-2010, therefore, households were able to increase their spending power on energy products.

This first explains why energy consumption increase mainly through activity effect in 2002-2008 due to the increase in energy expenditure. Households paid more and more for energy products. Sharp increases in LPG price along with decreases in electricity price caused people switch partly from LPG to electricity. LPG in households had been used for two main purposes: cooking and water heating. Alternative energies for cooking are also electricity, coal briquette, kerosene, firewood, and other agricultural residues. While alternative for water heating are electricity and solar. This led to an increase in efficiency (electric cook stove is somehow more efficient than LPG stove), which can be observed through negative impact of structure effect on energy variation in 2002-2008. In the last period of 2008-2010, fossil fuel prices went down while electricity up. People therefore were able to switch back in short term to LPG from other fuel types. That's why activity effect had negative impact on energy consumption due to the decrease in energy expenditure. Structure effect in this period had positive impact on energy consumption thanks to energy efficiency reduction by the substituting electricity by LPG. Energy consumption consequently increased with the driving forces from intensity and structure effects.

Figure 4-8 presents results from decomposing energy consumption of households in Vietnam. It was a different story as compared to households in HCMC. Increases in energy consumption mainly occurred through activity effect. Intensity and structure effects had negative impacts on energy consumption (except period between 2006 and 2008, when intensity effect drove energy consumption increase). As mentioned in the analysis of fuel mix, households in Vietnam had been consuming significant amount of non-commercial energies. There was then a lot of room for other modern energies to replace non-commercial ones, especially in rural households where biomass energy accounts for nearly 50 percent of total energy consumption. The past trends show more and more people switch to LPG and electricity for cooking when income and living standard increased. This trend led to an increase in energy expenditure as well as a rise of energy efficiency. That explains why activity effect had positive impact while structure negative impact on energy consumption.

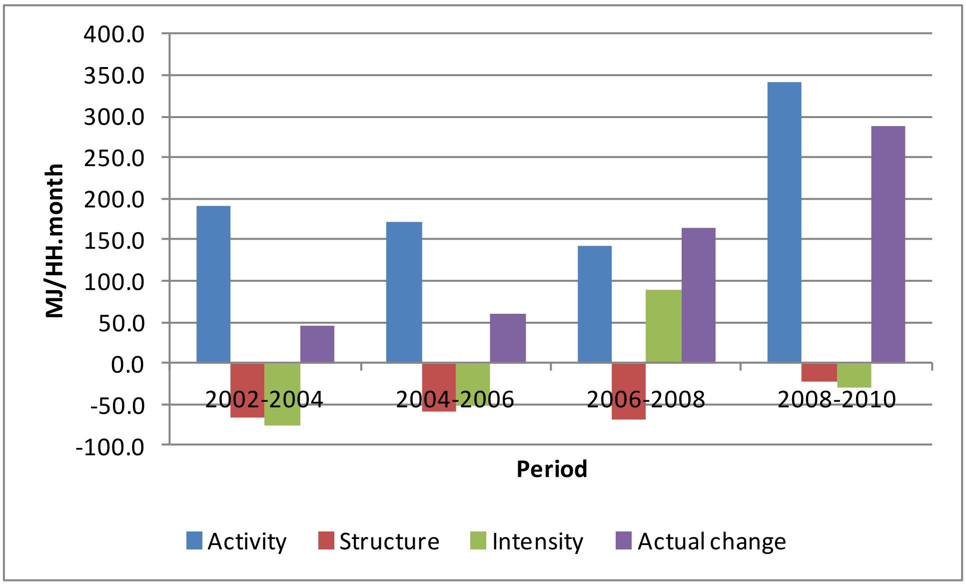

Figure 4-8: Decomposition of energy consumption for household of Vietnam

4.4 Findings

We investigated fuel mix and major factors underlying the variations in energy consumptions of households in HCMC and Vietnam. Firstly, fuel mix of households was derived from expenditure data on energy consumption. Secondly, based on data on consumption amounts by different energy types and their associated expenditures, we employed index decomposition analysis to decompose the variations of energy consumption between 2002 and 2010 into three effects. These effects are: activity, intensity, and structure. This has been the first attempt to calculate energy consumption and apply index decomposition analysis for households from the living standard data in Vietnam.

Fuel mixes for households in HCMC between 2002-1010 were characterized with large shares of electricity, gasoline and LPG. Kerosene and other biomass energies made up small parts of total energy consumption. The shares for electricity, gasoline and LPG for households in HCMC are some 40, 40 and 20 percent respectively. That contrasts with households in the rest of Vietnam, which still consumed much non-commercial energy for cooking. Fuel mix for households in HCMC did not change much during 2002-2010 thanks to the better living standard of households of the City as compared to other regions. Gasoline demand rose quickly in the meantime to meet increased transport demand.

In households of HCMC, activity effect was the main driver for energy consumption increases in 2002-2008 while intensity and structure effects had negative impacts on energy consumption of households in HCMC. However, in the period of 2008-2010, energy consumption increase was mainly drove by intensity effect. Variations of income and energy price were possibly main determinants for these changes of energy consumption. Checking the variations of prices and income helps explain the changing of role of these effects. Energy prices in Vietnam have been not yet deregulated, the Government still control directly or indirectly the prices of major energy products. Energy price scheme therefore should be reformed properly for the purpose of guaranteeing transparency and promoting efficient use.

In households in the rest of the country, during 2002-2010, activity effect was the main driving force for the increase in energy consumption. Structure effect, in contrary, had negative impacts on the increase. The structure effect indicates the fact that households in Vietnam had been changing gradually from non-commercial and inefficient energy types to commercial and modern ones. This change results in an increase in efficiency of energy end-uses leading to the reduction in total energy consumption.

The application of the decomposition analysis technique to the household energy consumption of HCMC and Vietnam provided adequate explanation for variations in energy consumption of the sector. Results from the analysis may suggest some policy implications in energy development. Firstly, authorities have to pay extra attention on energy consumption variations with the current trend of urbanization. Secondly, intensity and living area are two important factors underlying the increases in electricity consumption. This should be considered adequately in evaluating energy efficiency options as well as projecting future consumptions. Finally, rural electrification is essential to solve the problems of inequality that can be seen in the differences in the fuel mixes of urban and rural households.

Due to lack of consistent and detailed data in domestic energy consumption, few studies have been conducted for household energy consumption. Data from the living standard surveys, even though were no designed properly for energy consumption data, were useful to get initial insights on energy consumption of households. The surveys also brought important information and data on household characteristics, which allowed analysis the interaction between energy consumption and related factors such as income, expenditure, living area, household size etc… However, there is a need for an appropriate energy survey to get specific energy data for in-depth investigation of household energy consumption, especially in the linkages with other important aspects such as dwelling types in urban areas and appliance characteristics. The data from these surveys suggested the proper design for specific household energy survey for the PhD study. That’s the reasons and motivations for the PhD study to conduct a household energy survey in Ho Chi Minh City.

Chapter 5. Household Energy Demands: A Panel Data Analysis

5.1 Introduction

Vietnam is currently facing a severe electricity shortage, especially during hot summer. This is due to both delay in building new generating capacity as well as quickly increased demand for electricity. Electricity tariff improvement is also hot debate these days in Vietnam. Electricity tariff should be designed appropriately in such a way that high enough to attract investment in the power sector and meet the social equity purpose by giving subsidy to the poor. Tariff setting is also important instrument to promote energy efficiency and renewable energy options. This is a strong motivation for a study of elasticities for energy demands. We applied a panel data to investigate residential demand for electricity in relation to electricity price, household income, substitution price and other explanatory variables.

Energy efficiency improvement can be obtained through a range of activities including building legal framework, appropriate energy pricing, financial incentives, mandated regulation, voluntary agreements and setting standards. Energy efficiency is a means to conserve natural resources, reduce environmental degradation, and obviously save money (Reddy, Hasselmann, Assenza, & Assenza, 2010). The profit to consumers or producer of energy conservation through the reduced energy bill essentially comes down to a reduction of the energy service price. This reduction in energy service price leads to three kinds of effects (direct and indirect) on total energy use (Berkhout, Muskens, & Velthuijsen, 2000). Firstly, enjoying the reduction in energy service price, one may have propensity to use more appliance services; hence, part of energy conservation fades away. Secondly, reduced energy expenditure allows one purchase other services or commodities, which require energy to use or energy to provide. Thirdly, on economy-wide level, individual consumption behavior changes due to energy efficiency improvements may affect economy's structure of production or the economy's productivity, and consequently on aggregated energy demand. These effects are called as rebound effects (RE) in literature. The two former effects are direct effects, which can be decomposed into substitution and income effects while the latter is denoted as indirect effect or economy-wide effect (Greening, Greene, & Difiglio, 2000).

There is an ever-lasting interest in the economic analysis of energy demand and it is mainly due to societal concerns with respect to the environment, energy security, and energy price impacts on low income households and on industries. This type of information is particularly useful in energy demand forecasting and in the analysis of energy efficiency programs (Bernarda, Bolduc, & Yameogo, 2011). In the latest survey on electricity demand study (Dahl, 2011), from 1951 to the present, more than 450 of the studies include estimated demands for electricity with more than 5300 estimated equation on about 60 countries as well as studies on cross section time series of countries. Electricity demand analysis was started with three well-known classic studies: (Houthakker, 1951), (Fisher & Kaysen, 1962) and (Baxter & Rees, 1968). They employed static and dynamic models to estimate residential and industrial electricity demand using cross-section or time-series data in UK. Hundreds of studies on electricity demand elasticities have been done so far (Dahl, 2011). Values of elasticities are normally in the range of 0.32 to 0.95 indicating inelastic demand. Few studies estimated elasticity higher than unity, which show electricity demand is elastic. A number of applications of panel estimation for energy demand in households have been made recently. Using empirical panel analysis, based on electricity consumption, price, and income by households in different regions in Japan, elasticity was found elastic (Nakajima, 2010). In another hand, panel analysis was employed to estimate elasticities for residential demand for electricity by time-of-day (Filippini, 2011). This study used aggregate data at the city level for 22 Swiss cities for the period 2000−2006. The log-log demand functions were estimated using several econometric approaches for panel data. Moreover, random-effects model for panel data was used to estimate elasticity for electricity demand in Spain. Panel data was proved as a useful and simple instrument for estimating electricity demand with the incomplete data (Labandeiraa, Labeagac, & López-Otero, 2012). The first difference generalized method of moment estimator is employed to estimate elasticities of Japanese residential price electricity from 1990 to 2007. Short-run elasticities in the study were similar to those in previous studies, but long-run elasticities were significantly lower (Okajima & Okajima, 2013). Using aggregate panel data at the province level for 47 Spanish provinces for the period from 2000 to 2008. Dynamic partial adjustment approach was employed to estimate a log–log demand equation for electricity consumption. Results from this study show that particular attention has been paid to the influence of price, income, and weather conditions on electricity demand (Blázquez, Boogen, & Filippini, 2013). Another panel data application used fixed-effects model for estimation of elasticity for aggregate data of EU countries and US states. Residential electricity demand is found price-inelastic (Azevedo, Morgan, & Lave, 2011). In another study, a mixed panel/multi-year cross-sections of dwellings/households in the 50 largest metropolitan areas in the United States was used to estimate static and dynamic models of electricity and gas demand. Strong household response to energy prices, both in the short and long term were found (Alberini, Gans, & Velez-Lopez, 2011).

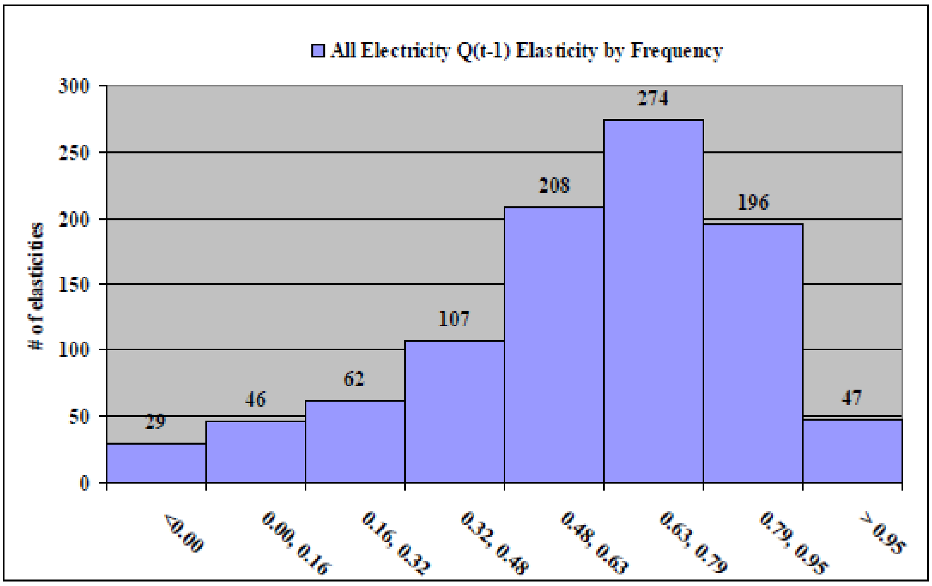

Figure 5-1: Distribution of elasticities by studies

Source: (Dahl, 2011)

In general, studies of electricity demand to present focused on the use of electricity prices (marginal, average, full-schedule), incorporating capital stock into demand equation and using different techniques for estimating elasticity. Data have been used for the studies are time-series, cross-sections and recently more with panel data. Data used for analysis elasticities can be micro level data, state, provincial or country aggregate data.

Analysis of demand for electricity has been done intensively around the world. However, to our best knowledge, estimation of elasticity of electricity demand has never been done so far in Vietnam. In case of aggregate electricity demand study, direct rebound effects are difficult to find out due to the complexity of household electric appliances. Studies on rebound effect in electricity demand should distinguish electricity use into small groups of end-use such as air-conditioner, refrigerator, and water heater and so on… However, based on current definition of rebound effects, study of elasticities of electricity demand is still interesting starting point to further investigate rebound effects. This part, therefore, is to answer the following questions: (1) building econometric models for household energy demands, including electricity, LPG and gasoline, (2) employing panel data analysis to estimate elasticities for these demands. It is worth noting that this is the first attempt to estimate the elasticities in Vietnam. The part of the PhD Study also contributes to literature an empirical evidence of elasticities for domestic energy demand, which is estimated by a panel data econometric analysis.

5.2 Energy Consumption in Residential Sector

5.2.1 Social Economic Development

Vietnam has experienced high economic growth rate after implementing “Doi moi” (Renovation) policy. Hanoi and HCMC are the two biggest cities of the country, which are located in Red River Delta and South-East regions respectively. Therefore, average income and electricity in the two regions were remarkably higher than in other region. The areas surrounding the two cities are two most dynamic regions for economic development.

Vietnam has high electrification rate of 99.6% and 96.8% of total household in urban and rural areas in 2008. Its population in 2009 was of 86 million persons with the growth rate during 2000-2009 was 1.15% per year. A large part of population lives in rural area, however, the urbanization rate has been increased significantly recently. Urban population share was 24% in 2000, 27% in 2005 and 30% in 2009. Economic development and living standard are much different by regions of the country. Income levels in big cities were obviously much higher than that in rural areas.

Vietnam is divided into 6 economic regions due to their different characteristics of geographic, weather, climate, demography and economic condition (Figure 5-2) . Brief overview on the regions is presented in Table 5-1.

Table 5-1: Overview of regions

Region	North Mountain	Red River Delta	Central Coastal	Central Highland	South-East	Mekong River Delta
Terrain	100-800m	0-4m with large delta areas	80% of total area are mountainous and plain along coastal line	100-800m, mainly highlands	Less than 50m, mainly plain	Largest delta area of the country
Raining level (mm/year)	1200-1800	1400-1800	1200-2000	1400-2000	1600-2000	1600-2000
Average temperature (^{o}C)	18-23	23-24	23-27	24-28	26.5-27.5	28
Sunny hours (hrs/year)	1400-2000	1400-1700	1500-2000	2000-2500	2400-3000	2200-2700

Source: (Institute of Energy, 2011), (General Statistics Office, 2010)

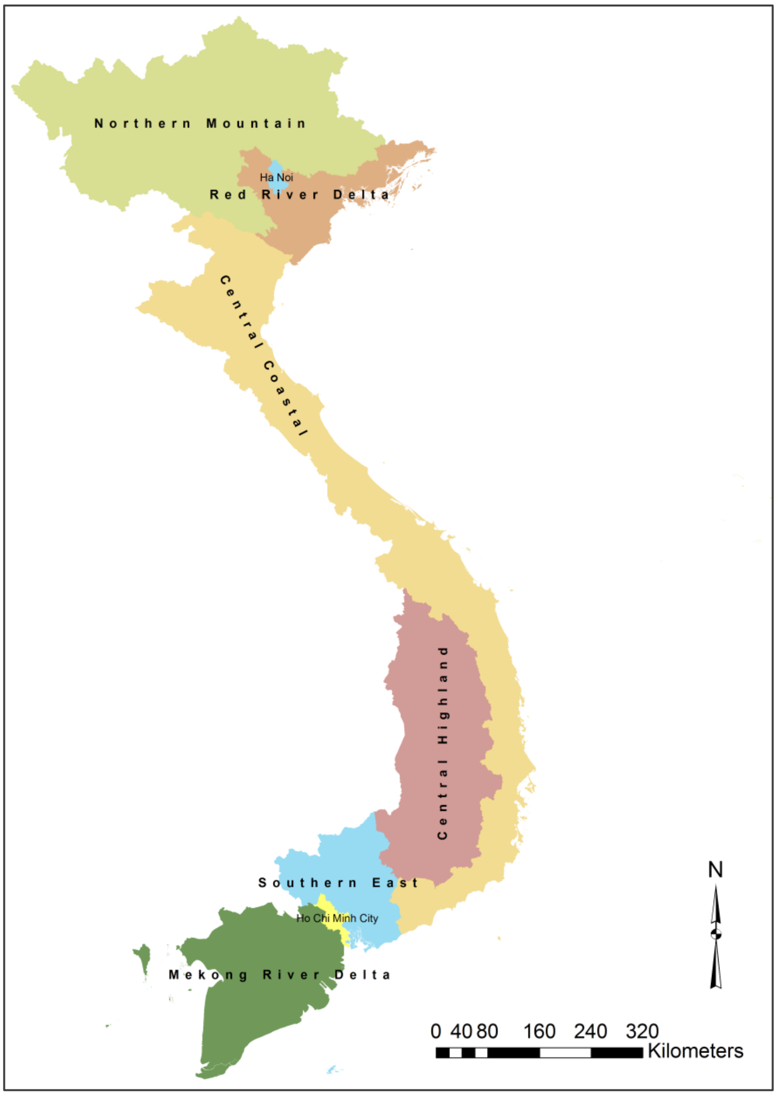

Figure 5-2: Six regions and two biggest Cities in Vietnam

Regions in Vietnam are characterized by different ecological features. Regions in the South of the country are located in the hot climate with greater average temperature and longer sunny hour per year. These differences obviously influence energy consumption behavior of people. Moreover, economic and development levels were also different significantly among regions.

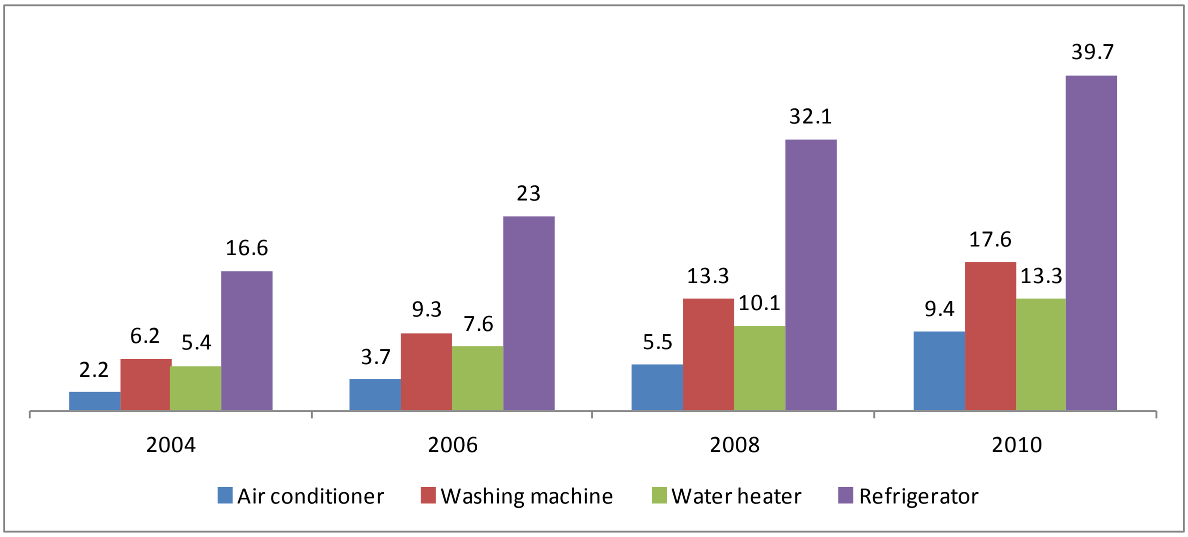

Figure 5-3: Quantity of major household appliances (pieces in 100 households)

Due to recent economic development, households' living standard has been improved much through increased income, more comfortable life, larger living area etc… Monthly income per person in nominal term increased more than 3.5 times in 2004-2008. Living area per person in 2008 was two times higher than that in 2000. Living area shows a linearity relationship with income during 2000-2008, especially in urban areas where rapid urbanization is taking place. Household appliance stock has been increased significantly with some main appliances reaching to saturation level in urban household. Quantities of household appliances have increased significantly in 2002-2010. Evolution of some household appliances is shown in Figure 5-3. Air-conditioner and electric water heater are two main electric consumers. Characterized by high temperature, regions in the South have larger quantity of air-conditioner while regions in the North larger quantity of water heater. It is expected that appliance stock in household keep increasing in the coming years.

5.2.2 Energy Consumption Pattern

In recent years, total electricity consumption by economic sectors has rapidly increased with average growth rate of 14.3% annually during 2000-2008, which increased from 25,800GWh in 2001 to 65,900GWh in 2008. In general, increase in electricity consumption was two times higher than that in GDP in the same period. In 2008, due to financial crisis impacts on the economy, electricity consumption reduced in the later months of the year

Residential share in total consumption has decreased from 48.9% in 2001 to 40.3% in 2008 while other sectors increased. The share for industrial sector has increased from 40.6% to 50.2% in the same period. Residential load is the main contributor to the evening peak for the system. Although residential share has decreased recently, the system is now still facing to the lack of peaking capacity, especially in dry season when availability of hydropower capacity is rather low. In recent years, EVN has promoted a number of Demand Side Management (DSM) programs with a focus on peak clipping (energy saving lighting, time-of-use meter, solar water heater etc…) in order to reduce investment in expensive peaking capacity. In general, the severe lack of generating capacity is caused by short-term and long-term reasons as follows: (1) delay in putting in operation of power facilities, (2) severe low water inflow into hydropower reservoir, (3) Inappropriate tariff scheme, (4) low progress on power sector reform and (6) inefficient implementation of energy efficiency programs.

Fuel mix, which was based on calculations in Chapter 4, shows that an urban household consumed monthly 1595.4 MJ and a rural household 1190 MJ in 2010. During 2002-2010, total energy consumption by an urban household increased at 5.92 percent per annum while rural household quicker at 7.56 percent. Fuel mixes were remarkably different from urban to rural households. The share for firewood in rural household, which included firewood and other biomass types, decreased from 62 percent in 2002 to 46 percent in 2010. This share was however still much larger than the share in urban household, which reduced from 23 percent to 14 percent during the same period. This period also observed the significant increase in gasoline share from 24 percent to 34 percent of total energy consumption in urban household. Electricity share remained the same of 34 percent in urban households.

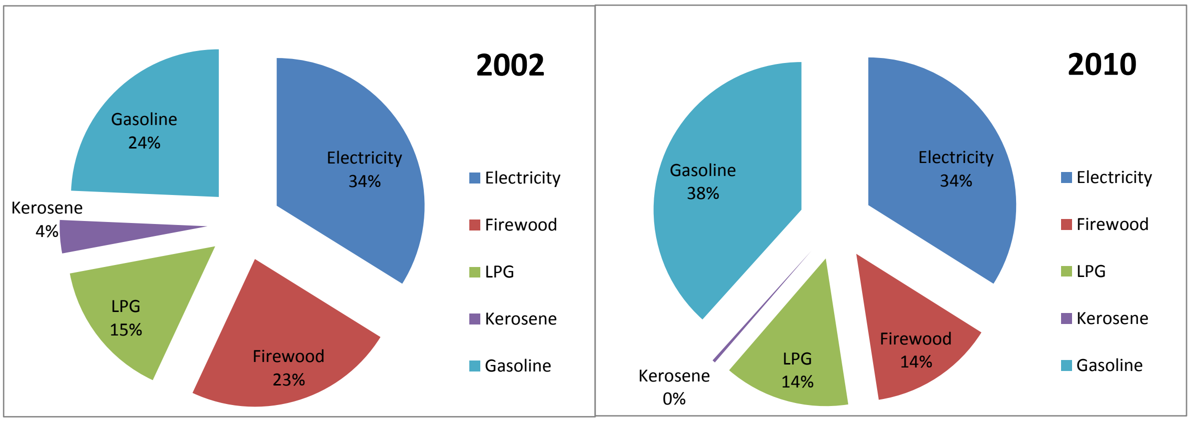

Figure 5-4: Fuel mix for urban household in Vietnam between 2002 and 2010

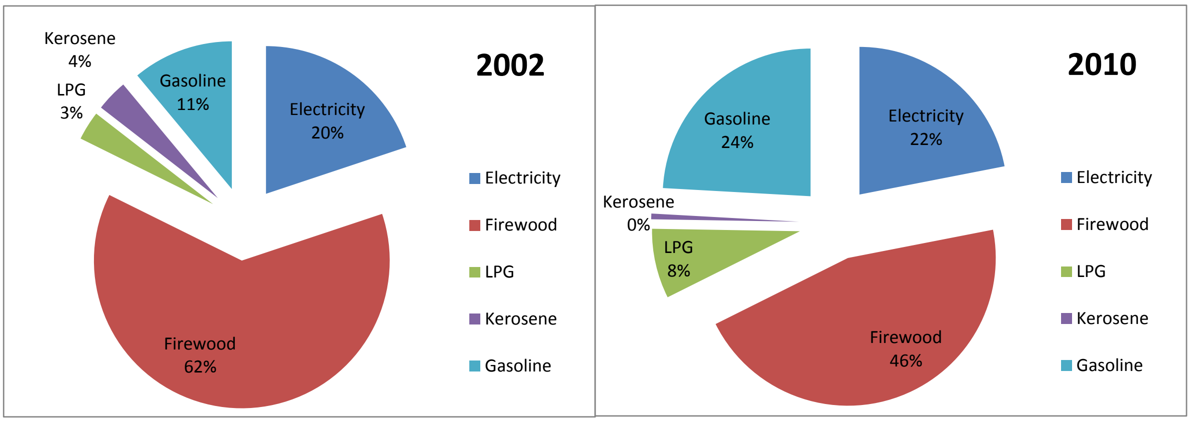

Figure 5-5: Fuel mix for rural household in Vietnam between 2002 and 2010

5.2.3 Electricity Consumption

In recent years, total electricity consumption by economic sectors has rapidly increased with average growth rate of 14.3% annually during 2000-2008, which increased from 25,800GWh in 2001 to 65,900GWh in 2008. In general, increase in electricity consumption was two times higher than that in GDP in the same period. In 2008, due to financial crisis impacts on the economy, electricity consumption was reduced in the last couple of months.

Residential share in total consumption has decreased from 48.9% in 2001 to 40.3% in 2008 while other sectors increased. The share for industrial sector has increased from 40.6% to 50.2% in the same period. Residential load is the main contributor to the evening peak for the system. Although residential share has decreased recently, the system is now still facing to the lack of peaking capacity, especially in dry season when availability of hydropower capacity is rather low.

Elasticity of electricity consumption with respect to GDP tends to increase in recent years. This trend may remain in future due to the development orientation toward to industrialization with the expansion of energy intensive industrial sectors like cement, steel, paper, chemical etc… The elasticity of the country was 2.23 times in 2001, decreased to 1.55 in 2005, but then increased to 2.03 in 2008. Changes in economic structure (increasing contribution from industrial sector to total GDP, i.e. 35.4% in 2001 to 41.6% in 2008) and low energy efficiency are two main reasons for this increasing trend. Therefore, energy efficiency improvement should be considered adequately in energy development in the country. In 2008, urban population was less than half of rural population (24 million persons in urban areas as compared to 62 million in rural areas, GSO 2008). However, electricity consumption by urban and its contribution to systems load curve was 1.5 times higher than that by rural. During peak period, the difference was reduced due to an increase in lighting use, the main purpose of use in rural areas. The higher load factor of urban areas indicates urban load curve was much flatter as compared to the one of rural.

The maps in Figure 5-6 represent geographically monthly average household electricity consumption by province in 2004, 2006 and 2008. Same scales of consumption levels are applied in all three maps to investigate the dynamic changes in household electricity consumption by provinces. Visual information conveyed by these maps reveals an interesting observation on electricity consumption. Hanoi in the North and HCMC in the South were the two cities with largest residential electricity consumption in all three years. Household electricity consumption had increased significantly in all provinces indicated by the darker red color in these maps. However, neighboring provinces, which are nearby these two big cities, had bigger increment in average household electricity consumption as compared to other provinces. This may be partly explained by two factors: (1) dynamic economic development by these two cities aided the development in these neighboring provinces and (2) these neighboring provinces enjoyed the well-developed infrastructure (i.e. power network) in the area surrounding these two countries. This indicates somewhat the spatial convergence of electricity consumption by households. Some provinces remained low levels of consumption are located in mountainous areas in the North or in Mekong River Delta in the South. They are the poorest provinces of the country.

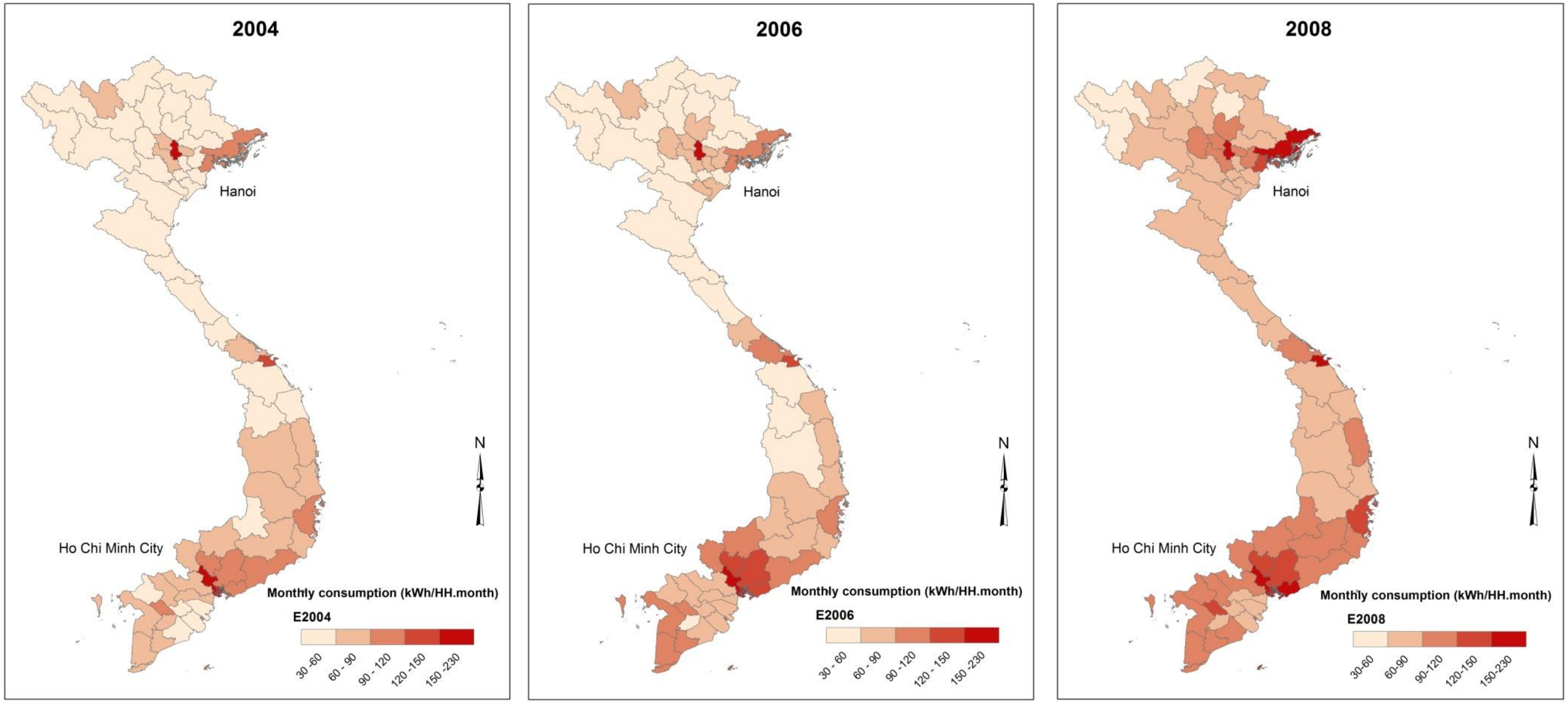

Figure 5-6: Variations of household electricity consumption by province in 2004, 2006 and 2008

5.2.4 LPG Consumption

Import license of petroleum product is controlled by the government, and eleven companies are at present authorized to import petroleum products. The sales amount of the company is evenly distributed among three sectors, which are direct sales to large industrial customers, wholesale to agents and retail marketing. There are about 80 companies and 5000 retail agents in LPG market in Vietnam. However, infrastructure, port, storage and transport vehicles have been developed in correspondingly and lack of overall planning. Retail price of LPG in Vietnam is based on market mechanism without Government's control. Retail price of LPG is decided based on investment size, corporate management and distribution cost for each company. However, distribution network has not been managed well enough leading to the disorder in retail market.

There is no currently LPG pipeline network to distribute LPG to end users. LPG in fact has been distributed to end-users in cylinders, which are in various sizes. Management of LPD cylinders has not been implemented appropriately. Quality control of cylinders, ownership of cylinders and responsibility of company in case of accident are real issues and challenges for the sustainable development of domestic LPG market. Some retail companies are collecting cylinders from many sources, but they are in fact appropriating other companies' cylinder. These cylinders then are distributed to the market with violations of safety standards. This phenomenon has been a great danger for LPG end-users due to safety and reliability of cylinders.

Management of LPG cylinder becomes the biggest issue in the domestic LPG market. Among 80 LPG companies, only 40 ones have registered for cylinder label. About 30% of total number of cylinders in the market is fake label. However, current sanction for this activity is not heavy and very small as compared to the profit. Government management of LPG cylinder is under Ministry of Finance (tax on cylinder), Ministry of Public Security (social security), Administration of Fire Preventing, and Administration of Intellectual Property etc... Management in the LPG market lacks of one ministry taking the lead. Ministry of Industry and Trade is compiling decree on management of LPG business with standard and label. Legal documents will help close and transparent control of LPG business.

LPG use has been increased significantly in households along with improved income, especially in cities, where it replace gradually other types of energy used for cooking and water heating. LPG has some advantages over other types of energy in households, such as price as compared to electricity, or cleanliness and human health impact as compared to coal briquette and kerosene.

5.2.5 Energy Prices

Energy prices in Vietnam are still under control of Government of Vietnam (GOV). The Government sets the tariff for electricity and other energy products based on changes in inflation rate, prices of inputs, taxation policy, environmental duties, etc… Among main fuel types used in households, briquette coal and LPG prices are set by suppliers and importers based on market mechanism.

Vietnam is currently importing oil products from abroad to meet its domestic demand. Its first oil refinery was put into operation in the latter 2009 with the capacity about 6 million tons of oil products. However, output from this first oil refinery, which uses the local light crude oil from off-shore fields in the South of the country, has fulfilled only one third country's total petroleum demand. The remainder is being imported from foreigner country. The prices of oil products, therefore, are significantly based on import prices. The Government of Vietnam controls the petroleum products' price by a number of instruments including import tax, special duties and environmental duties. The Government may relax them in case of sharp increase in world oil price to reduce domestic prices and vice versa. Oil products' retail prices in Vietnam are currently set by the following formula:

Retailed price = [CIF + Import tax + Special consumption tax] x Exchange rate + VAT + Petroleum fee + Price stabilization fund + Environmental duty + Distribution expenditure + Regulated return

Electricity tariff in Vietnam is complexly characterized by sector (agricultural, industrial, service, residential, and governmental), by time-of-use (peak, shoulder and off-peak), by voltage level (high, medium and low), by retail or bulk supply. Electricity residential tariff is inclining block tariff with a design of higher rate for higher consumption, which implies a lifeline rate for the social purpose. The application of such a tariff has been argued for (1) social purpose of giving subsidy to the poor and (2) limitation of electricity use when generating capacity is insufficient. Under the current tariff (applied from March 2011), the poor, who regularly consumes less than 50kWh per month, enjoy the low price of electricity, which is lower than average cost of supply by EVN. The residential electricity tariffs in the past years are as follows:

Table 5-2: Electricity tariffs in the past

Consumption level (kWh/HH.month)	Time of application				
	1/10/2002	1/1/2005	1/1/2007	1/3/2009	1/3/2010
First 50 kWh	550	550	550	600	600
51 - 100 kWh	550	550	550	865	1004
101 - 150 kWh	900	900	1110	1135	1214
151 - 200 kWh	1210	1210	1470	1495	1594
201 - 300 kWh	1340	1340	1600	1620	1722
301 - 400 kWh	1400	1400	1720	1740	1844
More than 400 kWh	1400	1400	1780	1790	1890

Sources: The Institute of Energy Economics Japan (2007) and Institute of Energy (2011a)

The current structure of electricity tariff is complex and not giving incentives to rational use of electricity due to existing cross-subsidy among different groups of consumer. Three kinds of cross-subsidy can be seen in the current electricity tariff: from service sector to industrial and agricultural sectors, from urban to rural areas, and among electricity distribution companies. Industrial sector has enjoyed low tariff due to the Government's development orientation towards industrialization. It was suggested that electricity tariff reform shall be properly implemented in accordance with the set schedule and, at the same time, social consideration to the poor is required under the increase their economic burden (The Institute of Energy Economics, Japan, 2007). Removing monopoly power and setting price transparently in energy sector has attracted largely public concerns in Vietnam nowadays.

5.3 Data and Model Specification

5.3.1 Data Sources and Preparation

To analyze elasticities of household electricity demand, we used data obtained from the Vietnam Household Living Standard Surveys (VHLSS). These were carried out by Vietnamese General Statistical Office and had been biannually repeated to get understanding of living standard changes in household sector of Vietnam. The questionnaire surveys covered some 9889 households in 64 provinces in Vietnam, in which some of households were repeatedly interviewed in all surveys.

From the micro data on households, average household income, electricity and other types of energy consumptions, and other related variables were summarized on provincial basis. This formed a panel data for 64 provinces in Vietnam for five years biannually from 2002 to 2010. Each province's urban or rural represents one cross-section unit. This panel data was then employed to perform an econometric analysis of household electricity and LPG demands.

Data used for the analysis in this part enjoyed estimations performed in Chapter 4, which calculated energy consumptions in households from expenditure data. As discussed in 4.2.1, in Vietnam, electricity tariff has been applying uniformly for the whole country. Different electricity tariffs used for the calculation were taken from different points of time in these past years. In case of gasoline, Government also regulates the retail prices for the whole country. LPG and gasoline prices are quoted from price changes in the past from some of major domestic supplier of LPG. All price and income data were converted to real terms of VND in the year 2000.

5.3.2 Model Specification

The use of panel data for econometric analysis has number of advantages as mentioned (Baltagi, 2005). Some of the most important benefits are: (1) controlling for heterogeneity by suggesting that individuals (cross sections units) are heterogeneous; (2) giving more informative data, more variability less co-linearity among variables, more degrees of freedom and more efficiency; (3) capturing better the dynamics of adjustment; (4) capability to identify and measure effects that are simply not detectable in pure cross-section or pure time-series data. Using panel data is necessary for studies of electricity demand like Vietnam. Due to the limited availability of data, a pure time-series data is not long enough to estimate reliably parameters. By decomposing electricity demand into provincial basis with its own characteristics on demography, level of social-economic development, one may carry out more accurate empirical econometric analysis. In general, household energy demand can be formulated as below:

$$E_{it} = f(P_{it}, Y_{it}, X_{it}, Z_{it})$$

Where E_{it} is monthly household energy consumption in province i at time t; P_{it} is the retail price of electricity paid by household; Y_{it} denotes monthly household income; X_{it} represents the price of substitute energy carriers (optional), and Z_{it} represents other related variables.

We built the model in double log form, based on the Cobb–Douglas type of demand function, for household electricity demand as follows:

$$\ln(E_{it}) = \beta_0 + \beta_1 \ln(P_{eit}) + \beta_2 \ln(Y_{it}) + \beta_3 \ln(X_{it}) + \beta_z \ln(Z_{it}) + \varepsilon_{it}$$

In the above equation, β_1, β_2, β_3, β_z are parameters to be estimated and ε is random error term. According to economic theory, the income elasticity and the cross-price elasticity for a substitute product (for example, LPG substitute for electricity in cooking need), are expected to be positive, while the own-price elasticity of this energy demand is expected to be negative.

Detailed variables included in the equation for electricity demand

$$\begin{aligned}\ln(E_{it}) &= \beta_0 + \beta_1 \ln(P_{Eit}) + \beta_2 \ln(Y_{it}) + \beta_3 \ln(P_{Lit}) + \beta_4 \ln(ER_{it}) \\ &+ \beta_5 \ln(DR_j) + \beta_6 \ln(DS_r) + \varepsilon_{it}\end{aligned}$$

i: province index; i=1 to 64

t: year index; t = 2002, 2004, 2006, 2008, 2010

E_{it}: average monthly electricity consumption by household in province i at year t (kWh/HH.month)

P_{Eit}: electricity price by household in province i at year t (VND/kWh)

Y_{it}: average monthly household income in province i at year t (VND/HH.month)

P_{Lit}: LPG price by household in province i at year t (VND/kg)

ER_{it}: electrification rate of province i at year t (fraction)

DR_j: dummy variables to classify provinces in to 8 regions including 6 regions plus two additional regions for the two megacities of Hanoi and Ho Chi Minh City

DS_r: dummy variables to classify each province into urban and rural sectors

Detailed variables included in the equation for LPG demand

$$\ln(L_{it}) = \beta_0 + \beta_1 \ln(P_{Lit}) + \beta_2 \ln(Y_{it}) + \beta_3 \ln\left(DR_j\right) + \beta_4 \ln(DS_r) + \varepsilon_{it}$$

i: province index; i=1 to 64

t: year index; t = 2002, 2004, 2006, 2008, 2010

L_{it}: average monthly LPG consumption by household in province i at year t (kg/HH.month)

P_{Lit}: LPG price by household in province i at year t (VND/kg)

Y_{it}: average monthly household income in province i at year t (VND/HH.month)

DR_j: dummy variables to classify provinces in to 8 regions including 6 regions plus two additional regions for the two megacities of Hanoi and Ho Chi Minh City

DS_r: dummy variables to classify each province into urban and rural sectors

The panel consists of 640 observes representing urban and rural sectors of 64 provinces in 5 years from 2002 to 2010. To control the regional and sectoral (urban and rural) differences, regional and sectoral dummies were added. Regional dummy variables were sorted from 1 to 8 representing Red River Delta, North Mountain, Central Coastal, Central Highland, South Eastern, Mekong River Delta, Ha Noi, and Ho Chi Minh City respectively. Sectoral dummy variables are 1 denoting urban and 2 rural. The presence of these dummy variables is necessary due to the significant difference in natural conditions and development level of the regions. Due to high development level, Ho Chi Minh City and Hanoi were separated into two regions.

All monetary variables in these equations were deflated to real term in the year 2000 by national CPI index. As discussed in Section 3.2.3 about models for estimating coefficients in these equations, fixed effects, random effects, and Hausman-Taylor estimators were employed using Stata software package. Classification of variables into endogenous and exogenous due to Hausman-Taylor estimator as follow:

- x_{1it}: exogenous variables that vary over time and individuals: electricity price, LPG price, electrification rate
- x_{2it}: endogenous variables that vary over time and individuals: income
- w_{1it}: time-invariant exogenous variables: regional dummies
- w_{2it}: time-invariant endogenous variables: sectoral dummies

The variable sectoral dummy, which distinguishes urban and rural households, is chosen as endogenous variable on the grounds that it will be correlated with household attributes such as appliance stock and consumption behavior. Income is obviously classified as endogenous based on its importance controlling households' activities and possibly correlated with the individual effects. Regional dummy variables were classified as exogenous thanks to their representation for natural conditions (i.e. temperature, rainy level, humidity, sunny hours) in the regions. Price variables are clearly classified as exogenous and assumed uncorrelated with the individual effects.

Table 5-3: Variable definitions and descriptive statistics

Variable	Unit	N	Mean	Stdard Deviation	Min	Max
Real income	VDN/month	640	2203.6	927.2	808.6	8987.3
Electricity consumption	kWh/month	640	79.34	36.91	4.25	271.29
LPG consumption	Kg/month	640	2.15	1.59	0.00	7.99
Real electricity price	Thousand VND/kWh	640	0.5	0.1	0.3	0.7
Real LPG price	Thousand VND/kg	640	10.0	2.0	5.8	12.4
Electrification rate	Fraction	640	0.94	0.13	0.03	1.00
Regional dummy	1-8	640	3.4	1.9	1.0	8.0
Sectoral dummy	1: urban; 2: rural	640	1.5	0.5	1.0	2.0

5.4 Empirical Results

This section presents the empirical evidence with the aim providing some insights into the electricity and LPG demands of households. The results for different estimators for electricity demand are presented in Table 5-4 and for LPG demand in Table 5-5. In the tables, firstly, values of coefficients for different variables included in the demand equations are estimated based on fixed-effects, random-effects and Hausman-Taylor estimators with values for associated t statistics in the parentheses. Coefficients for time-invariant variables cannot be estimated under the fixed-effects model. Secondly, results for Hausman test contrasting other models' estimates against the fixed-effects model are shown next. Finally, results for Breusch-Pagan Lagrange multiplier (LM) test to detect random effects are also presented. The null hypothesis in the LM test is that variance across provinces is zero. These LM tests in this part, which reject the null hypothesis, concluded that random effects are appropriate.

In the result of Hausman test contrasting fixed-effects and random-effects for electricity demand, here χ^2has p=0.000. This leads to strong rejection of the null hypothesis that random-effects provide consistent estimates. In contrary, the test result for Hausman-Taylor model, which χ^2has p=0.1211, did not reject the null hypothesis. The test is useful to test strict exogeneity of regressors used as instrument in Hausman-Taylor estimation. Once this second test has identified which regressors are strictly exogenous, they are then used as instruments in the Hausman-Taylor estimation (García-Mainar & Montuenga-Gómez, 2011). Coefficients estimated in Hausman-Taylor model therefore are consistent and more efficient.

Results for the electricity demand show that all coefficients have expected signs. Coefficients for income and LPG price have positive while coefficient for electricity price negative signs. Due to log-log form of the equation these coefficients are elasticities of income, own price and cross price for electricity demand. Hence, income elasticity for electricity demand is estimated at 0.470 indicating electricity demand may grow 47.0 percent in case of 100 percent increase in income. In contrary, the demand may fall 61.1 percent if electricity price would rise 100 percent. LPG price also have some impact on electricity demand. A double increase in LPG price may lead to 22.1 percent increase in electricity use due to some user switch to electricity for cooking or water heating. This indicates that there was possibly the substitution between the two energy types. People had switched to electricity in case LPG price rising. Electrification rate has coefficient of 0.481, it consequently has positive impact on electricity demand. Increase in electrification rate leads to increase in household electricity consumption. Coefficients for regions, which estimated by Hausman-Taylor model, are almost significantly except Central Highland and Mekong River Delta. Coefficients for Ho Chi Minh City and Hanoi are also highly significant. Electricity demands for rural and urban households are also different significantly.

Table 5-4: Elasticities for electricity demand

		Fixed-effects	Random-effects	Hausman-Taylor
Income		0.464***	0.619***	0.470***
		(-13.55)	(-18.73)	(-13.98)
Electricity price		-0.614***	-0.494***	-0.611***
		(-11.84)	(-8.65)	(-11.99)
LPG price		0.232***	0.128**	0.221***
		(-5.66)	(-2.93)	-5.49
Electrification rate		0.451***	0.610***	0.481***
		(-12.68)	(-17.78)	(-14.27)
North Mountain		.	0.139***	0.180**
		.	(-4.08)	(-2.99)
Central Coastal		.	0.138***	0.167**
		.	(-4.63)	(-3.169)
Central Highland		.	-0.031	-0.000174
		.	(-0.75)	(-0.00)
South Eastern		.	0.287***	0.382***
		.	(-6.51)	(-5.05)
Mekong River Delta		.	0.0509	0.104
		.	(-1.62)	(-1.92)
Ha Noi		.	0.578***	0.706***
		.	(-6.76)	(-4.71)
Ho Chi Minh City		.	0.509***	0.672***
		.	(-5.82)	(-4.45)
Rural		.	-0.363***	-0.615***
		.	(-14.17)	(-12.60)
Hausman test against the fixed-effects	Chi2	.	232.23	7.29
	Probability	.	0.0000	0.1211
Breusch-Pagan Lagrange multiplier (LM)	LM	.	125.84	.
	Probability	.	0.0000	.
N		640	640	640

*t statistics in parentheses; * p<0.05, ** p<0.01, *** p<0.001; Red River Delta and Urban coefficients are omitted in the equation*

In the result of Hausman test contrasting fixed-effects and random-effects for LPG demand, here χ^2has p=0.4682. This indicates that random-effects provide consistent estimates. The test result for Hausman-Taylor model, which χ^2has p=1.000, also did not reject the null hypothesis. This test once again confirms that regressors can be used as instruments in the Hausman-Taylor estimation. Comparing coefficients by Hausman-Taylor with ones by other models, the Hausman-Taylor estimation provides coefficients that are consistent and Coefficients estimated in Hausman-Taylor model therefore are consistent and more efficient.

The results for LPG demand also show statistical significances in major coefficients, such as income and LPG price. Income elasticity for LPG demand is little bit lower than that for electricity demand which is estimated at 0.452. Own price elasticity for LPG demand is estimated at -0.533 which is once again inelastic demand. Coefficients for regions, which estimated by Hausman-Taylor model, are almost significantly except Central Highland and Hanoi. Coefficient for Ho Chi Minh City is also highly significant. Estimation for electricity price (not shown, but available in another equation, which include electricity price as explanatory variable for LPG demand) shows no significant impact on LPG demand due to the limited options for people to switch to LPG in substituting to electricity (i.e. in service demands only served by electricity such as lighting, air conditioning, and other electric appliances).

Table 5-5: Elasticities for LPG demand

Variables / Model		Fixed-effects	Random-effects	Hausman-Taylor
Income		0.452***	0.486***	0.452***
		(-7.78)	(-9.73)	(-7.96)
LPG price		-0.533***	-0.549***	-0.533***
		(-9.12)	(-9.63)	(-9.32)
North Mountain		.	0.180***	0.178**
		.	(-3.71)	(-3.2)
Central Coastal		.	0.128**	0.125*
		.	(-2.63)	(-2.24)
Central Highland		.	0.111	0.11
		.	(-1.71)	(-1.47)
South Eastern		.	0.273***	0.278***
		.	(-4.23)	(-3.74)
Mekong River Delta		.	0.151**	0.154**
		.	(-3.07)	(-2.73)
Ha Noi		.	0.245*	0.252
		.	(-1.96)	(-1.76)
Ho Chi Minh City		.	0.321*	0.336*
		.	(-2.55)	(-2.32)
Rural		.	-0.153***	-0.0749
		.	(-4.83)	(-0.05)
Hausman test against the fixed-effects	Chi2	.	1.5200	0.0000
	Probability	.	0.4682	1.0000
Breusch-Pagan Lagrange multiplier (LM)	LM	.	6.43	.
	Probability	.	0.0056	.
N		629	629	629

*t statistics in parentheses; * p<0.05, ** p<0.01, *** p<0.001; Red River Delta and Urban coefficients are omitted in the equation*

Detailed results for panel estimations are stored in Section 10.2 in Appendix.

5.5 Conclusions

The aim of this part has been to extend the existing research on elasticity for energy demand in households. This has been carried out by providing empirical evidence by using panel approach with efficient estimation method. Hausman-Taylor estimator is used to estimate coefficients in the electricity and LPG demands with the use of appropriate instrumental variables. The study contribution is twofold. Firstly, in case of lack of long-term time-series data like in Vietnam, employing panel data is indispensable to perform a reliable empirical econometric analysis of energy demands. Using aggregate panel data for provinces increase remarkable degree of freedom; hence; strengthen the reliability of elasticity estimation. Using panel data on the provincial basis also helps take into account the heterogeneity of household electricity consumption in each province. This is also important factor in electricity consumption in particular and in energy consumption in general. Secondly, to the best of our knowledge, this has been the first attempt to estimate elasticity of household energy demand in Vietnam. Estimation of elasticity has been neglected in Vietnam despite the fact that the elasticity plays an important role in formulating energy policy price. The result of the study is in line with other results in literature. The demand equation took into account almost relevant explanatory variables for electricity demand such as own-price, substitution price, income, sectoral and regional dummies. Hausman-Taylor model should be used in the demand equations with regional and sectoral differences, which are time-invariant in panel data.

The panel data analysis showed expected signs of elasticities of electricity and LPG demands, two main energy types in households, with respect to its own-prices, income, and other variables. Elasticities for electric demand are -0.611, 0.470, and 0.221 with respect to electric price, household income and LPG price. Elasticities for LPG demand are -0.533 and 0.452 with respect to LPG price and household income. Own-price elasticities for both demands are less than unity indicating both products are inelastic demands. The estimation show also significant differences for different regions, including Ho Chi Minh City.

In the current context of energy price volatility, values of own-price and income elasticities are useful in formulating energy price policy as well as undertaking of energy demand forecast, which takes into account of price and income trends in future. Currently, the Government of Vietnam is under pressure of raising electricity tariff to attract more investment in the power sector and guarantee creditworthiness of the national electricity utility (i.e. Electricity of Vietnam). In contrary, there emerges also an increased public request for disclosure of energy price scheme and removing monopoly. These concerns relate to guaranteeing transparency, building competitiveness and promoting efficiency in energy sector. The analysis shows that households adjust their consumption following energy price changes. Future demand therefore may not increase as expected, so does the revenue from energy sale. Authority consequently should pay extra attention on the elasticity values when making decision to set energy tariffs.

Chapter 6. Analysis of Household Energy Use and Energy Efficiency Measures by Dwelling Type

6.1 Introduction

Concerns about reduction of greenhouse gases in fighting climate change impacts have led to a major international debate over effective what could and should be done. Reducing fossil fuel consumptions through energy efficiency activities have been proved as one of the most promising options as mentioned in The Fourth Assessment Report (AR4) of the Nobel Peace Prize-winning Intergovernmental Panel on Climate Change (IPCC). Bearing in mind the share of residential electricity consumption and the benefits of energy efficiency, this part of research focused strongly on households in HCMC and has the following objectives:

- Household fuel mix by dwelling type;
- Impact of dwelling type on energy use intensity and income on energy consumption;
- Appliance stock and utilization;
- Energy and electricity consumption by end-use; and
- Energy saving potential in households.

From results of previous parts of the PhD Study, the core work of this part related to analysis of data from the questionnaire survey, which was hoped to add necessary data for in-depth investigation of energy consumption and energy efficiency measures for different dwelling type in the City. The results from this part are expected to form a basis for household energy demand forecast and estimates of energy saving potential in future. Many studies have been paid attention on changes in energy consumption pattern, fuel mix and appliance stock. Few studies on energy use intensity in the linkage with dwelling type have been carried out so far. Difference of household energy consumption was found in different of urban forms in an Indonesian city (Permana, Perera, & Kumar, 2008). In another study, end-use energy consumption is modeled and calculated for different districts with different urban form. The goal of the study is to propose an approach to manage energy consumption (Yamaguchi, Shimoda, & Mizuno, 2007). For another point of view, household energy use was examined how much related to socio-economic, demographic characteristics, dwelling type in UK. The results from the study were expected to target energy efficiency measures for households (Druckman & Jackson, 2008). Associating options for energy saving and reducing GHGs with urban forms was examined for Utsunomiya City in Japan. The results show meaningful energy saving by applying proper technologies in different urban forms (Ishii, Tabushi, Toshiya, & Hanaki, 2010). Energy use in households was also examined in relations to occupancy and dwelling characteristics in UK. This study found a clear correlation was found between average annual electricity consumption and floor area (Yohanis, Mondol, Wright, & Norton, 2008). There is consequently a strong motivation to have knowledge on energy use intensity by different dwelling type in a dynamic growing city like HCMC.

To slow down or even reverse the trend in the electricity consumption of households many countries have introduced labeling programs and minimum energy performance standards for a selection of electrical appliances. Mandatory labeling of electrical appliances exists in 54 countries (World Energy Council, 2010). Energy labeling program was initiated in Vietnam in 2012 for some groups of energy consuming equipment in household, service and industrial sectors. For household appliance, voluntary labeling was encouraged to implement until end of 2012, and obligatory labeling from the beginning of 2013. Household appliances included in the program are:

- Fluorescent tube lamp;
- Compact fluorescent lamp;
- Magnetic and electronic ballast for fluorescent lamp;
- Air conditioner;
- Refrigerator;
- Washing machine;
- Electric rice cook;
- Electric fan; and
- Television.

Within the program, import and manufacture of inefficient appliances, which energy efficiency is lower than regulated minimum energy performance standard (MEPS), will be prohibited from First of January 2014. MEPS have been regulated in the series of Vietnamese standard for each of these household appliances. Energy performance is rated with five levels ranging from one star (the lowest efficiency) to five stars (the highest). The MEPS had been initiated since 2013; however, the progress of the labeling program is currently behind the schedule due to capacity of testing labs for energy consuming devices in Vietnam.

Table 6-1: MEPS for compact fluorescent lamp

Rated capacity (W)	Energy efficiency (lm/W)			
	Color temperature < 4,400 K		Color temperature >= 4,400 K	
	Lowest	Highest	Lowest	Highest
5-8	45	55	40	50
1-14	50	60	45	55
15-24	55	65	50	60
25-60	60	70	55	65

Table 6-2: MEPS for household air conditioner

Type	Nominal capacity f, kW (Btu/h)	Level				
		1	2	3	4	5
Window Type	-	2,6	2,8	3,0	3,2	3,4
Split Type	f < 4,5 (15000)	3,0	3,2	3,4	3,6	3,8
	4,5 (15000) < f < 7 (24000)	2,8	3,0	3,2	3,4	3,6
	7 (24000) < f < 14 (48000)	2,6	2,8	3,0	3,2	3,4

Table 6-3: MEPS for refrigerator

Type	MEPS
Refrigerator	$P_{max} \leq 0.037\ V + 16.75$
Freezer with volume less than 500l	$P_{max} \leq 0.025\ V + 29.45$
Freezer with volume greater than 500l	$P_{max} \leq 0.043\ V + 16.19$

P_{max}: maximum monthly electricity consumption (kWh)
V: adjusted volume (l)

6.2 Data and Methodology

6.2.1 Household Questionnaire Survey

Five dwelling types were investigated in the paper, they are: rudimental, shop house, row house, apartment and villa. These dwelling types are characterized by number of stories, wall material, purpose of use and access. Details for each dwelling type are as below:

Table 6-4: Definition of dwelling types in HCMC

Dwelling type	Rudimental	Shop house	Row house	Apartment	Villa
Number of stories	1-2	2-9	3-5	4-25	1-4
Wall material	Brick, wooden	Concrete, brick	Concrete, brick, glass	Concrete	Concrete, brick
Purpose of use	Residential and commercial (in case in front of street)	Residential and commercial (or totally commercial)	Residential only	Residential	Residential (some old colonial used for commercial purpose)
Access	Chanel, alley	Street, alley	Street	Street, garden	Street

Source: adapted from (Thinh, Hung, & Scharte, 2010) [1]

[1] The PhD study adapted the definitions of building types by grouping some subsets into one representing set. In the original source, shop house includes three types (traditional, new and commercial); apartment four types (colonial, social, low-rise and high-rise); and villa three types (colonial, individual and collective).

Data used by the paper were acquired by employing a questionnaire survey, which was randomly distributed by hand to 520 households in eight districts of HCMC. The interviewer directly helped household owner to answer the questions in the questionnaire form. The number questionnaire forms with completed information were 498 (some household were not responded and some not enough information for analysis). The questionnaire surveys were carried out during April to June 2011. Number of respondents by house type and districts are as follows:

Table 6-5: Number of respondents by dwelling type and district

Dwelling type	District							
	2	4	6	7	8	9	Binh Thanh	Thu Duc
Rudimental	17	1	26	22	16	0	26	6
Shop house	32	0	67	18	14	1	47	17
Row house	7	0	13	8	2	0	5	10
Apartment	3	0	28	11	29	0	10	1
Villa	37	0	5	7	1	2	3	6

Source: author’s survey

From the distribution of respondents, rudimental and shop house are located in six main districts of the survey. Row houses are mainly from Districts 6 and Thu Duc. Apartments were mainly taken from Districts 6 and 8, while villa mainly in District 2, which is one of new quarter of the City.

Due to the wide scope of data and information, the household survey employs a questionnaire form for interviewing work, which is designed specially to obtain required data. Therefore, the questionnaire form includes the main contents as follows:

- Household characteristics: name, address, population profile, profession, age, number of person, business activity etc…
- House characteristics: dwelling type, area, number of room, number of floor, building material, roof material, insulation method, shading method, number of window, etc…
- Energy consumption amount and purpose of use: electricity, coal, LPG, oil, biomass, biogas, solar, etc…
- Energy consuming appliances: lighting, cooking, water heating, space cooling, refrigerator, etc…
- Income, movement in the past, plan in future
- Attitude towards energy efficient use

Information on consumption of energy types, which are other than electricity, will be gathered through the survey. Moreover, electricity consumption data for each household are expected to be obtained directly from HCMC Power Company through customer codes from households. By purchasing electricity consumption data from the company, the accuracy of data was guaranteed. The electricity consumption data will include monthly consumption for one-year long. This data will serve to the examination of monthly change in electricity consumption of household sector as well.

Other energy consumption data were obtained based on information filled by the respondents. Energy for private transport was calculated based on gasoline/diesel consumption by households. Almost households are using liquefied petroleum gas (LPG) for cooking along with electricity, coal, and fired wood. We analyzed energy consumption and energy efficiency in relations to following aspects: dwelling type, income, demography characteristics; appliance stock and attitude towards energy efficiency activities.

6.2.2 Analysis of Variance for Electricity and Energy Use Intensities

In this part, Analysis of Variance (ANOVA) of energy and electricity use intensity in different dwelling types was employed to substantiate the impacts of dwelling types on energy consumption. ANOVA was developed by R. A. Fisher in the 1920s which is a significance test, using F distribution, to distinguish differences among different group means. Because the five levels of the categorical independent variable (i.e. dwelling type) involved different households, we used a one-way between groups ANOVA.

In this part, we focus on energy use intensity of households in different dwelling types. Hence dependent variables are electricity use intensity (kWh.m^{-2}) and energy use intensity (MJ.m^{-2}). Independent variables are dwelling type for which we want to compare the means of energy use intensity by different dwelling type.

Using an ANOVA allows us to test for statistically significant differences among multiple groups while holding significant level constant. However, to determine which of dwelling types differ, we must conduct a post hoc test. A post hoc (after the fact) test is performed after we find a significant F test, or overall difference among means. The post hoc test is a second level of analysis that allows us to test for differences between pairs of conditions.

The idea underlying post hoc test is to perform tests on each pair of groups, but to correct the level of significance for each test so that the overall type I error rate across all comparisons remains constant at a certain level such as α=0.05. We used Games-Howell post hoc test which is the most widely used in research. Violations of the assumption of homogeneity of variances can have serious consequences; especially group sizes are not equal. Due to randomness of the household survey, the sizes of different dwelling groups included in the paper are unequal. Shop houses accounts for almost 40% of total number of observations. When population variances are different and groups are of unequal sample sizes, the application of Welch test is generally recommended. After carrying out ANOVA, one may examine the effect size that represents how large the effect of categorical independent variable on the dependent variable.

6.3 Summary of Survey

6.3.1 Summary of Main items

After removing outliers, number of observation was of 461 households. Shop houses account for 39.7%, rudimental houses 22.8%, apartments 17.4%, villas 12.6%, and row houses 7.6%. Demographically, household size varies from 4.24 persons in rudimental houses to 5.14 persons in villas. The largest living area obviously belongs to villas with 167.45 m^2, in contrary, the smallest to rudimental houses with 47.08 m^2. Households in the survey consumed monthly 257 kWh, with the highest associated with villas (329kWh) and the lowest with rudimental houses (203kWh). In term of energy consumption, households consumed averagely 2,400 MJ per month. Villa again consumed the highest amount of energy, which was of 2,818.7 MJ. The total energy use was broken down into purposes of use (household or private transport) and energy types (electricity, coal, LPG, gasoline, and agricultural residues). Differences in total energy are mainly caused by variations in household energy. Transport energy uses show similar gasoline consumption amounts among the dwelling groups. This is due to the lack of adequate inner-city public transport system in the city. Households have mostly been used private vehicles (i.e. car and motorbike, and partly bicycle) for their mobility demand.

Table 6-6: Summary of main results from the questionnaire survey

Dwelling type	N	Number of person	Living area (m2)	Monthly income (1000VND)	Monthly electricity use (kWh/HH)	Electricity use intensity (kWh.m^{-2})	Monthly energy use (MJ/HH)	Energy use intensity (MJ.m^{-2})
Rudimental	105	4.24	47.08	8463.81	203.46	4.63	2028.51	26.33
Shop house	183	4.39	99.12	12470.80	273.21	3.41	2493.62	18.20
Row house	35	4.26	124.00	14442.86	278.09	2.40	2576.61	13.45
Apartment	80	4.65	61.03	9263.75	230.93	4.15	2294.41	22.74
Villa	58	5.14	167.45	17341.38	329.62	2.14	2818.70	11.27
Total	**461**	**4.48**	**91.14**	**11764.11**	**257.45**	**3.58**	**2400.32**	**19.61**

From correlation analysis, we can see that the correlation coefficients between income and electricity consumption is 0.438 and the p-value for two-tailed test of significant is less than 0.001. From these figures, there is positive correlation between household income and electricity consumption. The similar observations can be seen in pairs of income and household energy consumption, living area and household energy consumption, living area and electricity consumption. All these items are significantly correlated with each other.

6.3.2 Fuel Mix by Dwelling Type

Three main energy types in households are gasoline (42.46%), electricity (38.61%) and LPG (18.21%). Gasoline are mostly used for transport vehicles (i.e. car and motorbike), LPG for cooking and water heating, while electricity versatile purposes. The shares for the energy types are slightly different in different dwelling types. Electricity shares are highest in villas (42.10%) and lowest in rudimental houses (36.11%). Gasoline shares were highest in apartments (46.27) and lowest in villas (38.78%).

Table 6-7: Monthly energy use in households

Dwelling type	Total energy use (MJ)	By purpose		By energy type					
		Household energy use (MJ)	Transport energy use (MJ)	Electric energy use (MJ)	Coal energy use (MJ)	LPG energy use (MJ)	Kerosene energy use (MJ)	Gasoline energy use (MJ)	Agri. residues energy use (MJ)
Rudimental	2028.5	1131.8	896.7	732.4	13.9	363.6	10.3	896.7	11.5
Shop house	2493.6	1445.2	1048.4	983.5	2.6	450.7	5.5	1048.4	2.8
Row house	2576.6	1563.0	1013.6	1001.1	0.0	560.9	1.0	1013.6	0.0
Apartment	2294.4	1232.8	1061.7	831.3	0.0	387.0	13.1	1061.7	1.3
Villa	2818.7	1725.6	1093.1	1186.6	0.0	521.5	17.5	1093.1	0.0
Total	**2400.3**	**1381.2**	**1019.1**	**926.8**	**4.2**	**437.1**	**9.1**	**1019.1**	**3.9**

Coal and agricultural residues, which are mainly fuel for low income class (probably rudimental houses and partly apartments), have been used in some rudimental and shop houses. Kerosene has been used in all dwelling types for the purpose of back-up lighting equipment in case of black-out or other special purpose (praying kerosene lamp).

LPG is the main fuel for cooking and water heating in households. Due to the hot weather of the city area, most of households have been using LPG water heater instead of electric water heater, which has large water storage tank. Some households included in the survey have been installing solar water heater, especially after recent increases in electricity tariff. Electricity is used for versatile purposes from lighting, cooling, cooking, water heating etc…

The fuel mix derived from the questionnaire survey is a little bit different from fuel mix derived from the living standard survey in Chapter 4. The most difference is LPG share. LPG share here was larger while electricity one smaller. There are two reasons for the difference. Firstly, the questionnaire mainly focuses on households in urban districts of the City. Secondly, the questionnaire was carried out one year later than the living standard survey (2011 versus 2010 for the last living standard survey). Data from the questionnaire survey allows one to characterize energy consumption by different dwelling type.

Summary on descriptive statistics of main variables is presented in Section 10.4 in Appendix.

6.4 ANOVA of Energy Use Intensities, Income and Appliance Stock

6.4.1 Analysis of Electricity Use Intensity by Dwelling Type

There are highly statistically significant differences between dwelling types $F(4, 456) = 21.24$, $p < 0.001$, $\omega^2=0.15$. Therefore, electricity use intensities are basically significantly different among dwelling groups at 5% significant level. Some pair comparisons show significant difference at 0.1%. Two insignificant differences can be observed in the pairs of (1) rudimental and apartment and (2) row house and villa. The effect size $\omega^2 > 0.14$ represents a large effect of dwelling type on electricity consumption.

Table 6-8: Pair comparison for electricity use intensity by dwelling type

Dwelling type	Rudimental	Shop house	Row house	Apartment	Villa
Rudimental		***	***		***
Shop house	***		**	**	***
Row house	***	**		***	
Apartment		**	***		***
Villa	***	*		***	

* represents significant at 10% level, ** at 5% level and *** at 1% level

6.4.2 Analysis of Energy Use Intensity by Dwelling Type

There are highly statistically significant differences between dwelling types $F(4, 456) = 27.34$, $p < 0.001$. Therefore, energy use intensities are basically significantly different among dwelling groups at 5% significant level. Row houses and shop house are different in energy use intensity at 10% significant level. Again, two insignificant differences can be observed in the pairs of (1) rudimental and apartment and (2) row house and villa. The effect size $\omega^2 > 0.19$ represents a large effect of dwelling type on electricity consumption.

Table 6-9: Pair comparison for electricity use intensity by dwelling type

Dwelling type	Rudimental	Shop house	Row house	Apartment	Villa
Rudimental		***	***		***
Shop house	***		*	***	***
Row house	***	*		***	
Apartment		***	***		***
Villa	***	***		***	

* represents significant at 10% level, ** at 5% level and *** at 1% level

Based on ANOVA results, we concluded the significant differences in electricity and energy use intensities among all dwelling types. The intensities are almost different at 5%, and few at 10%. The only indifference has been found for the pairs of villa versus row houses and rudimental versus apartment. The significant differences found in energy use intensities among different dwelling types consolidate the use of intensity as basis for demand projections in taking to account of dwelling type in future. This is important factor for energy demand due to the dynamic changes between dwelling types in urban areas. Each of these dwelling types has their own characteristics on demography, building envelope, appliance stock etc… which decide proper energy efficiency measures needed.

6.4.3 Analysis of Electricity Consumption by Income

Households are classified into three different income groups namely low, medium and high to test income effect on total electricity and energy consumption. Average income levels are of VND 5.75 million, 10.2 million, and 20.5 million per month for low, medium and high income groups. Electricity and energy consumption amounts for these groups also increased along increased income.

Table 6-10: Descriptive statistics for different income groups

Income group	N	Monthly income (thousand VND)		Monthly electricity consumption (kWh)		Monthly household energy consumption (MJ)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Low	182	5,753.6	1,796.2	212.6	112.1	1,122.1	481.0
Medium	130	10,164.9	1,239.0	250.7	123.3	1,370.8	546.6
High	149	20,484.3	11,025.5	318.1	149.7	1,706.7	646.9
Total	**461**	**11,758.7**	**8,969.9**	**257.5**	**135.7**	**1,381.2**	**608.6**

ANOVA showed highly statistically significant differences between income groups $F(2, 460) = 27.834$, $p < 0.001$, $\omega^2=0.104$. Therefore, electricity consumptions are significantly different among income groups at 5% significant level. Post hoc test showed the significant for every pairs of these income groups. The effect size $\omega^2 > 0.104$ represents a medium effect of dwelling type on electricity consumption.

Table 6-11: Pair comparison for electricity consumption by income

Income group	Low	Medium	High
Low		***	***
Medium	***		***
High	***	***	

* represents significant at 10% level, ** at 5% level and *** at 1% level

6.4.4 Analysis of Energy Consumption by Income

There are highly statistically significant differences between income groups $F(2, 460) = 45.066$, $p < 0.001$, $\omega^2=0.16$. Therefore, energy consumptions are significantly different among income groups at 5% significant level. Post hoc test showed the significant for every pairs of these income groups. The effect size $\omega^2 > 0.16$ represents a large effect of dwelling type on electricity consumption.

Table 6-12: Pair comparison for energy consumption by income

Income group	Low	Medium	High
Low		***	***
Medium	***		***
High	***	***	

* represents significant at 10% level, ** at 5% level and *** at 1% level

6.4.5 Analysis of Electricity Use by Ownership of Air conditioner

Bearing in mind the importance of air conditioner in household electric load, the analysis checked the effect of owning air conditioner on electricity consumption. Households were classified into two groups: with and without air conditioner. Descriptive statistics for these groups is shown in Table 6-13.

Table 6-13: Descriptive statistics for households with and without air conditioner

Having air conditioner	N	Monthly electricity consumption (kWh)	
		Mean	Standard Deviation
No	350	225.9057	109.60988
Yes	111	356.9189	160.58496
Total	461	257.4512	135.74380

Houses with air conditioner consumed averagely 1.6 times higher than houses without air conditioner. Result from ANOVA showed that there are highly statistically significant differences between these households $F(1, 459) = 94.45$, $p < 0.001$, $\omega^2=0.17$. Therefore, electricity consumptions are significantly different between houses with and houses without air conditioner at 5% significant level. The effect size $\omega^2 > 0.17$ represents a large effect of having air conditioner on electricity consumption.

Detailed results for ANOVA analyses are stored in Section 10.4 in Appendix.

6.5 Estimation of Energy Consumption by Different End-Use

6.5.1 Appliance Stock in Households

Air Conditioner

Electricity consumption by cooling loads contributes the most important part of total electricity consumption in households. From the surveyed data, it ranges from 10 to 50 percent in different dwelling types. With the increased trend of air conditioner in households in recent years, it is meaningful to promote energy efficiency for this appliance. Energy performance of air conditioner is mainly rated by Seasonal Energy Efficiency Ratio or Energy Efficiency Ratio (Power Knot LLC, 2011).

- Seasonal Energy Efficiency Ratio (SEER): This is a measure of equipment energy efficiency over the cooling season. It represents the total cooling of a central air conditioner or heat pump (in Btu) during the normal cooling season as compared to the total electric energy input (in watt-hours) consumed during the same period.

- Energy Efficiency Ratio (EER): This is a measure of the instantaneous energy efficiency of cooling equipment. EER is the steady-state rate of heat energy removal (e.g., cooling capacity) by the equipment in Btuh divided by the steady-state rate of energy input to the equipment in Watts. This ratio is expressed in Btuh per Watt (Btuh/Watt).

According to the questionnaire survey results, villa had averagely 81 pieces of air conditioner per 100 households. These figures for rudimental, shop house, row house and apartment were 16.2, 29.5, 17.1 and 11.3 respectively. That explains the large share of electricity consumption for air conditioner of this dwelling type. Window unit type of air conditioner was popular among two main types of air conditioner (window and split units).

Table 6-14: Quantity of air conditioner by dwelling type (pieces in 100 households)

Air conditioner type	Rudimental	Shop house	Row house	Apartment	Villa	Total
One-way window unit	1.9	12.6	2.9	2.5	44.8	11.7
Two-way window unit	11.4	9.3	11.4	2.5	20.7	10.2
One-way split unit	2.9	3.8	0.0	2.5	1.7	2.8
Two-way split unit	0.0	3.8	2.9	3.8	13.8	4.1
Total	16.2	29.5	17.1	11.3	81.0	28.9

Air conditioners in households of HCMC had normally had capacity range from 9000 to 18000 BTU per hour. One-way window unit had the largest average capacity of more than 13,000 BTU per hour. All four types had average capacity larger 10,000 BTU per hour. Households had been changing from window type to split type and one-way to two-way. Data on average year of purchase reveals this trend of purchasing air conditioner in households.

Table 6-15: Average cooling capacity and year of purchase of air conditioner

	Average cooling capacity ($BTU.h^{-1}$)	Average year of purchase	Estimated EER
One-way window unit	13,326	2005	2.6
Two-way window unit	10,431	2006	2.6
One-way split unit	11,296	2007	2.8
Two-way split unit	10,121	2008	2.9

EER data for conditioners were collected from two sources. Firstly, EER was collected directly in the questionnaire. Secondly, in case of missing information of EER in questionnaire, EER was referenced from the information on model of air conditioner or models with similar cooling capacity and year of introduction.

Table 6-16: EER (cooling) and COP (heating) of best available technology (BAT) on the European market

Air conditioner type	EER BAT in EU	COP BAT in EU
Split < 4kW, variable speed	5.63	5.68
Multi split, variable speed	4.97	4.65
Split > 4kW, variable speed	4.52	4.52
Mobile split	3.22	3.67

Source: www.topten.eu

In case of replacement of current air conditioner with the best available technologies (BAT) of air conditioner, saving amount of 20 percent of electricity consumption for air conditioner can be achieved.

Refrigerator

In most homes the refrigerator is the second-largest user of electricity, right after the air conditioner. Villas reached to 100 pieces per 100 households while apartment at the lowest only 62.6 pieces. Two-door type of refrigerator was popular in households. Side-by-side (featured with big capacity and luxury design) type accounted for 10 percent of total quantity in villas. In general, refrigerator had high penetration in households as compared to other household appliances.

Table 6-17: Quantity of refrigerator by dwelling type (pieces in 100 households)

	Rudimental	Shop house	Row house	Apartment	Villa	Total
1-door	33.3	26.2	8.6	13.8	24.1	24.1
2-door	42.9	61.2	51.4	48.8	65.5	54.7
Side-by-side	1.9	1.6	5.7	0.0	10.3	2.8
Freezer	0.0	1.1	0.0	0.0	0.0	0.4
Total	78.1	90.2	65.7	62.5	100.0	82.0

One-door type had smallest capacity and earliest year of purchase while side-by-side type owns largest capacity. Annual consumption amounts were estimated based on model information or references from capacity and year of purchase.

Table 6-18: Average capacity, year of purchase and consumption of refrigerator

Refrigerator type	Volume (litres)	Year of purchase	Estimated annual consumption (kWh per annum)
1-door	221	2005	242
2-door	395	2005	415
side-by-side	972	2006	Not enough information
freezer	525	2008	Not enough information

Table 6-19 compares energy performance of inefficient and one of the most efficient refrigerators in Europe (featured with A+++ class). Replacement of current inefficient refrigerators in households with efficient technologies of refrigerator helps reduce some 50 percent in electricity consumption.

Table 6-19: Comparison of top energy performance and inefficient refrigerators

Type	1-door refrigerator freestanding		2-door refrigerator freestanding (<190cm)	
Brand	Liebherr	inefficient model	AEG	inefficient model
Model	TP 1434		S83600CSM1	
Total net volume (litres)	122	136	335	375
Zero degree zone (l)	0	0	0	0
Cooling compartment (l)	108	118	245	280
Freezing compartment (l)	14	18	90	95
Height (cm)	85	85	185	170
Width (cm)	55.4	55	59.5	70
Depth (cm)	62.3	61	66.8	69
Ambient temperature (°C)	10-38	16-32	10-43	16-43
Energy class	A+++	A+	A+++	A+
Energy Efficiency Index	22%	43.70%	21.90%	43.80%
Energy (kWh/year)	93	191	156	347

Source: www.topten.eu

Lighting

Lighting is one of important electric load in households thanks to its contribution to peak load of electric system. Electric load mainly occurs during evening time during 6 to 10 P.M. of a day. Therefore, cutting electric load is a win-win option for both electric user and utility. Improvement in lighting efficiency involves replacement of inefficient lamps and effective use of day lighting. As can be seen in Table 6-20, incandescent lamps were still quite popular in households, so does inefficient fluorescent lamps (i.e. lamps with capacity of 40 and 20w). In these houses, current utility of efficient lamps such as thin fluorescent tube (T8 and T5), compact fluorescent lamp (CFL), and light-emitting diode product (LED) is not dominant. The dominance of inefficient lamps was significant in shop houses where a large amount of bulbs and inefficient fluorescent tubes have been found. With long utilization of lighting devices during a day in this dwelling type, energy saving potential is great in case of replacing the inefficient with the efficient lamps.

Table 6-20: Quantity of lamp by dwelling type (pieces in 100 households)

Lamp type	Rudimental	Shop house	Row house	Apartment	Villa	Total
Bulb lamp 25w	23.8	79.2	37.1	78.8	36.2	57.9
Bulb lamp 60w	8.6	20.2	8.6	5.0	8.6	12.6
Bulb lamp 75w	16.2	27.3	62.9	0.0	6.9	20.2
Fluorescent lamp 40 w	287.6	404.9	297.1	385.0	648.3	397.2
Fluorescent lamp 20 w	33.3	87.4	54.3	46.3	46.6	60.3
Fluorescent lamp 36 w	44.8	76.0	162.9	65.0	12.1	65.5
CFL	50.5	66.7	60.0	40.0	248.3	80.7
Halogen lamp	0.0	0.0	0.0	0.0	1.7	0.2
LED lamp	0.0	7.1	0.0	0.0	27.6	6.3

Lamp efficiency is rated in lumens per watt (lm/W), the higher the lumens per watt the more efficient the lamp. Table 6-21 shows energy performance for popular lamp types in household. CFL is far superior as compared to incandescent lamps in terms of efficiency and lifetime. Options for lighting efficiency involves replacing incandescent bulbs and tube fluorescent lamps (T10) with CFLs and thin tube fluorescent lamps (T8 and T5).

Table 6-21: Performance characteristics of lamps in households

Type of Lamp	Lumens/Watt		Typical Application	Typical Life (hours)
	Range	Average		
Incandescent	8-18	14	Homes, restaurants, general lighting, emergency lighting	1000
Fluorescent Lamps	46-60	50	Offices, shops, hospitals, homes	5000
Compact fluorescent lamps (CFL)	40-70	60	Hotels, shops, homes, offices	8000-

Source: (Bureau of Energy Efficiency, 2005)

Water heating

Water can be heated using electric resistance heaters, gas or oil heaters, solar/gas/electric systems, heat pumps or by connection to a district heat system. The use of nonrenewable energy to make hot water can be reduced by: (1) reducing amount of hot water used; (2) heating with solar energy; and (3) heating it more efficiently (Harvey, Energy and the New Reality 1: Energy Efficiency and the Demand for Energy Services, 2010). In HCMC, households are mainly employing electric, LPG heaters and solar/electric system for water heating. Penetration rate of water heater in households of was not high due to the City's hot climate. Quantity of water heater was highest in villas and lowest in apartments. Electric heater was dominant one in households followed by gas heater. Thermal solar energy can be collected from flat-plate or evacuated-tube collectors that are mounted on the roof or that form part of the building fabric, stored in hot water tanks and used for domestic hot water or to provide space heating (Harvey, Energy and the New Reality 2: Carbon-Free Energy Supply, 2010). The evacuated-tube collector type of solar water heater has been used in Vietnam, and can be supplied by local manufacturers. Employment of solar system was only found in villas, row houses and shop houses. This current low penetration rate of solar water heater indicates a potential room for energy efficiency improvement in water heating.

Table 6-22: Quantity of water heater by dwelling type

	Rudimental	Shop house	Row house	Apartment	Villa	Total
Electric	15.2	20.8	20.0	7.5	22.4	17.4
Gas	4.8	4.9	8.6	3.8	1.7	4.6
Solar/Electric	0.0	1.6	2.9	0.0	1.7	1.1

Solar systems, even though very efficient in hot climate area, are however characterized with high up-front system costs for households. Electricity of Vietnam has therefore given direct subsidy to every new purchase of solar water heater from the local suppliers. The subsidy amount accounts for 10 to 15 percent of the system's total price. The national utility have seen benefit of peak clipping for electric system. It avoids the utility buying expensive electricity from external power generators during peak period. Due to its high initial investment and space needed on the roof for installing, replacing electric and LPG water heaters with solar ones is suitable for villas and row houses which characterized with large living area and high income. The solar fraction is a performance metric that indicates how much of the energy demand is supplied by the SWH system. This parameter will vary geographically and with time based on hot water usage and solar resource. A research on solar fraction in US shows that the fraction ranges from 45 to 85 percent SWH system with an electric auxiliary water heater in different areas (Cassard, Denholm, & Ong, 2011).

HCMC has an abundant solar radiation potential, averagely 1,581kWh/m2/year with the highest of 6.3kWh/m2/day in February and the lowest of 3.3kWh/m2/day in July. Average sunny hour varies from 100 to 300 hours per month. In the dry season, this figure reaches to 300hrs (in March), however, in the wet season, the figure is 150hrs (in October). Solar radiation in HCMC is relatively high; therefore, the potential for using solar energy is promising.

Total radiation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
kWh/m2.month	141,9	176,8	186,1	168,6	129,1	103,5	103,5	111,6	103,5	116,3	119,8	121,0	1581,7
kWh/m2.day	4,6	6,3	6,0	5,6	4,2	3,5	3,3	3,6	3,5	3,8	4,0	3,9	4,3

Source: (Institute of Energy, 2010)

Windows

Energy performance of windows is measured by five major ratings as follow (Carmody & Haglund, 2012):

- U-factor measures how well a product prevents heat from escaping a home or building. U-factor ratings generally fall between 0.15 and 1.20. The lower the U-factor, the better a product is at keeping heat inside the building.
- Solar Heat Gain Coefficient (SHGC) measures how much heat from the sun is blocked. SHGC is expressed as a number between 0 and 1. The lower the SHGC, the more a product is blocking solar heat gain. Blocking solar heat gain is particularly important during the summer cooling season.
- Visible Transmittance (VT) measures how much light comes through a product. VT is expressed as a number between 0 and 1, therefore, the higher the VT the higher the potential for day lighting.
- Air Leakage measures how much outside air comes into a home or building through a product. Air leakage rates typically fall in a range between 0.1 and 0.3. The lower the air leakage, the better a product is at keeping air out.
- Condensation Resistance measures how well a product resists the formation of condensation. Condensation resistance is expressed as a number between 1 and 100. The higher the number, the better a product is able to resist condensation.

Table 6-23: Window type by dwelling type

Window type	Rudimental	Shop house	Row house	Apartment	Villa	Total
Single-glazed, glass, metal	47.6%	60.7%	60.0%	65.0%	79.3%	60.7%
Single-glazed, glass, non-metal	14.3%	11.5%	11.4%	8.8%	3.4%	10.6%
Multiple-glazed, glass, metal	1.9%	12.0%	8.6%	6.3%	5.2%	7.6%
Multiple-glazed, glass, non-metal	1.0%	1.1%	0.0%	0.0%	3.4%	1.1%
No window	14.3%	7.1%	8.6%	8.8%	0.0%	8.2%
Others	19.0%	6.0%	11.4%	6.3%	3.4%	9.1%
Total	98.1%	98.4%	100.0%	95.0%	94.8%	97.4%

Table 6-23 shows percentage of different window types in households of HCMC. The single-glazed types were very dominant in these households accounting for more than 60 percent in all five dwelling types. Multiple-glaze types (with more than two glass layers) accounted for less than 10 percent of total quantity. The current dominance of windows with single-glazed type with metal frame shows the low energy performance of windows in households. Replacement of these windows with energy efficient windows with better SHGC and improved air leakage will help reduce significant amount of cooling load in households.

Table 6-24: Shading methods by dwelling type

Shading method	Rudimental	Shop house	Row house	Apartment	Villa	Total
Window drape	32.4%	51.4%	60.0%	43.8%	39.7%	44.9%
Window shade	11.4%	8.2%	8.6%	6.3%	5.2%	8.2%
Window film	0.0%	1.1%	0.0%	0.0%	3.4%	0.9%
Paperhanging	1.0%	0.5%	0.0%	1.3%	0.0%	0.7%
Mobile eaves	8.6%	18.6%	8.6%	13.8%	17.2%	14.5%
None	39.0%	18.0%	22.9%	25.0%	27.6%	25.6%
Others	6.7%	1.1%	0.0%	6.3%	1.7%	3.3%
Total	99.0%	98.9%	100.0%	96.3%	94.8%	98.0%

HCMC is located in the hot and sunny area with high temperature and long sunny hour. Efficient use of day lighting is therefore useful in reducing artificial lighting loads. For effective use of day lighting, shading method is very important. It not only reduces solar heat gain but also increase day lighting amount into house. Information about status of shading method in households reveals that effective shading methods (such as window film) were not popular employed in these houses which accounted for less than 1 percent in total quantity of house. Improvement of window and its associated shading method becomes important content in energy efficient building envelope of households.

It was estimated that cooling load may reduce by 28 to 33 percent by replacing conventional single pane with Energy Star low solar gain nonmetal frame. As can be seen in Figure 6-1, both U-factor and SHGC were improved by the replacement.

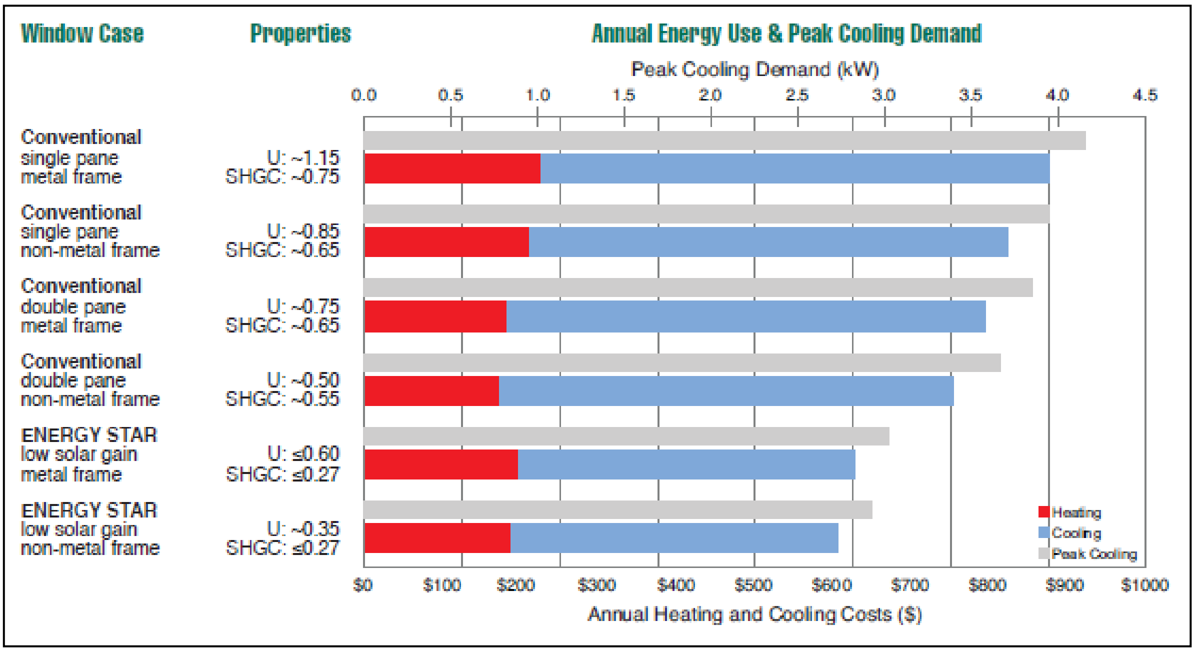

Figure 6-1: Cooling load reduces with improvement in energy performance of windows

Source: (The Efficient Windows Collaborative, 2011)

6.5.2 Estimation of Energy Consumption for Major End-Uses

In order to examine energy efficiency potential, it is necessary to break down total energy consumption into components for different purposes. From the survey analysis, based on quantity, capacity, and utility of household appliances, electricity consumption was broken down into four types of end use including lighting, water heating, refrigerator, air conditioner. Bases for estimation of electricity consumption for these four main purposes are as follow:

Table 6-25: Basis for energy consumption estimation for different end uses

Purpose	Available information from questionnaire survey	Basis for energy consumption estimation
Lighting	Type, quantity, wattage, utilization	Quantity x Wattage x Utilization
Air conditioner	Type, quantity, capacity, model, EER, utilization	Cooling capacity x EER x Utilization
Refrigerator	Type, quantity, volume, model	Referenced from similar model or volume
Water heater	Type, quantity, capacity, volume, model, utilization	Wattage x Utilization

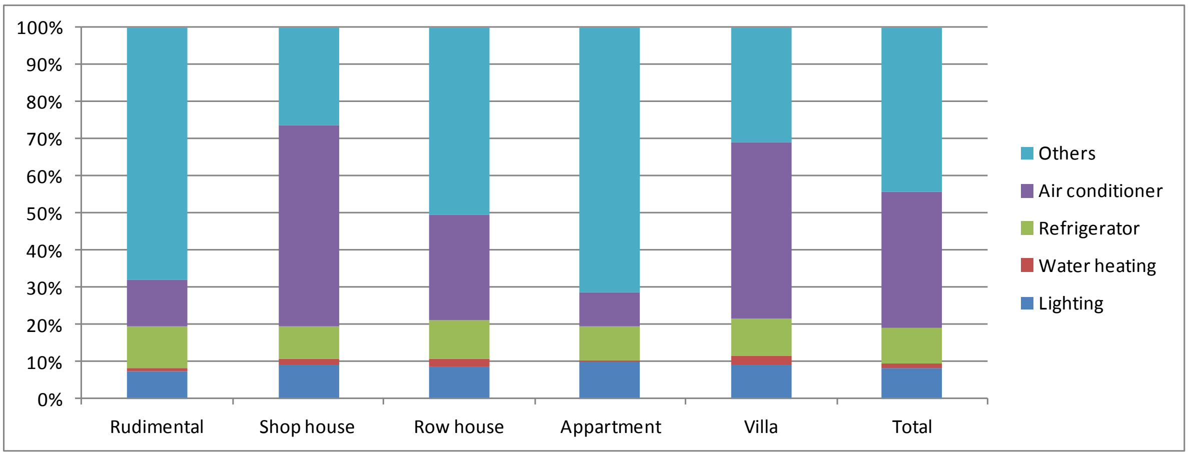

Figure 6-2: Shares of different end uses in total electricity consumption

The results show these four end uses account for 30 percent (in rudimental houses and apartments) to 70 percent (in shop houses and villas). Electric use for air conditioner was very high in shop houses and villas. Along with increased living standard, air conditioner has increased quickly its penetration rate in recent years and become the most important electric load in households. Lighting and refrigerator accounted for about 10 percent. Water heating made up a small share of total electricity use in households. Hot climate results in the low domestic hot water (DHW) for the households.

Table 6-26: Monthly electricity consumption by end use (KWh)

	Rudimental	Shop house	Row house	Apartment	Villa	Total
Total electricity consumption	203.5	273.2	278.1	230.9	329.6	257.5
Lighting	14.8	25.1	23.9	22.6	30.1	20.9
Water heating	1.4	3.6	6.2	1.4	7.9	3.5
Refrigerator	23.4	24.5	28.5	20.6	33.2	25.0
Air conditioner	25.0	147.7	79.5	21.1	156.3	93.7
Others	138.9	72.2	140.0	165.3	102.1	114.4

It is worth to examination how much energy can be saved in case of promoting energy efficiency options for these four major uses in households, especially cooling. Electricity consumption for air conditioner was remarkably high by shop house, row house and villa. Lighting and refrigerator also have an important contribution to total electricity consumption. Water heating makes up a small share in electricity consumption due to available alternatives (such as LPG and solar) and the low demand for hot water.

6.5.3 Static Analysis of Energy Efficiency Options in Households

Energy consumption in households can be reduced largely by replacement of old and inefficient appliances with new and efficient appliances. The study assumed an improvement in energy efficiency of these household appliances. The penetration of efficient appliances in future may increase with the MEPS and other supporting measures. Static analysis did not take into account economics of devices and dynamic changes among dwelling type. Energy saving potential for each energy efficiency options is as follow:

Table 6-27: Energy efficiency options for households

Demand	Energy efficiency options
Lighting	Replacing bulb with CFL and tube fluorescent with thin tube fluorescent lamps
Water heater	Replacing electric and LPG with solar water heaters in row houses and villas
Refrigerator	Replacing all current with BAT refrigerators
Air conditioner	Replacing all current with BAT air conditioners
Windows	Replacing all current with energy efficient windows (25 percent reduce in cooling load)

The results show that household may save from 8.8 percent to 36.2 percent of energy consumption by increasing their appliances' energy efficiency. The highest saving amount takes place in villas where cooling load accounted for a large share of total energy consumption. Improvement in air conditioners efficiency benefits remarkably households. Employing SWH also helps reduce much energy consumption. Apartments have the lowest percentage of energy saving amount of 8.5 percent. Shop houses and row houses both have quite high percentage of energy saving, with 32.9 and 26.4 percent respectively.

Table 6-28: Energy saving potential by dwelling type

End use	Unit	Rudimental	Shop house	Row house	Appartment	Villa	Total
Lighting	kWh	2.4	9.0	3.8	3.4	3.7	3.5
Water heating (electricity)	kWh	0.0	0.0	4.3	0.0	5.5	2.4
Refrigerator	kWh	11.7	12.3	14.3	10.3	16.6	12.5
Air conditioner	kWh	12.5	73.9	39.8	10.5	78.1	46.8
Air conditioner (by window improvement)	kWh	6.2	36.9	19.9	5.3	39.1	23.4
Total electricity saving	kWh	32.9	132.0	82.0	29.5	143.0	88.7
Water heating (LPG)	kg	0.0	0.0	2.6	0.0	2.4	2.0
Total energy saving	MJ	118.32	475.28	412.98	106.14	624.48	411.06
Percentage of energy saving	%	10.5%	32.9%	26.4%	8.6%	36.2%	29.8%

Reduced energy consumption in households results in CO2 reduction. The reduction takes place in households with reduced LPG use and in power plants with reduced electricity use. Amount of CO2 saved therefore depends on generation mix of power system. The system with high share of coal power plant causes high CO2 emissions factor. Research showed an estimation of 0.5 kg CO_2 per kWh of electricity generation for Vietnamese power system in 2010 (Institute of Energy, 2011). With transmission and distribution loss of 10 percent in 2010 (Institue of Energy, 2009), saving of electricity generated can be estimated. Energy consumption for the whole City was estimated based on energy use intensities and total living area in 2010.

Table 6-29: Summary of monthly energy saving and CO2 reduction for the whole City

	Unit	Rudimental	Shop house	Row house	Appartment	Villa	Total annual
Total living area in the City *	ha	527.06	7,154.27	2,872.45	194.58	896.69	139,741
Unit electricity use intensity	kWh/HH.m2	4.63	3.41	2.40	4.15	2.14	
Total electricity consumption	MWh	24,384	244,257	69,077	8,077	19,183	4,379,729
Electricity saving	MWh	3,939	118,032	20,368	1,031	8,325	1,820,347
Unit energy use intensity	MJ/HH.m2	26.33	18.20	13.45	22.74	11.27	
Total energy consumption	GJ	138,750	1,301,983	386,286	44,257	101,040	23,667,779
Energy saving	GJ	14,505	428,168	102,065	3,811	36,566	7,021,367
CO2 reduction	ton	2,188	65,573	13,037	573	4,995	1,036,406

Source: * adapted from (Le, 2013)

Shop houses consumed the largest amount of electricity and energy consumption in 2010 followed by row houses and villas. Households in the City can save up to 1.8 GWh of electricity consumption by replacing their inefficient appliances. The saving amounts are different by dwelling type. The analysis shows that the City would save its energy consumption by 7 million GJ with the actions in energy efficiency. Consequently, CO_2 can be reduced by more than 1 million tons per year. Bearing in mind the increased energy demand for households, city expansion and land use changes, amount of CO_2 reduction will be much greater in future.

6.5.4 Barriers for Energy Efficient Devices in Households

Even though energy efficiency has been proved economic viable in many cases, initial penetration of these devices into households have been so low thanks to barriers. General barriers to the diffusion of energy efficient appliances are mentioned as follow (Figueres & Bosi, 2006):

- Policy barriers: lack of institutional capacity; lack of national budget; lack of MEPS; low electricity price
- Finance barriers: price sensitivity of appliance market; no financial incentives
- Business and management barriers: uncertainty about market demand of efficient appliances;
- Information barriers: lack of awareness about residential sector energy end-use; lack of information about precise energy saving potential, lack of information about efficient appliances
- Technology barriers: limited access to the efficient appliances; lack of R&D efforts;

Among the barriers, we would like to emphasize the need for understanding on residential energy end-use and information about precise energy saving potential. That is the true obstacle for promoting energy efficiency in households in Vietnam. Beside the living standard household survey, which has been implemented biannually, there is no specific survey for getting energy consumption data in the sector. The circumstance motivated the PhD study to examine this data gap. Within the scope of household questionnaire survey, we asked households about barriers for them to buy efficient appliances (Figure 6-3). 44 percent mentioned about initial cost, 24.3 percent about lack of information and 19.7 percent about reliability of appliances. In summary, cost, information, reliability, and quality of appliances are the largest barriers for household to implement energy efficiency activities.

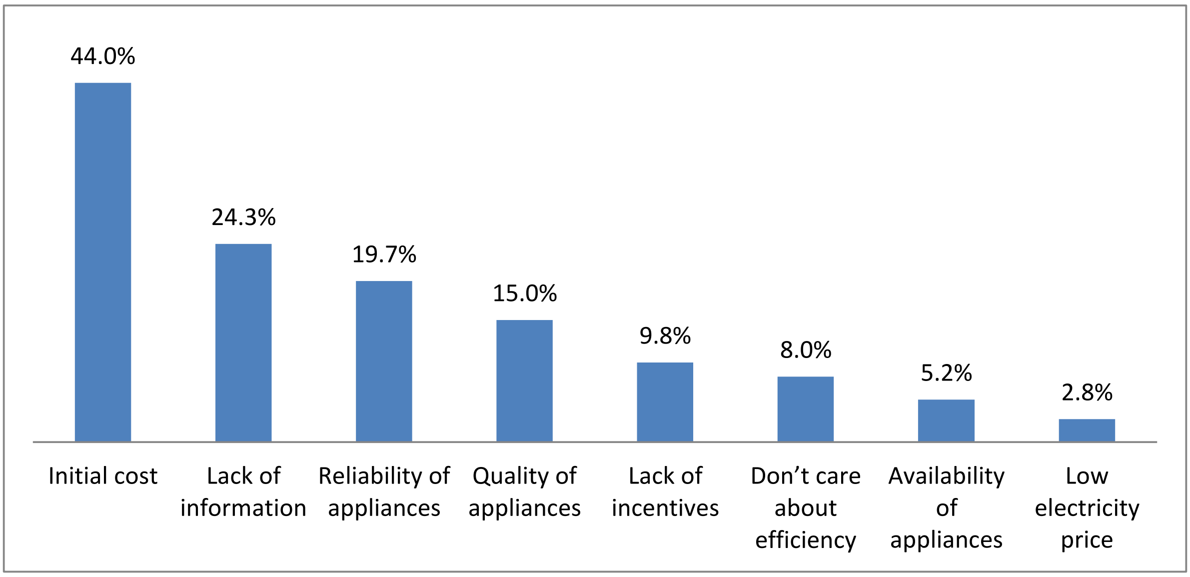

Figure 6-3: Barriers for households to diffusion of efficient appliances

6.6 Findings

We examined fuel mix and consumption pattern of households in HCMC. In all five types of dwelling, electricity and gasoline contribute the two largest shares followed by LPG uses for cooking. Coal and firewood are being used for cooking and heating in some low-income level dwelling types. Electricity and gasoline for transport were two main energy types in households of the City. LPG accounted for some 20 percent of total energy use. Kerosene, coal and firewood were being used in low-income dwelling types.

Households in villa characterized with the highest income, the largest living area, and the biggest energy consumption. These households had also high daily mobility demand as compared to other households. Rudimental houses are characterized by lowest income, smallest living area and lowest energy and electricity consumptions. Electricity use intensity in these dwelling types is very high, which is significantly higher than ones in other types of dwelling.

ANOVA analyses showed that electricity and energy use intensities (kWh.m^{-2} and MJ.m^{-2}) are statistically significantly difference in almost dwelling types. There are only two insignificant differences in two pairs of dwelling types: rudimental versus apartment and row house versus villa. Income had significant effect on electricity and consumptions according to ANOVA results. Houses with air conditioner also consumed significantly more electricity than house without air conditioner. Electricity and energy intensities (in kWh/m2 and MJ/m2) are different significantly in almost dwelling types according to ANOVA analysis. Monthly electricity density from the survey are 4.63 kWh/m2 for rudimental houses, 3.41 for shop houses, 2.40 for row houses, 4.14 for apartments and 2.14 for villas. Monthly energy density from the survey are 26.33 MJ/m2 for rudimental houses, 18.20 for shop houses, 13.45 for row houses, 22.74 for apartments and 11.27 for villas. Income and having air conditioner have significant impacts on electricity and energy consumptions.

Households in the City have been using large amount of inefficient appliances, especially lighting devices and air conditioner. Quantity of air conditioner has increased quickly in recent year and cooling load contributed major part in total electricity consumption, especially in villas, row houses, and shop houses. Incandescent and inefficient tube fluorescent lamps still have been using in all five dwelling types. Programs for phasing-out inefficient lamps, especially incandescent lamps, are extremely necessary. Penetration of refrigerator was very high in the surveyed households. Electric and LPG water heater were dominant in households to meet their domestic hot water. Few households were employing SWH in their houses.

In examination of energy consumption and saving by four main end-uses, namely lighting, air conditioner, refrigerator and water heater, high potential for energy saving can be gained by replacing current inefficient devices with efficient ones. Energy efficiency options in households are therefore very promising in conserving energy and tackling climate change. Percentage of energy saving is quite high in houses in well-planned areas such as row house and villa.

Air conditioner consumed up to 50 percent of total electricity consumption in villas. Lighting and refrigerator accounted for some 10 percent of electricity consumption.

Estimated energy efficiencies of current appliances were much lower than efficiencies of best available technologies. Villas may save up to 36 percent of total energy consumption while apartment more than 8 percent. The City would save an electricity amount of 1,820 GWh, an energy amount of 7 million GJ and cut more than 1.2 million tons of $CO2$ annually.

High initial cost and lacking information of efficient appliances are the two main barriers for implementing energy efficiency in households. It consequently requires more information propaganda programs on energy efficiency in residential sector.

In future, rudimental houses or old apartment buildings will be replaced by well-planned buildings in future. This causes increase in both energy and electricity consumptions as pointed out in the PhD study. Energy and electricity consumption as well as electricity use intensity from the paper can be a good basis to project these changes. The authority must give extra attention to these changes in future urban planning to avoid the current power shortages. Incorporating the installation of solar water heater in the building of new apartment building can be one of options for promotion of renewable energy use in household.

Chapter 7. Impacts of Energy Efficiency on Economic, Resource, Emission and Spatial Development

7.1 Introduction

Energy efficiency has been proved cost-effective measures in dealing with the increased demand as compare to other supply-side options. Employing an energy system model; that includes all energy end-uses, energy consuming appliances, energy conversion plants, and energy extraction resource; allows one to examine impacts of changes in demand side on the system. The impacts are possibly system cost, emissions, capacity of plants etc… The PhD study, therefore, employed MARKAL model for this purpose. Energy efficiency options were input into model as alternatives for providing demands beside the conventional options. The Vietnamese energy system was modeled in detail for this purpose. Demand sections for households in Ho Chi Minh City were also modeled specifically to examine energy saving potential and its impacts on economic, resource, emission and spatial development of the energy efficiency options. Three different scenarios were built to compare the impacts of energy efficiency on these different aspects. Impacts of energy efficiency was measured based on the comparisons of the results of these scenarios.

There are many energy models dealing with end-use demand such as LEAP (Long range Energy Alternatives Planning system), MARKAL (Market Allocation), AIMS End-use, EFOM (Energy Flow Optimization Model) etc… MARKAL is recommended as the tool for analyze the energy system in the research. MARKAL (abbreviation of MARKet Allocation) was developed in a cooperative effort between Brookhaven National Laboratory (BNL), USA and Kernforschungsanlage Juelich, Germany. About 15 countries belonging to the International Energy Agency (IEA) contributed to the joint effort within the frame work of the Energy Technology System Analysis Project (ETSAP) (Kleemann & Wilde, 1990). The model covers the energy system in Vietnam in four parts: resources, process, conversion and demand. Firstly, resource consists of energy extraction, import, export and stockpile. Processes include oil refineries, gas plants, gas pipelines etc… Conversion involves to power plants, electricity networks etc… Demand covers end-use devices and demand services, which provide final services in five sectors agriculture, industry, commerce, residential and transport. MARKAL is very strong for evaluation of alternative energy options including energy efficiency options in terms of economics, resource environment, and other energy-related aspects. Moreover MARKAL features with its advanced variants dealing with macro, micro, elastic demand, endogenous technology learning curve, stochastic, lumpy investment etc…

Studies on potential energy saving households have been made by using many approaches. Households may be divided into different regions and consumption levels. Electricity saving potential were estimated based on different scenarios, which included technical, economic and market potential. In a study for households in Brazil, electricity saving potential is estimated in the range from 11.3 to 45.3 for different scenarios (Schaeffer, Cohen, de Aguiar, & Faria, 2009). In another application of MARKAL for estimation of energy saving in household, results show significant cost-effective potentials for improvements for European countries (Mundaca, 2008). Spatial planning may bring about important potential for energy savings in building stock through accelerating the renovation of existing urban fabric or increasing the substitution of existing houses by new ones with contemporary energy standards and higher densities (Dujardin, Marique, & Teller, 2014).

Vietnam is quickly developing its power system to meet the increased electricity demand. Power development has great impacts on economic, society and environment. In term of environment, power development has major impacts as follow:

- Land use;
- Displaced communities;
- Natural resources;
- Emissions;
- Climate change;
- Water resources; and
- Risks to biodiversity.

This PhD study aims to examine energy efficiency options in household and its potential to mitigate the impacts of power development. Energy efficiency activities should be taken as strongest as possible to tackle these impacts. The PhD study focused on impacts on natural resources, emission, land use and quantity of displaced people.

7.2 Description of MARKAL Model

This section was heavily withdrawn from Documentation for the MARKAL Family of Models (Loulou, Goldstein, & Noble, 2004).

An optimization problem formulation consists of three types of entities:

- Decision variables: i.e. the unknowns, to be determined by the optimization,
- Objective function: expressing the criterion to minimize or maximize, and
- Constraints: equations or inequations involving the decision variables, that must be satisfied by the optimal solution.

The model variables and equations use the following indexes:

- r,r': indicates the region (omitted when a single region is modeled);
- t: time period;
- k: technology;
- s: time-slice;
- c: commodity (energy or material);
- l: price level (used only for multiple sources of the same commodity distinguished only by their unit cost)

Decision Variables

The decision variables represent the choices made by the model. The various kinds of decision variables in a MARKAL model are elaborated here.

- INV(r,t,k): new capacity addition for technology k, in period t, in region r.

- CAP(r,t,k): installed capacity of technology k, in period t, in region r. Typical units: same as for investments.
- ACT(r,t,k,s): activity level of technology k, in period t, in region r, during time-slice s.
- MINING(r,t,c,l): quantity of commodity c (PJ per year) extracted in region r at price level l in period t.
- IMPORT(r,t,c,l), EXPORT(r,t,c,l): quantity of commodity c, price level l, (PJ per year) exogenously imported or exported by region r in period t.
- TRADE(r,t,c,s,imp) and TRADE(r,t,c,s,exp):) quantity of commodity c (PJ per year) sold (exp) or purchased (imp) by region r to/from all other regions in period t, for time-slice s (for electricity).
- D(r,t,d): demand for end-use d in region r, in period t. In non-reference runs, D(r,t,d) may differ from the reference case demand for d, due to the responsiveness of demands to their own prices (based on each service demand's own-price elasticity).
- ENV(r,t,p): Emission of pollutant p in period t in region r.

Objective function

As explained in the previous section, the objective function is the sum over all regions of the discounted present value of the stream of annual costs incurred in each year of the horizon. Therefore:

where:

- NPV is the net present value of the total cost for all regions (the MARKAL objective function)
- ANNCOST(r,t) is the annual cost in region r for period t, discussed below
- d is the general discount rate
- NPER is the number of periods in the planning horizon
- NYRS is the number of years in each period t
- R is the number or regions

Note: the last factor in the expression is the intra period discount factor

The total annual cost ANNCOST(r,t) is the sum over all technologies k, all demand segments d, all pollutants p, and all input fuels f, of the various costs incurred, namely: annualized investments, annual operating costs (including fixed and variable technology costs, fuel delivery costs, costs of extracting and importing energy carriers), minus revenue from exported energy carriers, plus taxes on emissions, plus cost of demand losses. Mathematically, ANNCOST(r,t) is expressed as follows:

ANNCOST(r,t) = Σk {Annualized_Invcost(r,t,k) *INV(r,t,k) + Fixom(r,t,k) *CAP(r,t,k)

+ Varom(r,t,k) *Σs,s ACT(r,t,k,s) + Σc [Delivcost(r,t,k,c)*Input(r,t,k,c)* Σs ACT(r,t,k,s)] }

+ Σc,s { Miningcost(r,t,c,l)*Mining(r,t,c,t) + Tradecost(r,t,c)* TRADE(r,t,c,s,i/e)

+ Importprice(r,t,c,l)*Import(r,t,c,l) - Exportprice(r,t,c,l)*Export(r,t,c,l) }

+ Σc {Tax (r,t,p) * ENV(r,t,p)} + Σd {DemandLoss(r,t,d)} (1.4-1) where:

- Annualized_Invcost(r,t,k) is the annual equivalent of the lump sum unit investment cost, obtained by replacing this lump sum by a stream of equal annual payments over the life of the equipment, in such a way that the present value of the stream is exactly equal to the lump sum unit investment cost, for technology k, in period t. Note carefully that by stopping the summation over t at the end of the horizon, the objective function automatically accounts for the salvage value of all assets stranded at the end of the horizon.
- Fixom(k,t,r), Varom(r,t,k), are unit costs of fixed and operational maintenance of technology k, in region r and period t;
- Delivcost(r,t,k,c) is the delivery cost per unit of commodity c to technology k, in region r and period t;
- Input(r,t,k,c) is the amount of commodity c required to operate one unit of technology k, in region r and period t;
- Miningcost(r,t,c,l) is the cost of mining commodity c at price level l, in region r and period t;
- Tradecost(r,t,c) is the unit transport or transaction cost for commodity c exported or imported by region r in period t;
- Importprice(r,t,c,l) is the (exogenous) import price of commodity c, in region r and period t; this price is used only for exogenous trade, see below;
- Exportprice(r,t,c,l) is the (exogenous) export price of commodity c, in region r and period t; this price is used only for exogenous trade, see below;
- Tax(r,t,p) is the tax on emission p, in region r and period t; and
- DemandLoss(r,t,d) represents the welfare loss (in non reference scenarios) incurred by consumers when a service demand d, in region r and period t, is less than its value in the reference case.

Constraints (equations)

EQ_DEM(r,t,d) - Satisfaction of Demands

For each time period t, region r, demand d, the total activity of end-use technologies servicing that demand must be at least equal to the specified demand. Hence:

Sum {over all end-use technologies k, such that k supplies service d}of CAP(r,t,k) ≥ D(r,t,d)

EQ_CPT(r,t,k) - Capacity transfer

For each technology k, region r, period t, the available capacity in period t is equal to the sum of investments made by the model at past and current periods, and whose physical life has not ended yet, plus capacity in place prior to the modeling horizon and still in place.

CAP(r,t,k) = Sum {over t and all periods t’ preceding t and such that

t-t’<LIFE(k)} of INV(r,t’,k) + RESID(r,t,k)

where RESID(r,t,k) is the capacity of technology k due to investments that were made prior to the initial model period and still exist in region r at time t.

EQ_UTL(r,t,k,s) - Use of capacity

For each technology k, period t, region r, and time-slice s, the activity of the technology may not exceed its available capacity, as specified by a user defined availability factor

ACT (r,t,k,s) ≤ AF(r,t,k,s)* CAPUNIT* CAP(r,t,k) (1.4-4)

EQ_BAL(r,t,c,s) - Energy Balance

For each commodity c, time period t, region r, (and time-slice s in the case of electricity and low-temperature heat), this constraint requires that the disposition of each commodity may not exceed its supply. The disposition includes consumption in the region plus exports; the supply includes production in the region plus imports.

Sum {over all k} of: Output(r,t,k,c)*ACT(r,t,k,s) +

Sum {over all l} of: MINING(r,t,c,l) +

Sum {over all l} of: FR(s)*IMP(r,t,c,l)* +

XCVT(c,i)* TRADE(r,t,c,s,i)

≥ or =

XCVT(c,o) *TRADE(r,t,c,s,e) +

Sum {over all l} of: FR(s) *EXP(r,t,c,l) +

Sum {over all k} of: Input(r,t,k,c)*ACT(r,t,k,c,s)

where:

- Input(r,t,k,c) is the amount of commodity c required to operate one unit of technology k, in region r and period t;
- Output(r,t,k,c) is the amount of commodity c produced per unit of technology k, and
- FR(s) is the fraction of the year covered by time-slice s (equal to 1 for non-seasonal commodities).
- XCVT(c,i) and XCVT(c,o) are transaction or transport costs of importing or exporting one unit of commodity c. The constraint is ≥ for energy forms and = for materials.

EQ_EPK/HPK(r,t,c,s) - Electricity and heat Peak Reserve Constraint

For each time period t and for region r, there must be enough installed capacity to exceed the required capacity in the season with largest electricity (heat) commodity c demanded by a safety factor E called the peak reserve factor.

Sum {over all k} of CAPUNIT * Peak(r,t,k,c) * FR(s) *CAP(r,t,k) +

XCVT(c,i) * TRADE(r,t,c,s,i) + FR(s) * IMPORT(r,t,c)

≥ [1+ERESERVE(r,t,c)] * [Sum {over all k} of Input(r,t,k,c) *

FR(s) * ACT(r,t,k,s) +XCVT(c,o) * TRADE(r,t,c,s,e) + FR(s) * EXPORT(r,t,c)]

where:

- ERESERVE(r,t,c) is the region-specific reserve coefficient, which allows for unexpected down time of equipment, for demand at peak, and for uncertain hydroelectric, solar, or wind availability.
- Peak(r,t,k,c) (never larger than 1) specifies the fraction of technology k's capacity in a region r for a period t and commodity c (electricity or heat only) that is allowed to contribute to the peak load. Many types of generating equipment are predictably available during peak load and thus have a peak coefficient equal to unity, whereas others such as wind turbines or solar plants are attributed a peak coefficient less than 1 since they are on average only fractionally available at peak.

EQ_ENV(r,t,p) - Emission constraint or tax (optional)

In each region r, for each time period t, this constraint ensures that the total emission of pollutant p will not be greater than a user-selected upper bound, if such is provided. In MARKAL, pollutants may be emitted when a technology is active, but also when it is inactive (for example a hydro reservoir may emit methane even if no electricity is being produced). Emissions may also occur at the time of construction of the technology, in some instances. In each of these three cases, the emission coefficient is applied to the activity variable, to the capacity variable, or to the investment variable, respectively. This flexibility allows the accurate representation of various kinds of emissions. Technologies may also sequester or otherwise remove emissions as well via the use of a negative emission coefficient.

ENV(r,t,p) = Sum [over all technologies k of { Eminv(r,t,p,k)* INV(r,t,k)

+ Emcap(r,t,k,p)*CAP(r,t,k)

+ Emact(r,t,,k,p)* Sum {over s of ACT(r,t,k,s) }]

and

ENV(r,t,p) ≤ ENV_Limit(r,t,p)

where:

- Eminv, Emcap, Emact are emission coefficients for pollutant p (possibly negative) linked respectively to the construction, the capacity, and the operation of a technology, and
- ENV_LIMIT(r,t,p) is the upper limit set by the user on the total emission of pollutant p in region r at period t.

Instead of an emission limit, the user may specify an emission tax Etax(r,t,p). If so, the quantity ENV(r,t,p) * E tax(r,t,p) is added to the ANNCOST expression, penalizing emissions at a constant rate.

Note that emission caps may be set globally for all regions, or for a group of regions, or by sector, etc. It is also possible to set a cumulative emission cap (for a group of time periods).

EQ_BAS(r,t,c) - Electricity Base load constraint

For electricity c, in region r and period t, electricity generating technologies that are labeled as Base load must produce the same amount of electricity at night as in the day. They may, however, vary their production from season to season. Therefore, for Base load technologies there are only three ACT variables (one per season) instead of 6 for other electric generation technologies. The base load constraint then ensures that only a maximum percentage of the total night-time demand for electricity is met by such plants.

Sum { over all technologies k consuming electricity c at night of: input(r,t,k,c)* Baseload(r,t,c)*ACT(r,t,k,'N') } ≥ Sum { over all baseload technologies k producing electricity c

at night of: Output(r,t,k,c)*ACT(r,t,k,'N') }

where:

- Baseload(r,t,c) is the maximum share of the night demand for electricity c in region r and period t.

EQ_UDC(r,t,u) - User-defined constraints

In addition to the standard MARKAL constraints discussed above, the user interested in developing reference case projections of energy market behavior typically introduces many additional linear constraints to express special conditions.

User defined constraints may serve many functions in MARKAL. Their general purpose is to constrain the optimization problem in some way to account for factors based either on policy or on market behavior that affect investment decisions. For example, there may a user defined constraint limiting investment in new nuclear capacity (regardless of the type of reactor), or dictating that a certain percentage of new electricity generation capacity must be powered by renewable energy sources.

In order to facilitate the creation of a new user constraint, MARKAL provides a template for indicating a) the set of variables involved in the constraint, and b) the user-defined coefficients needed in the constraint.

The utilization of the MARKAL model requires a number of software elements to be in place. These are:

- The MARKAL model itself in which data is entered by users about energy supply sources, conversions, demand requirements and utilization technologies;
- An optimizing package which performs the calculations within the MARKAL model that produce least cost solutions. The most widely-used software for this purpose is General Algebraic Modeling System (GAMS) model generator software. There are two versions of the optimizer: MINOS and OSL.
- An interface to the MARKAL model allowing user-friendly access to it. Nowadays ANSWER is an integrated Windows-based system designed specifically for working with MARKAL models that allows the user to manage model input data, initiate model runs, and compare and graph model results.
- A standard operating environment upon which all elements run. Examples in the case of IBM type computers are Windows, DOS or UNIX.

These elements are represented diagrammatically below:

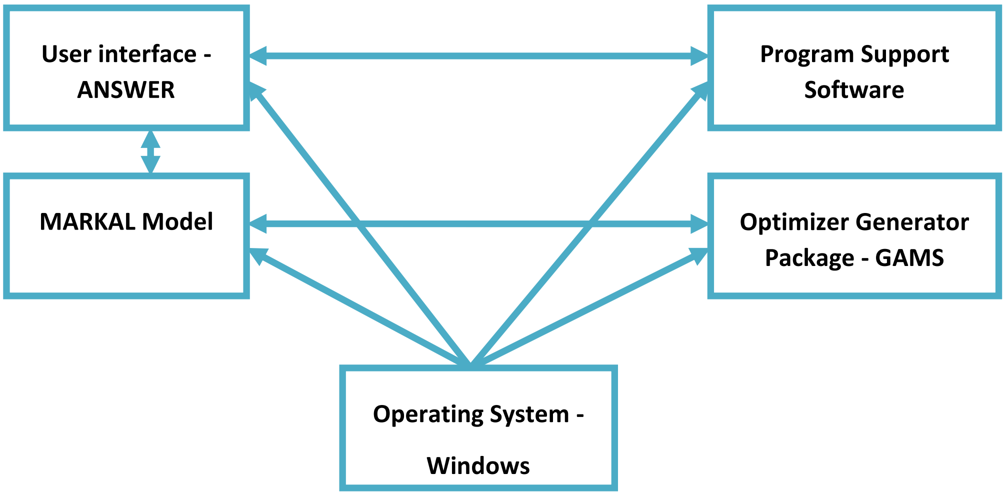

Figure 7-1: Simplified MARKAL software system diagram

7.3 Description of MARKAL Database

7.3.1 Resources

Vietnam has indigenous supplies of the fossil fuels:

- Natural gas;
- Crude oil;
- Coal (anthracite, sub-bituminous, peat, lignite);
- Hydro;
- Wind;
- Solar;
- Geothermal;
- Bio-fuels (bio ethanol and bio diesel)
- Biomass (including agricultural waste, wood fuel, bagasse…).

In addition, imports and exports of various energy carriers are allowed.

7.3.2 Electricity

Vietnam electricity system can be divided into three sub-regions: Northern, Central and Southern, those are interconnected by back bone 500kV link. Hydropower can be developed in all three regions, coal-fired are dominant in the Northern while the Southern has significant gas resources. Load centers are located in Ho Chi Minh City in the South and Hanoi in the North. Vietnam is importing electricity neighboring countries that have big potential of hydropower such as Laos, China and Cambodia. More than 150 hundred power stations are put in the model, which contain several different power plant types, such as coal, gas, oil, hydro, nuclear power etc… Existing hydro and thermal power plants are presented in Figure 7-2.

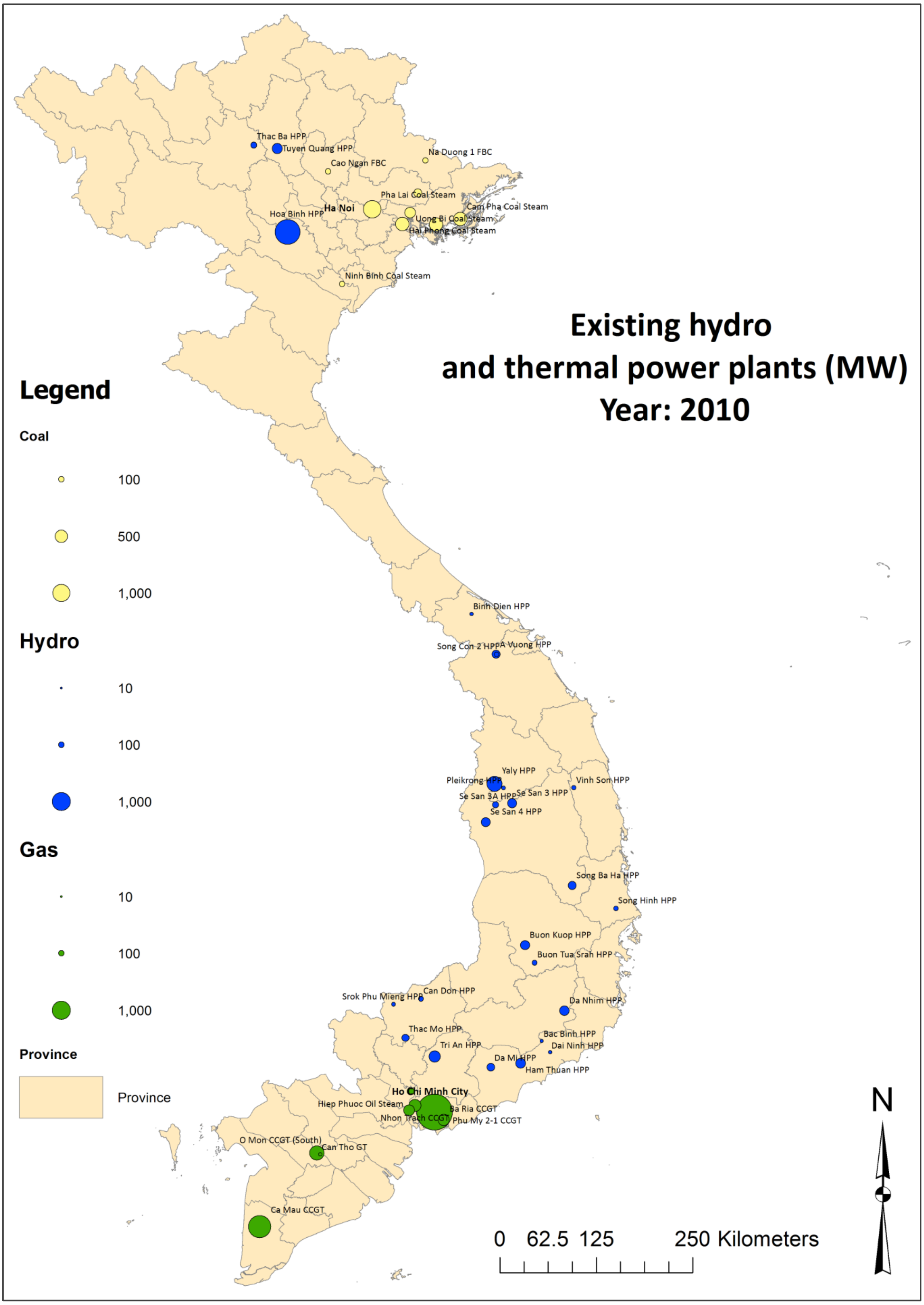

Figure 7-2: Capacity of existing power plants by 2010

Table 7-1: Characteristics of power plants

No.	Plant type	Units (MW)	Capacity (MW)	Base investment (EUR/kW)
1	Coal steam	2x220	440	947
		1x300	300	937
		2x300	600	925
		2x600	1200	850
		1000	1000	833
2	Gas steam	300	300	876
3	CCGT	450	450	637
		720	720	614
		750	750	609
4	Nuclear power			
	Ninh Thuan 1	2x1000		2182
	Ninh Thuan 2	2x1000		1939
5	Wind			1183
6	Photovoltaic			5175
7	Rice husk			1331
8	Bagasse			887
9	MSW			2218
10	Bio gas			1183
11	Geothermal			1848
12	Small hydro			1109

Source: convert from values in USD 2010 (Institue of Energy, 2009)

Coal power plants are mainly located in the North where rich anthracite coal deposits located. Gas thermal power plants are developed in the South along the coastal consuming natural gas from off-shore gas deposits. Hydro power plants are distributed in all three regions. Nuclear power plants are expected to be built in the Central. Distribution of current and potential power plants is shown in Figure 7-3 (small and decentralized renewable power plants were not added in this map).

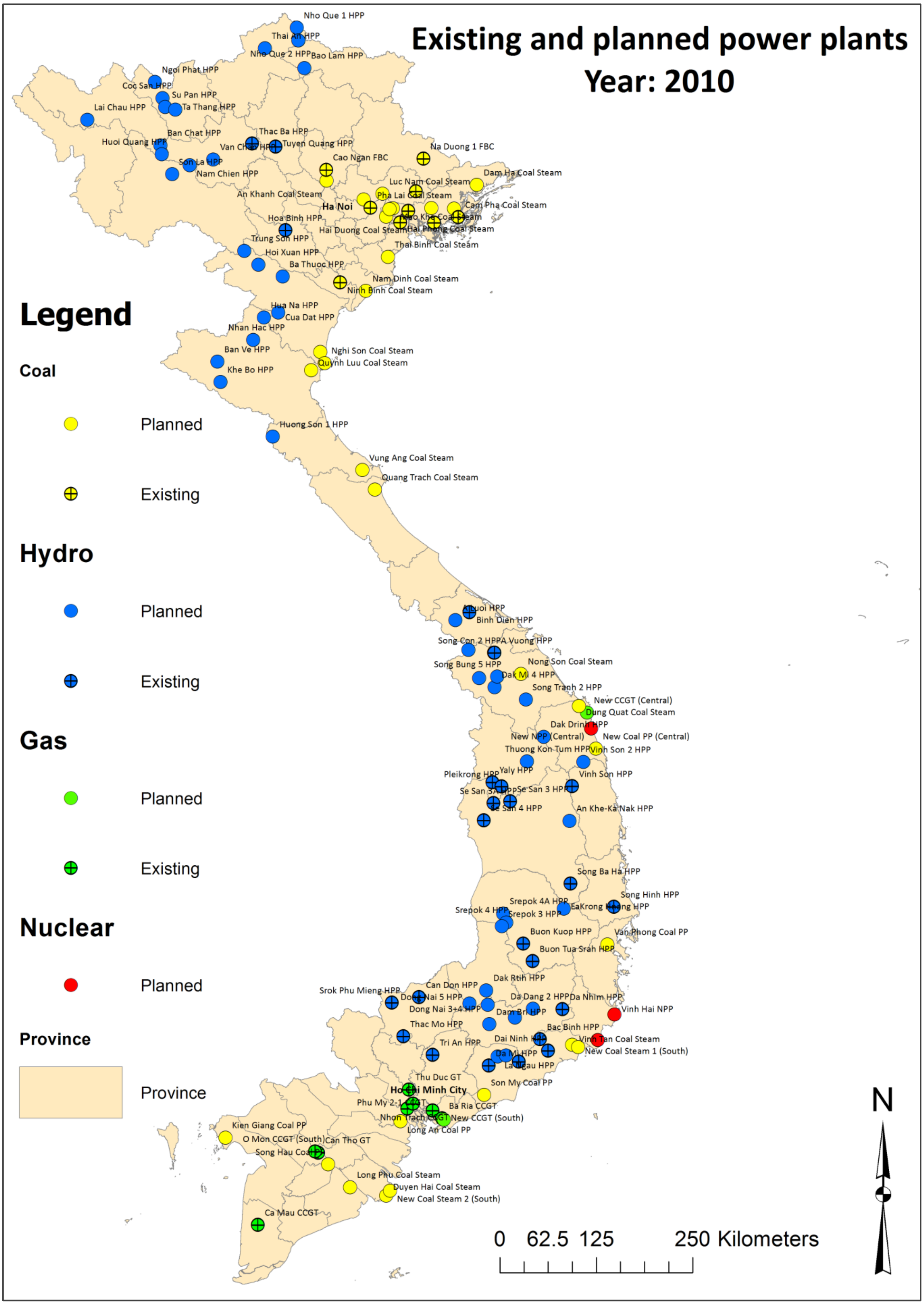

Figure 7-3: Existing and planned power plants in Vietnam (in 2010)

7.3.3 Coal Sector

The model includes mining, import and export of coal in Vietnam. Vietnam has important anthracite coal deposits in the North, which have been used for domestic demands such as power generation, cement, paper etc… and for export. Significant reserve amount of sub bituminous coal has been found underground in the Red River Delta. However, extraction of this coal is questionable due to concerns on food security, environment, and technology availability. The country is planning for importing steam coal for power plants in the Central and the South from 2015 onward.

7.3.4 Gas Sector

Vietnam has several off-shore natural gas fields in the Southern that have been currently using rather limited because of small downstream market. Natural gas is given priority to develop in future not only for power generation but also for other industries such as fertilizer… Off-shore natural gas is transmitted to inland by gas pipelines. Such infrastructure facilitates the promotion of natural gas use in Vietnam. Natural gas fields and corresponding pipelines in Vietnam are as follows:

- Cuu Long associated gas field and pipeline
- South Con Son natural gas field and pipeline
- Block B gas field and pipeline
- PM3-CAA gas field and pipeline

7.3.5 Oil Sector

Crude oil has been extracted offshore in the South of Vietnam. Before the operation of the first refinery, all crude oil were exported. The country imported all its oil product demand. Vietnam has one oil refinery in operation from the end of the year 2009, however, its capacity has met only about one third of the country's petroleum product demand. The 1st Refinery was scheduled in operation in 2005; however, its start is delayed until 2009 for some financial difficulties. After the first refinery using domestic crude oil, the 2nd and the 3rd are planned to come into the picture in 2015 and 2020. These refineries are expected to consume imported crude oil to produce some more refined products that could not be produced by the first Refinery.

7.3.6 Spatial Impacts

Spatial impacts are examined based on land occupied, quantity of people resettled, emissions by power plants. Land use for power plants are estimated based on specific data by coal, gas, and nuclear power plants. Data for land use and people resettled of hydro power projects are not enough for thoroughly estimation. Quantity of people resettled for each power plant was estimated based on land area and population density of power plants' location. Data on population density was taken at the district level of power plant locations.

Table 7-2: Data basis for examination of spatial impacts

Power plant type	Land occupied	People resettled	Source
Coal fired	11 MW per ha	Land area multiplied by population density	Quang Trach coal fired 2x660 MW [1]
Gas fired	26 MW per ha		Hiep Phuoc GCCT 2x390 MW in Ho Chi Minh City [2]
Nuclear	10 MW per ha		Nuclear power plants in Phuoc Dinh and Vinh Hai [3]

Emissions in the model include CO_2 and SO_2. Emissions factors are associated with energy carriers burnt.

Table 7-3: Emission factors

Fuel	C content (kg C/GJ)	CO2 content (thousand t/PJ)
Diesel	20.2	74.1
Fuel oil	20.9	76.6
Gasoline	18.9	69.3
Kerosene	19.8	72.6
Jet fuel	19.8	72.6
Liquefied natural gas	14	51.3
Liquefied pertroleum gas	17.2	63.1
Natutal gas	14	51.3
Crude oil	20	73.3
Lignite	26.2	96.1
Hard coal	26.2	96.1

7.3.7 Demand Sector

Demand sectors in Vietnam database are grouped into 5 main groups: (1) Agriculture, (2) Commercial, (3) Industrial, (4) Residential, and (5) Transport. However, each demand sectors is sub divided into three regions as described in electricity sector.

Service demand units are PJ for useful energy demands; billion passenger kilometers and billion ton kilometers for transport; billion lumen hour for lighting; kilotons of product for several specific industrial sectors; number of devices for some other technologies in residential and transport sectors. These service demands were projected based on economic outlooks as presented in Section 2.3.2.

7.3.8 Household Sector in Ho Chi Minh City

As mentioned in the model description, demand services in the residential sector of Ho Chi Minh City will be disaggregated. The disaggregation allows different kinds of devices competing to meet demands. Service demands are classified for five different dwelling types (rudimental, shop house, row house, apartment, and villa) including: (1) Cooling; (2) Cooking; (3) Lighting; (4) Refrigerator; (5) Water heater; and (6) Others.

These service demands are supplied by alternative household appliances which are characterized by efficiency, cost, fuel, lifetime etc… For example, lighting demand (measured in Lumen-hour) can

[1] Source: (Institute of Energy, 2011)

[2] Source: (Institute of Energy, 2012)

[3] Source: (Institute of Energy, 2009)

be provided by comparative lighting devices, such as incandescent, compact fluorescent, tube fluorescent, and thin tube fluorescent lamps. Demands are projected based on current stocks of appliances and increasing trends of household in future with growth rate taken from past years of 2002-2010. Lighting demand is presented in lumen-hours, amount of luminous energy. Demands for air conditioner, refrigerator, and water heater are exactly quantity of these devices in houses. Quantity for these large household appliances in future is projected in taking into account the penetration rate of them in relations to income trend. Demands are projected up to 2030 based on the trends in the past years from survey data in 2002-2010.

Table 7-4: Selected planned items in HCMC up to 2030

	Unit	2010	2015	2020	2030
GDP per capita	USD/person	3,100	4,856	8,430	13,340
Living area	m2/person	15.7	17.0	19.8	27.8
Population	Mililion persons	7.396	8.2	9.25	10

Source: Prime Minister’s Decision 2631 QD/TTg dated on 31st December 2013 on Approval for Socio-Economic Development Plan of HCMC up to 2020, with outlook to 2030

As projected, population of HCMC may reach to 10 million persons in 2030 from more than 7 million persons as in 2010. Average living area grows to 27.8 m^2 per person in 2030 while nominal GDP per capita to USD 13,340. Development plan for household building includes five subprograms:

- Replacement for out-of-date apartment buildings
- Social houses
- Resettlement houses
- Resettling rudimental houses along rivers and channels
- Houses for officials

Based on trends in the past as well as development plan of the City, service demands were forecasted.

Table 7-5: Demand classification and basis for forecast

Demand	Unit	Basis for forecast
Cooling	Quantity of air conditioner	Past trend in 2002-2010 and saturated level related to GDP per capita
Cooking	Joules	Past trends of living area and energy use intensity
Lighting	Lumen hour	Past trends of living area and electricity use intensity
Others	Joules	Past trends of living area and electricity use intensity
Refrigerator	Quantity of refrigerator	Past trend in 2002-2010 and saturated level related to GDP per capita
Water heating	Quantity of water heater	Past trend in 2002-2010 and saturated level related to GDP per capita

Based on findings from the previous part, it is reasonable to forecast based on quantity of appliance and living area. Cooling demand, for example, was projected with the following formula:

$$CD_t = CD_{2010} \times AG_{02-10}$$

In which:

CD_t: quantity of air conditioner in the year t

AG: average annual growth rate of air conditioner during 2002-2010

Lighting demand was projected as follow:

$$LD_{t=}LI_{2010} \times AGLI_{02-10} \times AGLA_{02-10}$$

In which:

LD_t: lighting demand in lumen hour in year t

LI: lighting intensity in lumen hour per m^2 in 2010

AGLI: average annual growth rate of electricity use intensity during 2002-1010

AGLA: average annual growth rate of living area during 2002-2010

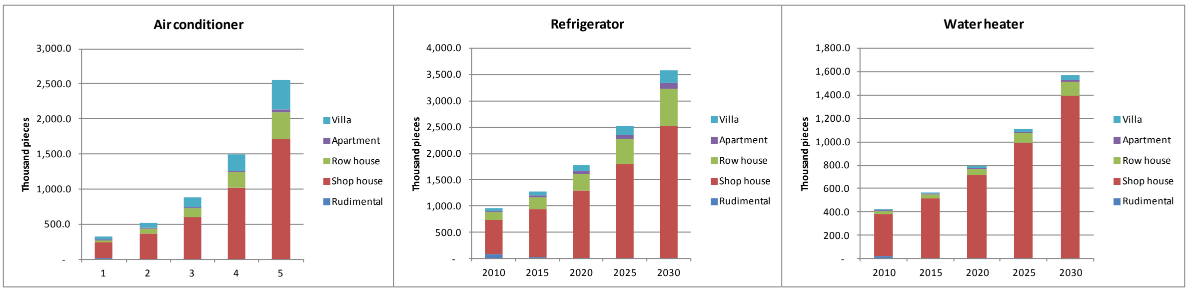

Figure 7-4: Projected quantity of air conditioner, refrigerator and water heater

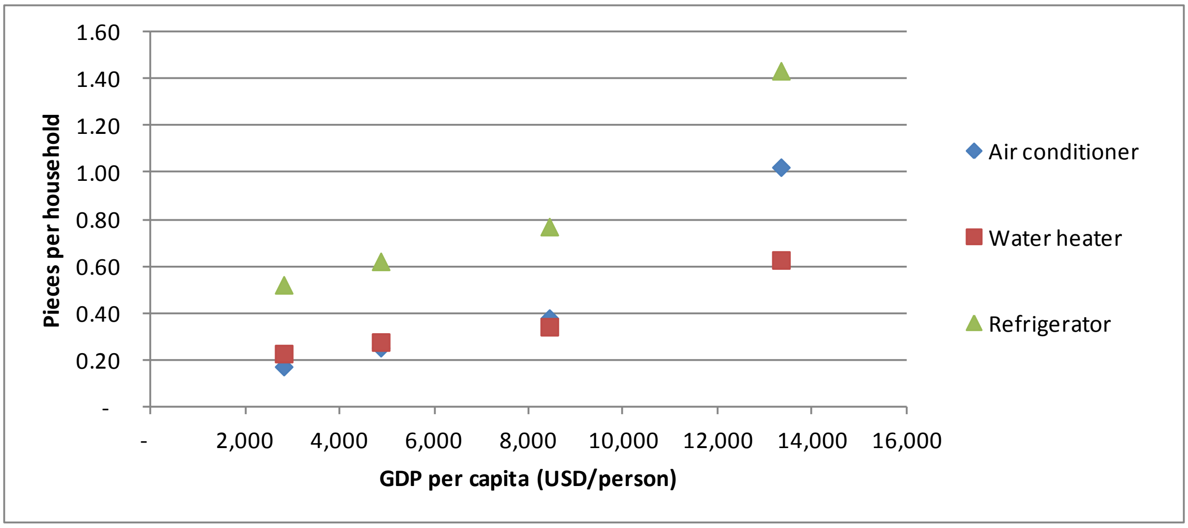

Figure 7-5: Forecast results for quantity of air conditioner, refrigerator and water heater

Demand forecast results show that quantity of refrigerator reaches to 1.4 pieces per household in 2030. The penetration rate come to 100 percent with GDP per capita would reach to more than USD 10,000 per year. Quantity of air conditioner increases from 0.2 to 1 piece per household. Quantity of water heater rises from about 0.2 to some 0.6 pieces per household.

Table 7-6: Demand projections for households of Ho Chi Minh City

Demand	Unit	2010	2015	2020	2025	2030
Cooling (rudimental)	1000 pcs	18.1	5.9	1.9	0.6	0.2
Cooling (shop house)	1000 pcs	213.0	358.9	604.7	1,019.0	1,717.1
Cooling (row house)	1000 pcs	39.7	70.0	123.3	217.4	383.1
Cooling (apartment)	1000 pcs	3.6	6.6	12.2	22.4	41.3
Cooling (villa)	1000 pcs	43.4	76.5	134.8	237.5	418.6
Cooking (rudimental)	PJ	0.5	0.2	0.1	0.0	0.0
Cooking (shop house)	PJ	2.6	3.8	5.5	8.1	11.9
Cooking (row house)	PJ	1.2	1.8	2.8	4.3	6.6
Cooking (apartment)	PJ	0.2	0.2	0.4	0.6	1.0
Cooking (villa)	PJ	0.2	0.3	0.5	0.7	1.1
Lighting (rudimental)	B Lm-hr	1,102.0	361.1	118.3	38.8	12.7
Lighting (shop house)	B Lm-hr	11,314.4	16,624.6	24,427.0	35,891.3	52,736.0
Lighting (row house)	B Lm-hr	3,331.6	5,126.0	7,887.0	12,135.1	18,671.4
Lighting (apartment)	B Lm-hr	423.1	681.4	1,097.4	1,767.4	2,846.4
Lighting (villa)	B Lm-hr	1,061.4	1,559.6	2,291.6	3,367.1	4,947.3
Other (rudimental)	PJ	0.7	0.2	0.1	0.0	0.0
Other (shop house)	PJ	3.8	6.5	10.9	18.4	31.0
Other (row house)	PJ	1.8	3.1	5.5	9.7	17.1
Other (apartment)	PJ	0.2	0.4	0.8	1.4	2.6
Other (villa)	PJ	0.3	0.6	1.1	1.9	3.4
Refrigerator (rudimental)	1000 pcs	87.4	28.7	9.4	3.1	1.0
Refrigerator (shop house)	1000 pcs	650.8	912.7	1,280.2	1,795.5	2,518.3
Refrigerator (row house)	1000 pcs	152.2	223.7	328.6	482.9	709.5
Refrigerator (apartment)	1000 pcs	19.9	30.7	47.2	72.6	111.7
Refrigerator (villa)	1000 pcs	53.6	78.7	115.6	169.9	249.6
Water heating (rudimental)	1000 pcs	23.5	7.7	2.5	0.8	0.3
Water heating (shop house)	1000 pcs	360.9	506.2	709.9	995.7	1,396.5
Water heating (row house)	1000 pcs	25.5	37.4	55.0	80.8	118.8
Water heating (apartment)	1000 pcs	2.9	4.4	6.8	10.5	16.1
Water heating (villa)	1000 pcs	8.0	11.8	17.3	25.5	37.4

7.3.9 Scenarios

In order to investigate impacts of different energy efficiency options in the domestic sector, a set of scenario will be required. These scenarios, which reflect changes in economic, technical and climatic factors, include Business-as-Usual and other scenarios. The BAU scenario will be built based on the current situation on economic, technology. The alternative scenarios represent different trajectories of employment of energy efficiency and renewable energy technologies in households. The scenarios included in the study are:

Table 7-7: Scenarios

No.	Name	Description
1	BAU	Business-As-Usual: limited penetration of energy efficient devices
2	EEC	Energy efficiencies of household appliances in HCMC increase to the highest level of current MEPS in 2015 and then increased to level of BAT in 2020 onward
3	ELS	Energy efficiencies rise similarly to EEC scenario plus elastic demands for households in HCMC using elasticities for electricity and LPG demands

The two later scenarios depict an improvement in energy efficiency of household appliances such as air conditioner, refrigerator, lamp, water heater and windows. These efficiencies increase to the highest level of current Vietnamese MEPS in 2015 and then rise to the level of current best technologies available. Other sectors are kept the same in all three scenarios. The last scenario features with elastic demands for households in HCMC. This scenario used results of elasticity estimation for electricity and LPG demands in Chapter 5. Own-price elasticities for electricity and LPG demands in household are estimated at -0.611 and -0.533 respectively. These elasticities were applied for the household demands in HCMC. The rebound effect may be approximated by the own price elasticity of energy demand for the relevant energy service (Sorrell & Dimitropoulos, 2008). The rebound effect results in part from an increased consumption of energy services following an improvement in the technical efficiency of supplying those services. This scenario therefore aims to investigate changes in demands of households due to changes in demand prices. Scenario analysis allows model specifying the impacts of these household energy efficiency options on energy consumption, energy development, emissions, and economic aspects.

More information on the model can be found in Section 10.5 in Appendix.

7.4 Results

Total discounted cost report the total cost incurred by the system to meet the imputed demands. Emission and energy consumption amounts are reported for the whole period 2010-2030. The main output shows a remarkable reduction in total cost in case of energy efficiency promotion. The main outputs for the three different scenarios are summarized in Table 7-8.

Table 7-8: Cumulative values for total cost, emission and primary energy consumption in three scenarios

Case Name	Unit	BAU	EEC	ELD
Total discounted cost	**EUR million**	712,000	710,669	710,368
Emission				
CO2 emission	**Million tons**	15,729	15,272	15,294
SO2 emission	**Thousand tons**	40,837	39,397	39,428
Primary energy consumption				
Hydro	MTOE	396	396	396
Coal	MTOE	2,022	1,965	1,967
Oil	MTOE	1,316	1,327	1,327
Gas	MTOE	407	393	396
Nuclear	MTOE	247	247	247
Renewable	MTOE	498	498	498
Total	**MTOE**	4,887	4,826	4,831

By promoting energy efficient devices in household sector in HCMC, cost can be saved by more than EUR 1.33 billion. CO_2 emissions can be reduced also by about 457 million tons in 2010-2030. SO_2 emission, the main cause for acid rain, reduces by 1.44 million tons in the same period. In term of energy consumption, a large amount of coal can be avoided in energy efficiency scenarios. Coal consumption would reduce by 57.5 MTOE in the study horizon. These are mainly imported coal for power plants in the Central and the South of the country. Gas consumption also can be saved by 14.1 MTOE in energy efficiency scenario. Total primary energy may be cut by 60.7 MTOE in total. Cost saving amount from the energy efficiency scenario can be used as a basis for calculating a budget for supporting energy efficiency and conservation in Vietnam.

In scenario with elastic demand (i.e. ELD), due to reductions in service demand prices, households have propensity to increase their demands. The total cost even though can be cut by EUR 1.63 billion as compared to the BAU scenario. CO_2 emission in this scenario reduces by 435 million tons which is less than in the EEC scenario. This scenario show the rebound effect when service demand price decrease due to the presence of energy efficiency. Both reductions in energy consumption and CO_2 emission are not as large as expected. This effect should be paid extra attention when projecting energy demand in future with energy efficiency options.

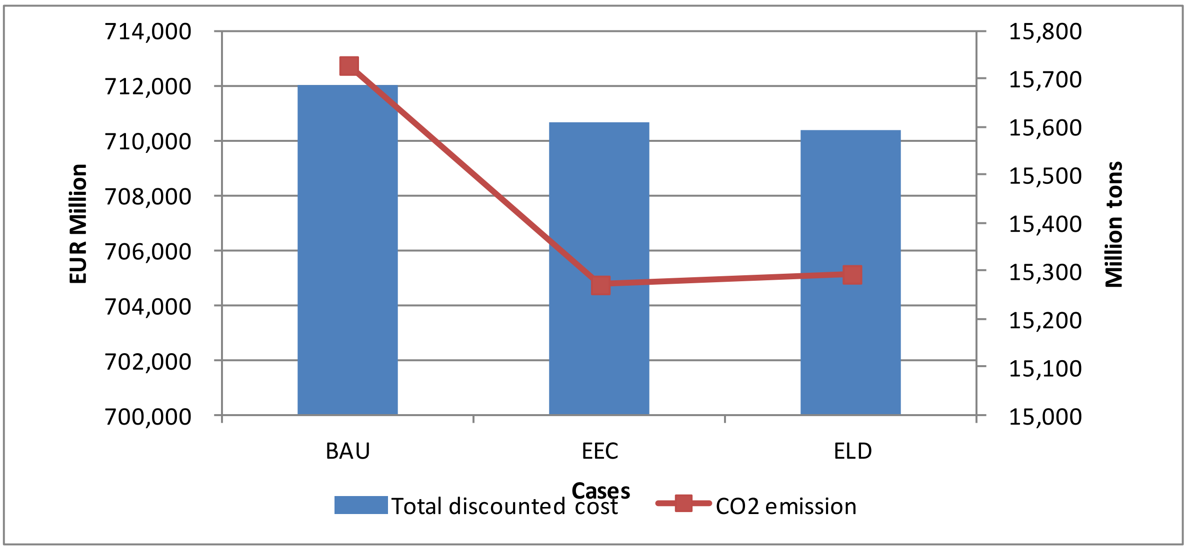

Figure 7-6: Comparisons of total cost and CO_2 emission in the three scenarios

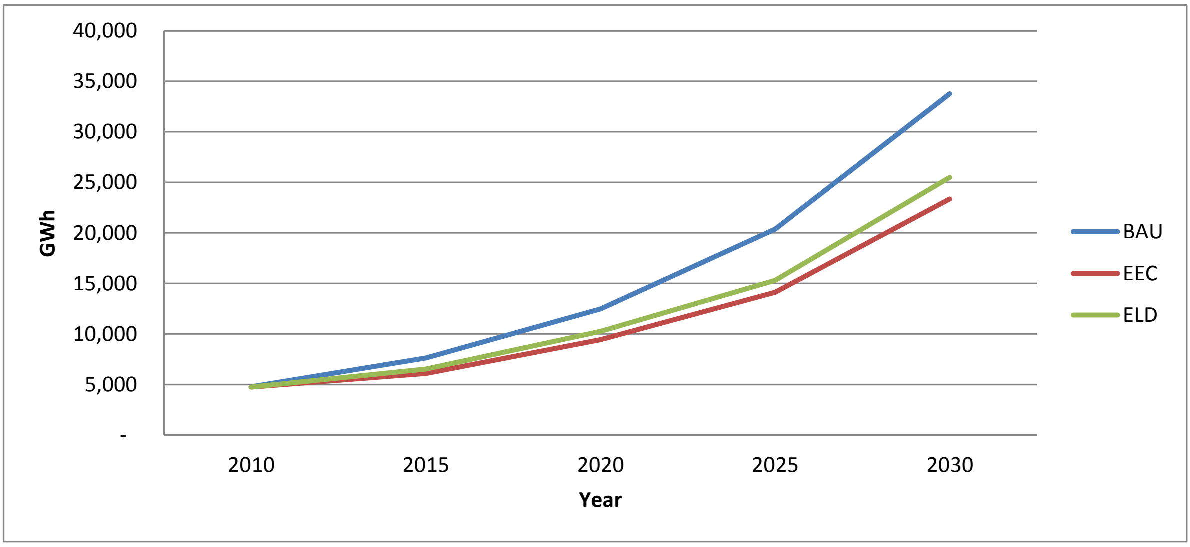

Figure 7-7: Comparison of electricity consumption by households in HCMC in the three scenarios

Penetration of efficient appliances results in reduction of electricity demand for household in HCMC of 3,317 GWh in 2020 and of 10,884 GWh in 2030. Energy efficiency options help save 26 percent of total electricity consumption in 2020 and 32 percent in 2030. The main reduction is air conditioner load. In the elastic demand scenario, electricity demand reduces as compared to BAU scenario, but increases by some 11 percent as compared to EEC scenario due to the rebound effect. Figure 7-7 compares trends of electricity consumption by the three scenarios. Energy efficiency helps reduce growth rate of electricity consumption of households in HCMC in 2010-2030 from 10.3 percent to 8.3 percent per annum.

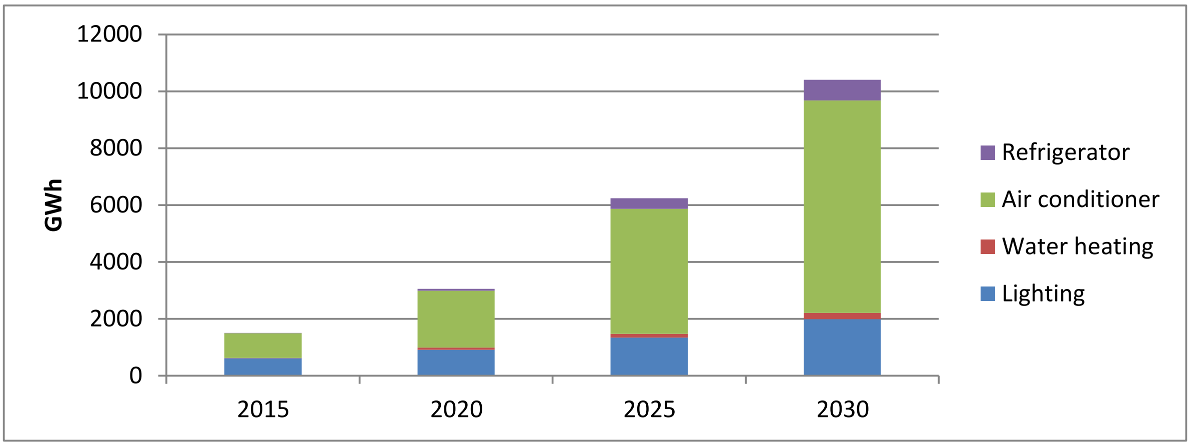

Figure 7-8: Electricity saving amount by four main end-uses

Figure 7-8 shows electricity saving amount by the four main end-uses. Efficient air conditioner and windows helps reduce the largest amount of electricity consumption. High penetration rate of air conditioner increases much cooling load of households in future. Energy efficient lamps save the second largest amount. Solar water heater not only saves electricity but also LPG in households.

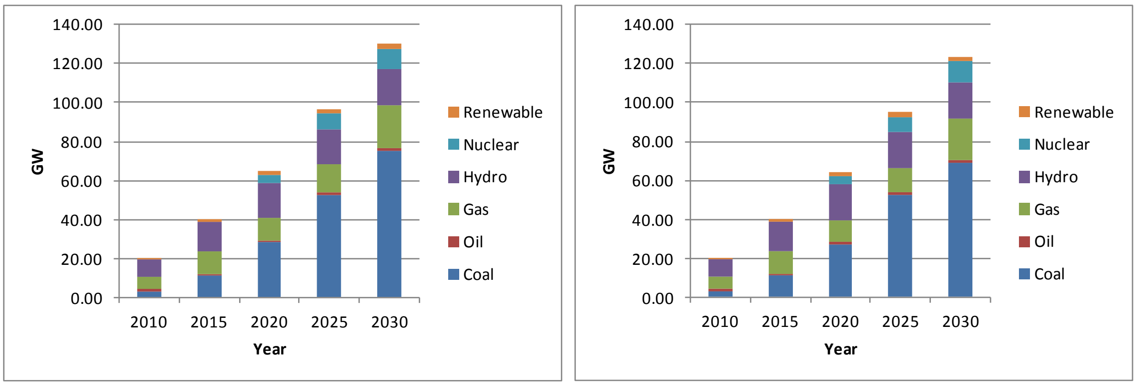

Figure 7-9: Comparison of generating capacity in BAU (left) and EEC (right) scenarios

As can be seen in the two above figures, a large amount of generating capacity can be avoided in energy efficiency scenario. About 1.2 GW can be reduced by 2020 and more than 6.6 GW by 2030 if energy efficient devices would be highly penetrated in households. Avoided capacity is mainly coal fired power plants in the South of the country. It is estimated that about 3 big coal fired power stations with total capacity of 6GW can be avoided in the energy efficiency scenario. Moreover, one gas fired station with capacity of 660 MW would be avoided in the Central, which consumed expensive imported gas from abroad. This amount of avoided capacity is almost three times larger the biggest hydro power plants of the country, which is Son La hydropower plant with capacity of 2,400 MW. Therefore, 5 percent of total capacity can be saved thanks to efficiency improvement in households of the City. Hydro and nuclear power plants (at the estimated cost by local consultant, which was lower than international reports on investment cost of nuclear power plant) are not affected from the changes of energy efficiency. The nation’s hydro power will be mobilized up to its maximum potential in 2020. CO_2 emission can be saved due to the decrease in coal thermal generating capacity. Coal thermal is the main source of CO_2 among power plants. In general, promotion of energy efficiency in household sector in HCMC brings about both economic and environmental benefits. Moreover, the country enhances energy security also by reducing energy imports from abroad.

Table 7-9 shows comparison of power plant capacity for the two scenarios. Due to ongoing and planned power plants, which were already built or prepared to build, avoided capacity in 2015 is null. Benefit of energy efficiency measures is avoided electricity generation, which amount of 1,650, 7,297, and 47,614 GWh in 2015, 2020, and 2030 respectively.

Table 7-9: Comparison of generating capacity in two scenarios

Scenario	Type	2010	2015	2020	2025	2030
Business-as-usual	Coal	3.14	11.21	28.31	52.48	75.30
	Oil	1.05	1.05	1.05	1.28	1.28
	Gas	6.69	11.27	11.54	14.26	22.04
	Hydro	8.53	15.39	18.09	18.33	18.50
	Nuclear	0.00	0.00	4.00	8.00	10.70
	Renewable	0.87	1.48	2.10	2.13	2.19
	Total	**20.28**	**40.40**	**65.09**	**96.48**	**130.01**
Energy efficiency and conservation	Coal	3.14	11.21	27.24	52.40	69.30
	Oil	1.05	1.05	1.05	1.28	1.28
	Gas	6.69	11.27	11.42	12.70	21.38
	Hydro	8.53	15.39	18.09	18.33	18.50
	Nuclear	0.00	0.00	4.00	8.00	10.70
	Renewable	0.87	1.48	2.10	2.19	2.19
	Total	**20.28**	**40.40**	**63.90**	**94.90**	**123.35**
Difference in total		-	-	1.19	1.58	6.66

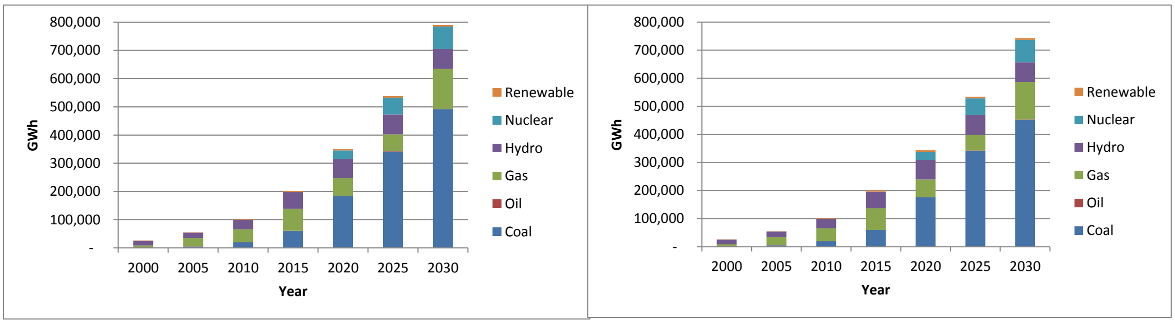

Figure 7-10: Comparison of electricity generation in BAU (left) and EEC (right) scenarios

Due to demand reduction in HCMC, the main load electric center in the South, power plant capacity in this region can be reduced as consequences. The map in Figure 7-11 shows the changes of power plant developments in two scenarios by 2030. Major changes of coal and gas fired power plants are marked with red circulars. Maps for capacity expansion under the two scenarios by 2020 and 2030 are presented in Figure 7-14, Figure 7-15, Figure 7-16 and Figure 7-17.

Avoided power plants results in reduction of land use for power plant development and quantity of people resettled. This change is depicted in Table 7-10. In the BAU scenario, power plants occupy land amount of 3,444 ha up to 2020, and of 5,346 ha up to 2030. Coal thermal power accounts for nearly 80 percent of this land amount by 2030. Energy efficiency activities reduce the land use for power development by 102 ha by 2020 and up to 469 ha by 2030.

Table 7-10: Comparison of quantity of new land use for thermal power plants in two scenarios

Plant type	Unit	Business-as-usual		Energy efficiency		Difference	
		2020	2030	2020	2030	2020	2030
Coal	Ha	2,560	4,272	2,463	3,824	97	448
Gas	Ha	484	404	480	383	5	21
Nuclear	Ha	400	670	400	670	-	-
Total	**Ha**	3,444	5,346	3,342	4,877	102	469

In the BAU scenario, power plants cause more than 17 thousand peoples leaving their houses by 2020 and other 22 thousand people by 2030. In the energy efficiency scenario, quantity of resettled people reduces by 400 persons by 2020 and other 1975 persons by 2030. Quantity of displaced people by thermal power plants is presented in Table 7-11.

Table 7-11: Comparison of quantity of people resettled by thermal power plants in two scenarios

Plant type	Unit	Business-as-usual		Energy efficiency		Difference	
		2020	2030	2020	2030	2020	2030
Coal	persons	12,572	15,444	12,189	13,548	383	1,896
Gas	persons	3,517	1,638	3,500	1,560	18	78
Nuclear	persons	1,585	5,254	1,585	5,254	-	-
Total	**persons**	17,675	22,337	17,274	20,362	400	1,975

Risks to displaced people by power plants may consist of land loss, jobless, homeless, health problems, resource inaccessibility (Institute of Energy, 2011). Energy efficiency, therefore, mitigate emerged problems and issues related to space clearing, land compensation, people livelihood, and environment protection. Bearing in mind the risks to displaced communities which are mainly the poor, options for avoiding power plants is extremely meaningful in a developing country. Comparisons for new land occupied and displaced people in two scenario are presented in Figure 7-12 and Figure 7-13.

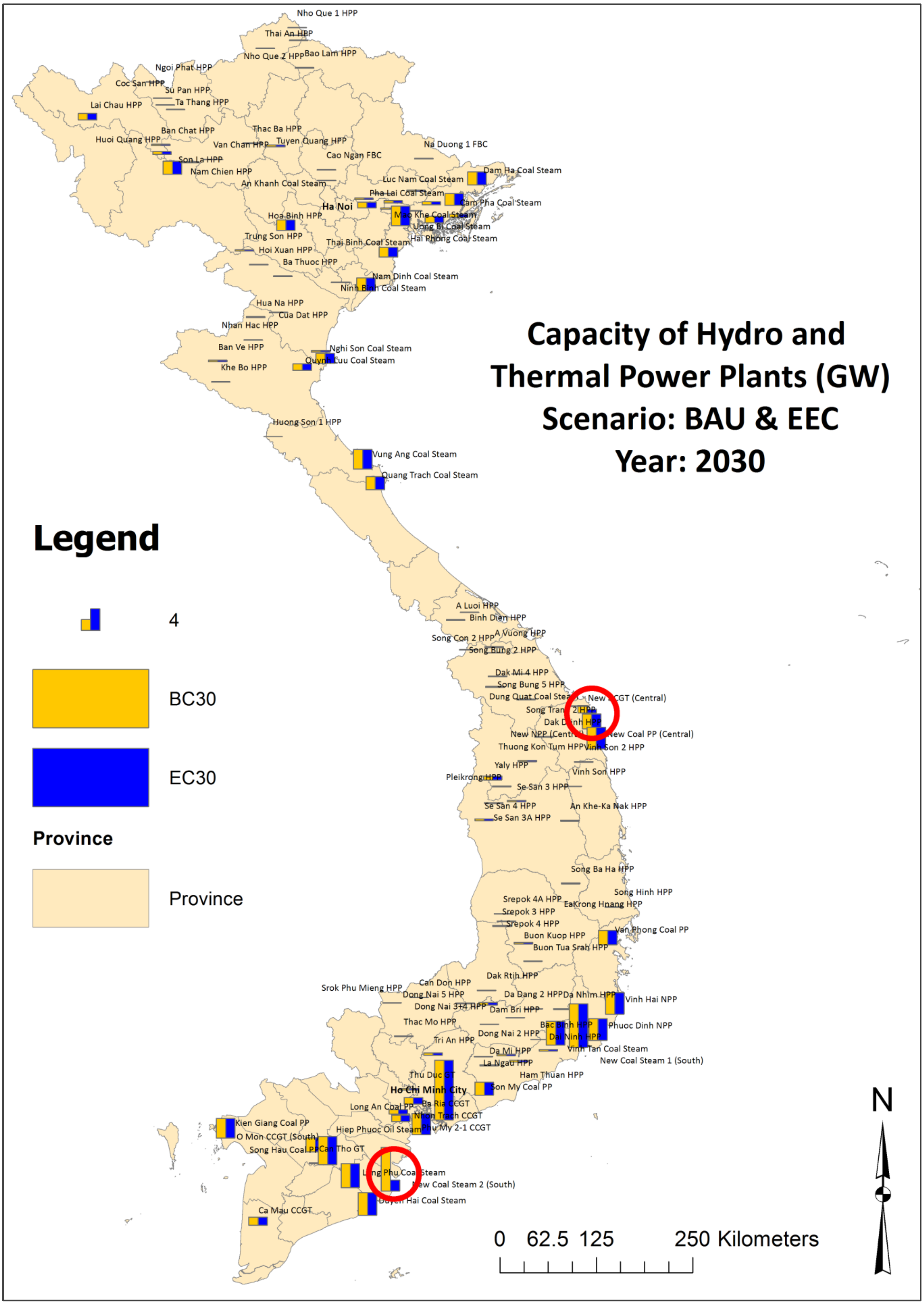

Figure 7-11: Comparison of power plant capacity in 2030 in two scenarios

Location and capacity of all power plants in 2020 and 2030 are presented fully in Table 10-4, Table 10-5, Table 10-6, and Table 10-7 in Appendix.

Table 7-12 shows total emission amounts by the two scenarios. CO_2 and SO_2 emissions can be saved in the energy efficiency scenario. Energy efficiency activities are able to reduce 6 million tons of CO_2 in 2020 and up to 81 million tons in 2030 when the large amount coal fired power will be built. It was estimated that annual external cost for emissions by power plants amount of USD 9.7 billion, which is higher than annual investment of power sector (Institute of Energy, 2011).

Table 7-12: Emissions cut in the two scenarios

Emission	Scenario	2010	2015	2020	2025	2030
CO2 (million tons)	BAU	122	233	453	828	1,391
	EEC	122	232	447	825	1,310
SO2 (thousand tons)	BAU	157	239	475	1,149	2,299
	EEC	157	239	474	1,127	2,296

Two displaced communities can be avoided belong to Vinh Long and Quang Ngai provinces where a coal and a gas fired power plant would be built up to 2030. Figure 7-12 and Figure 7-13 show graphically changes in amount of land occupied and quantity of displaced people by the two power stations.

After 2020, major candidates for power development in Vietnam are: coal, gas and nuclear. depicts the trend for power capacity expansion. The country expects to mobilize all of its hydro power resources up to 2020 (about 19 GW). Domestic natural gas reaches to its peak of supply in 2020. After 2020, importing LNG for gas fired power plants becomes an alternative. With the current estimated cost for the nuclear power plants by local consultants, which investment costs in the range of USD 2600 to 3000 per MW, nuclear is economic viable. Nuclear is planned to start operating in 2020 in Ninh Thuan province and then expanded to more than 10 GW up to 2030. The main candidates for power supply are then coal fired and nuclear power plants. The first candidate is termed with “dirty” energy which challenges the tackling of climate change. The second hides extreme dangers in case of accident. Promoting energy efficiency and conservation is consequently a dispensable pathway for the country to guarantee for its sustainable development. Energy efficiency for households in Vietnam can be promoted by employing different supporting measures:

- Increased MEPS by time: the current MEPS is low as compared to other countries’ MEPS and current best available technologies. It should be improved in the years to come.
- Accelerating implementation of labeling program: labeling program so far is seriously behind the schedule. The program should be accelerated with focus on air conditioner and lamp markets.
- Subsidies, soft loan, and/or tax reduction for energy appliance: Vietnam is mainly importing appliances from abroad, low tax scheme should be applied for energy efficient appliances.
- Innovative communication tools: Public awareness and information campaigns constitute an important element to support energy efficiency and to promote energy efficiency policies and programs.
- Effective monitoring and evaluation scheme: this relates to collecting data, detect success or failure factors, and support continuous improvements. This is very important to defend public commitments and attract complementary funding for energy efficiency.

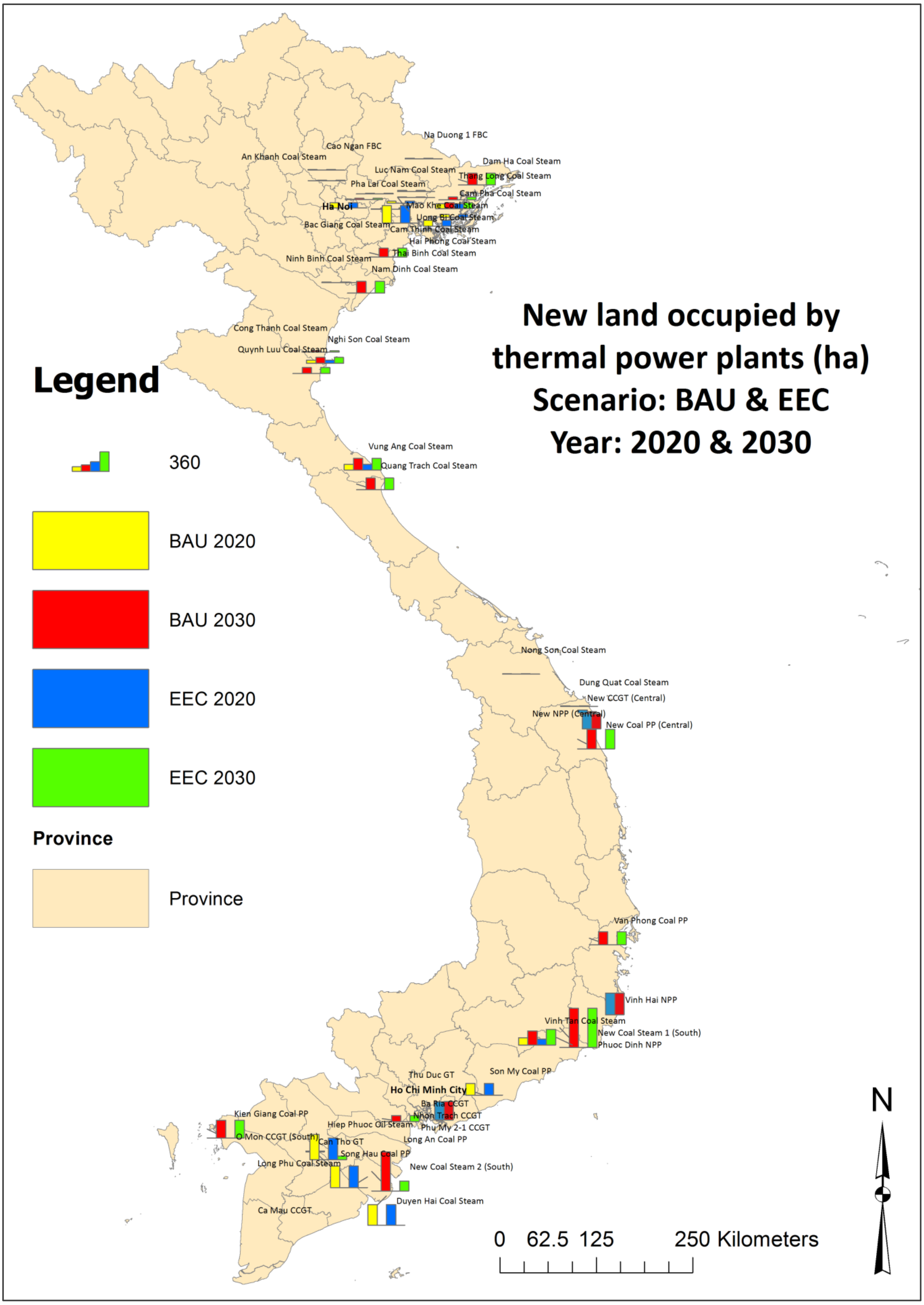

Figure 7-12: Comparison of land occupied by thermal power plants in 2030 for the two scenarios

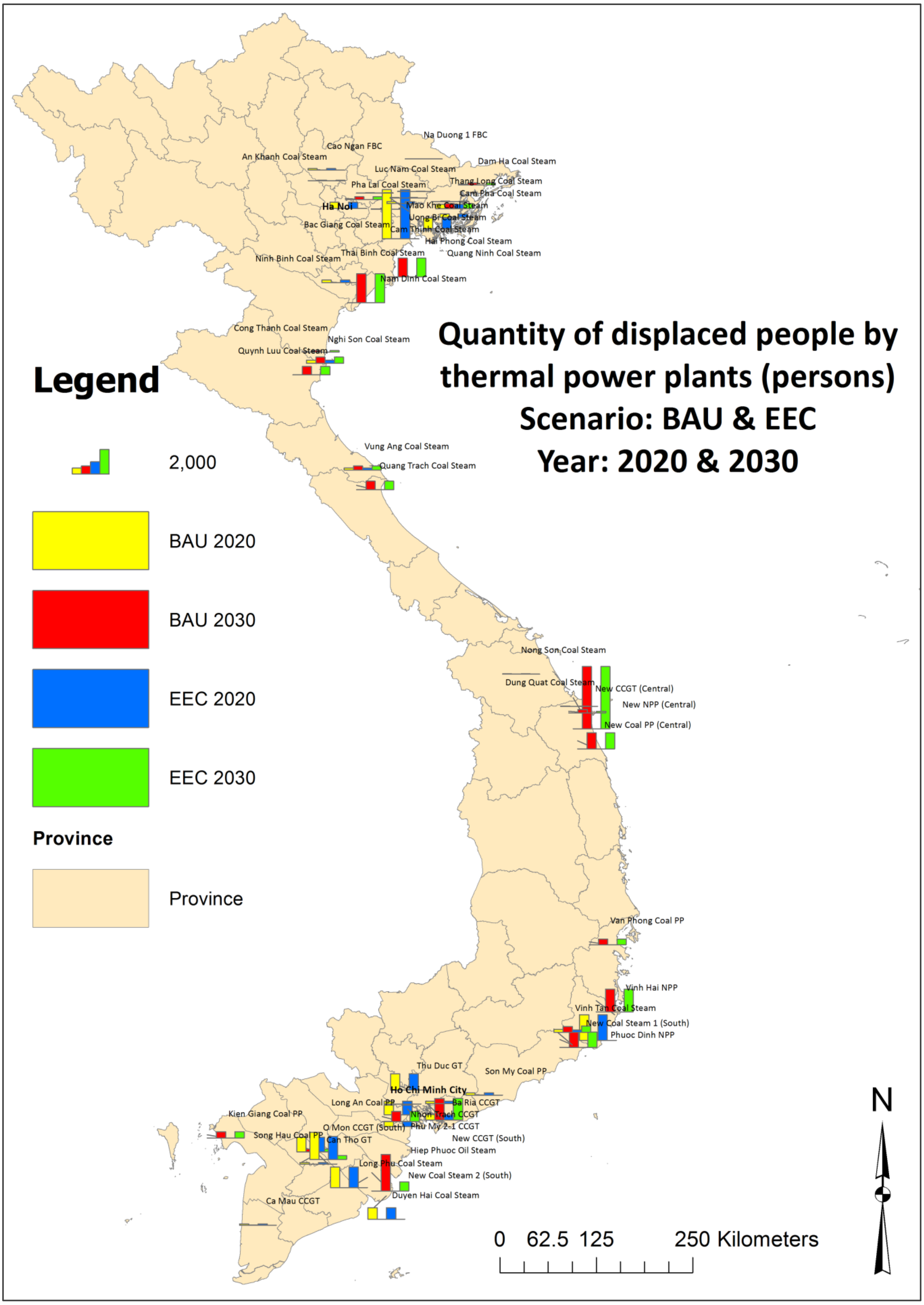

Figure 7-13: Comparison of displaced people by thermal power plants in 2030 for the two scenarios

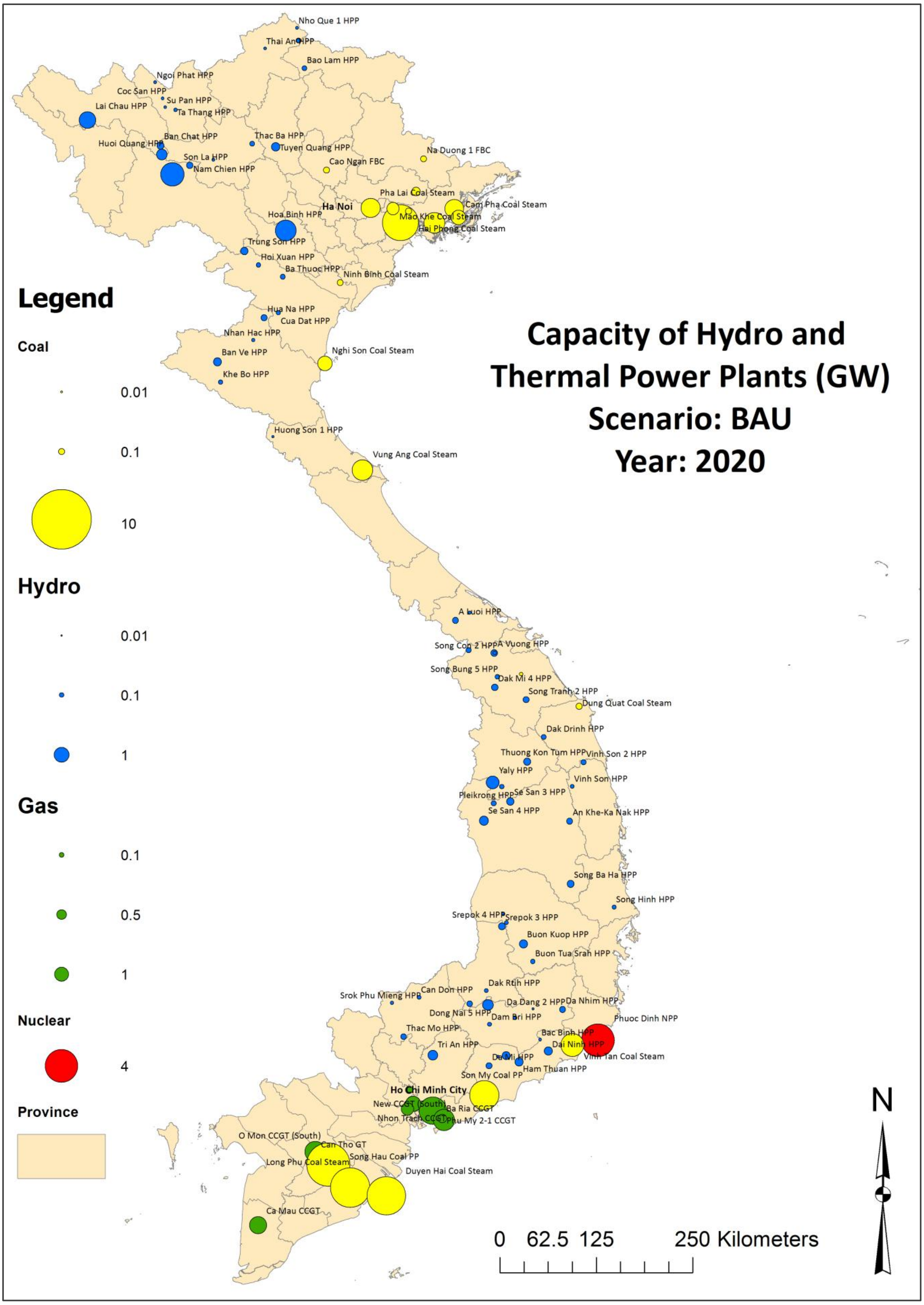

Figure 7-14: Capacity expansion of hydro and thermal power plants by 2020 under BAU scenario

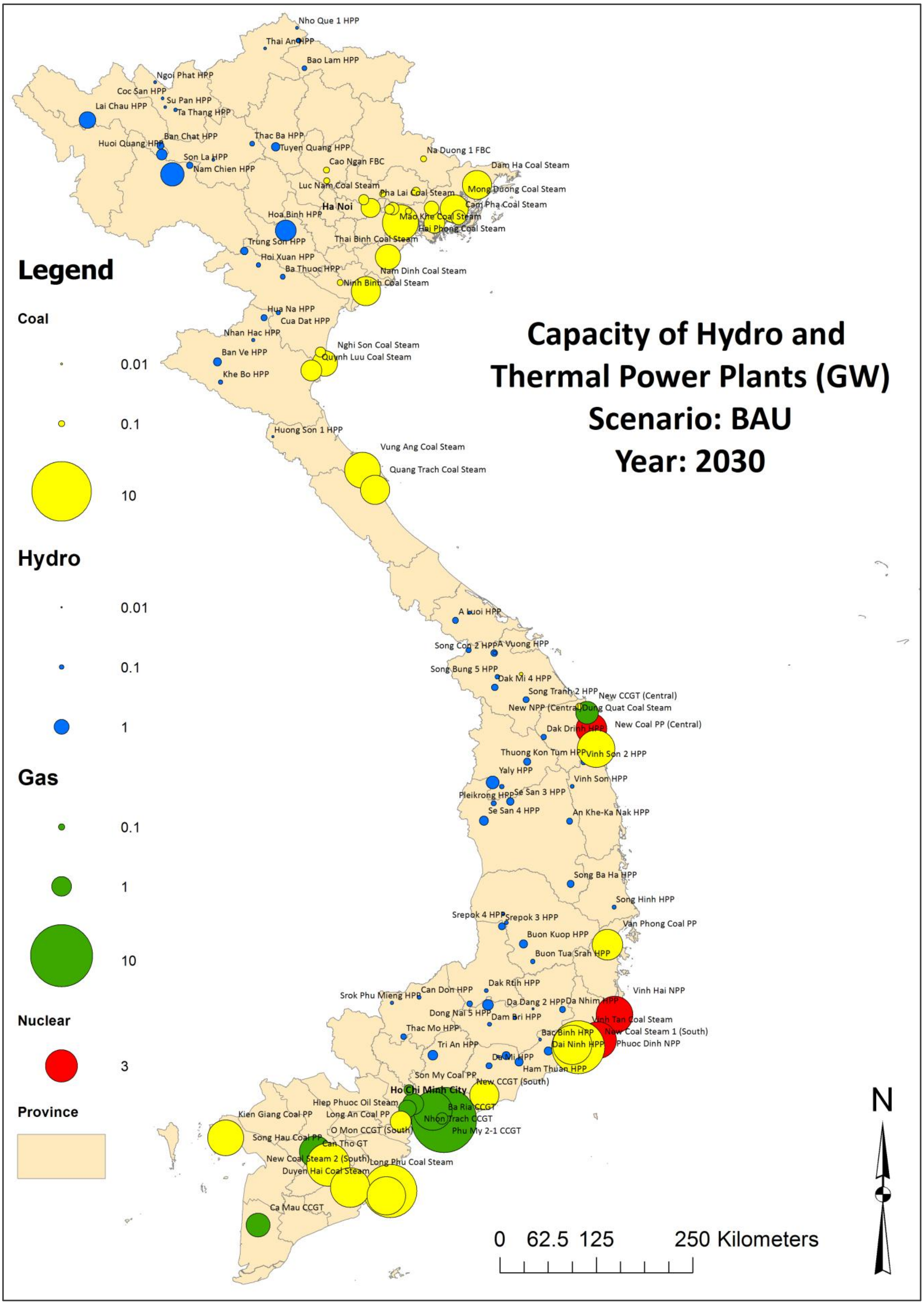

Figure 7-15: Capacity expansion of hydro and thermal power plants by 2030 under BAU scenario

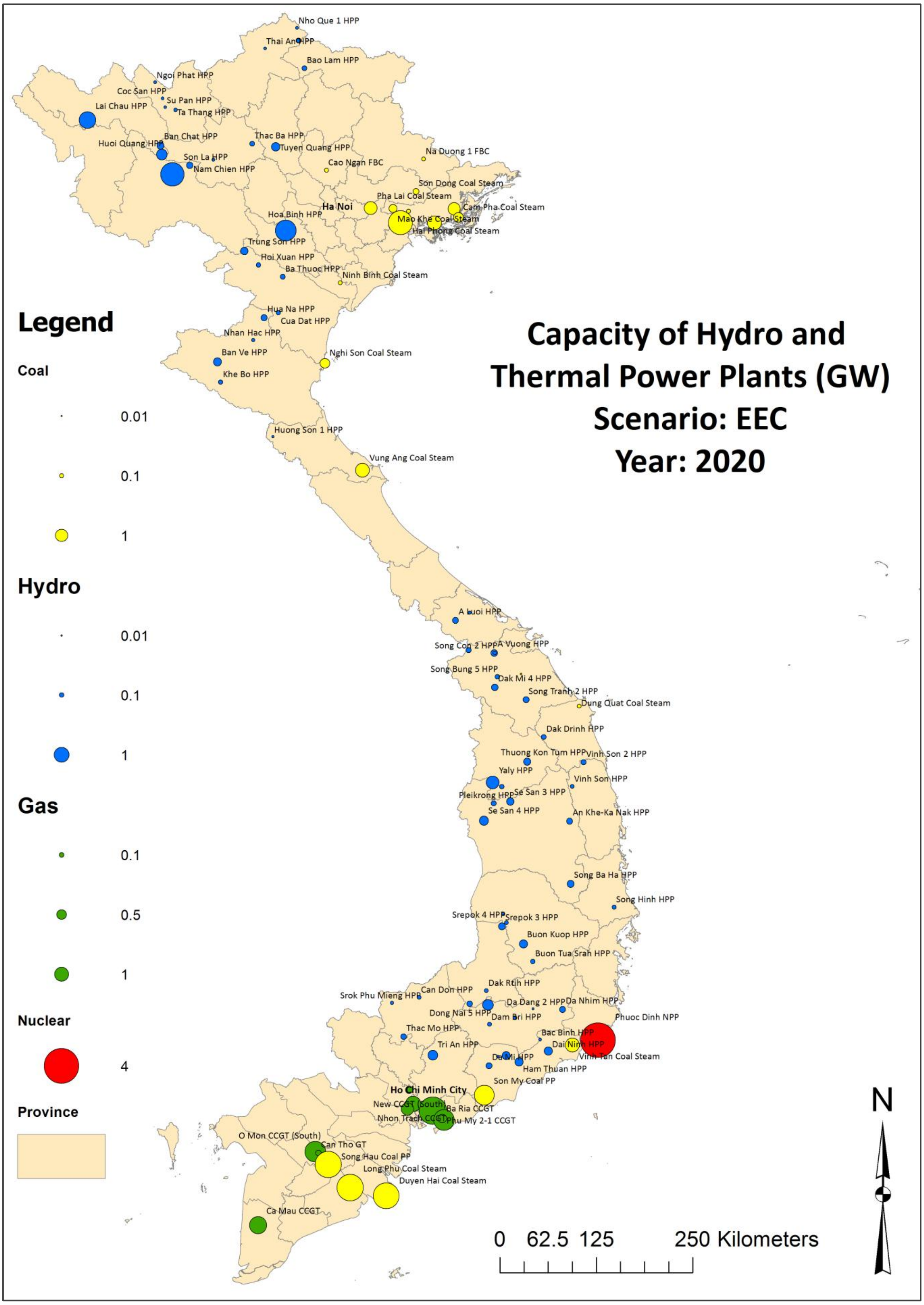

Figure 7-16: Capacity expansion of hydro and thermal power plants by 2020 under EEC scenario

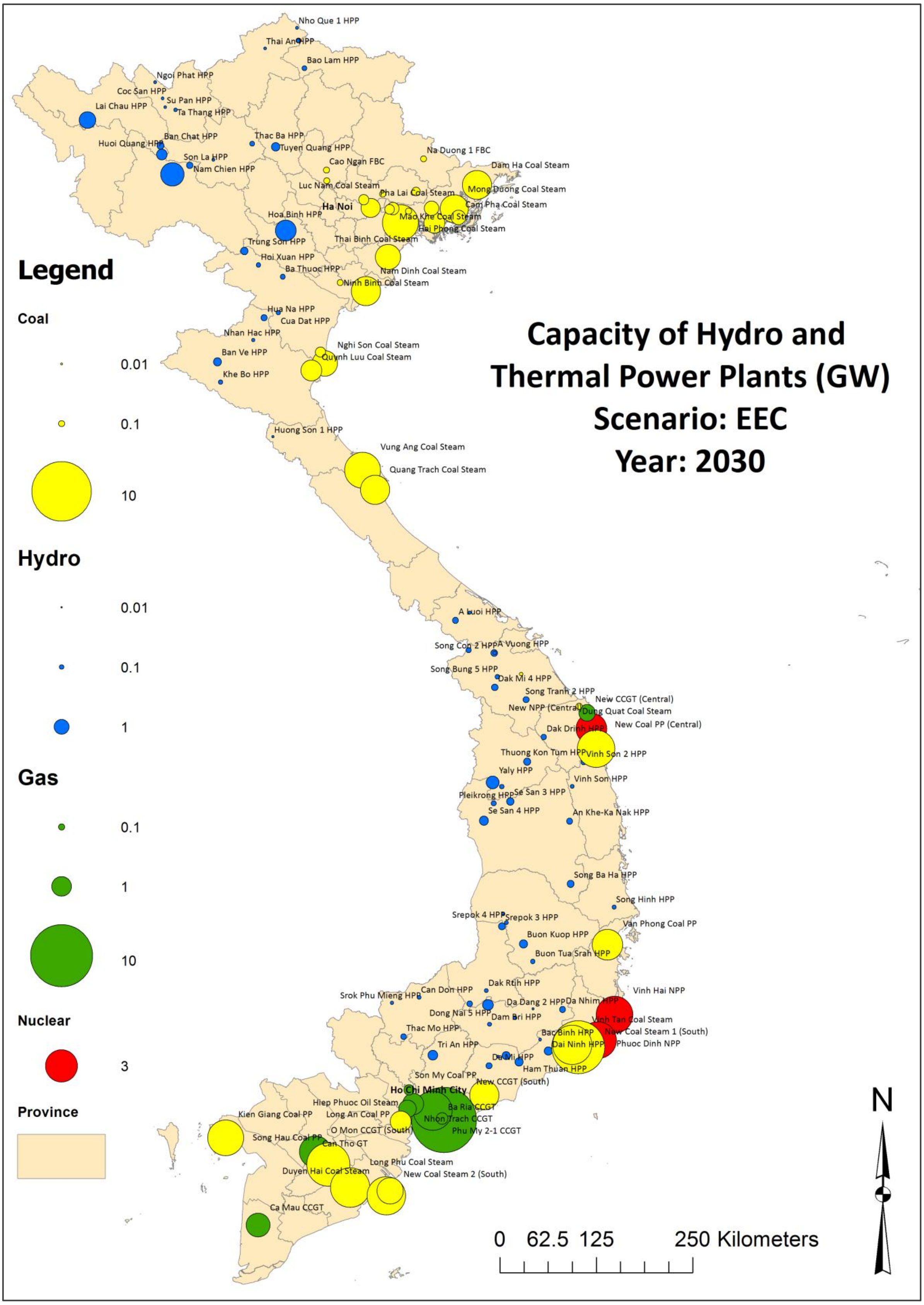

Figure 7-17: Capacity expansion of hydro and thermal power plants by 2030 under EEC scenario

7.5 Findings

Model outputs show that energy efficiency may bring potential benefits in terms of cost, resource, emission as well as spatial development. Efficient lamps, air conditioners, refrigerators, and water heaters are cost-effective even though without any intervention from Government. All energy efficiency options modeled are win-win options for both energy end users and the economy. In generally speaking, the soon promotion of energy efficiency in households brings about promising benefits for the country.

By promoting energy efficient devices in household sector in HCMC, cost can be saved by more than EUR 1.32 billion. CO_2 emissions can be reduced also by about 425 million tons in 2010-2030. SO_2 emission, the main cause for acid rain, reduces by 1.4 million tons in the same period. In term of energy consumption, a large amount of coal can be avoided in energy efficiency scenarios. Coal consumption would reduce by 54 MTOE in the study horizon.

About 1.2 GW can be reduced by 2020 and more than 6.6 GW by 2030 if energy efficient devices would be highly penetrated in households. Avoided capacity is mainly coal fired power plants in the South of the country. It is estimated that about 3 big coal fired power stations with total capacity of 6GW can be avoided in the energy efficiency scenario. Moreover, one gas fired station with capacity of 630 MW would be avoided in the Central, which consumed expensive imported gas from abroad.

In the output of the model, the largest impact of energy efficiency of household is coal power development, especially coal power plant in the South of the country, where energy efficiency options would take place. Reductions in coal power capacity also help country enhance its energy security by reducing coal import from abroad.

Energy efficiency activities reduce the land use for power development by 103 ha by 2020 and up to 467 ha by 2030. In the energy efficiency scenario, quantity of resettled people reduces by 315 persons by 2020 and 2,055 persons by 2030. Coal power plants are planned to be built in all three regions of the country with the quickly increased capacity in future to meet power demand. The avoided capacity of coal power plants therefore may help save a lot of land for plant development, reduce many people resettled, and cut emissions into surrounding areas. CO_2 and SO_2 emissions can be saved in the energy efficiency scenario. Energy efficiency activities are able to reduce 7 million tons of CO_2 in 2020 and up to 78 million tons in 2030.

In the scenario with elastic demands, reduction in energy consumption was lower than efficiency energy scenario. This is caused by rebound effect, when people have propensity to increase their consumption when the supply price reduced. This should be noted in designing energy efficiency programs; reduction in energy consumption may be not as large as expected.

Energy system modeling helps examine not only economic feasibility of energy efficiency options but also its impacts on important aspects of development. Energy efficiency is proved economic viable to tackle and abate these impacts for the country. Among energy efficiency options, improvement in efficiency of air conditioner and lighting devices bring about significant benefit.

Promoting energy efficiency in households needs supporting measures from authorities. These measures may include: (1) increased MEPS by time, (2) accelerating of labeling program, (3) providing subsidies, soft loan, and/or tax reduction for energy efficient appliances, (4) innovative communication tools, and (5) effective monitoring and evaluation scheme.

The PhD study examined only energy efficiency measures for households of HCMC, however, energy saving potential is quite high. It needs further examination of energy efficiency options for households in the whole country. Increased energy efficiency of household appliances may help the country reduce lots of its energy consumption and power capacity building, especially removing potentially harmful nuclear power plants in future (more than 6.6 GW avoided by energy efficiency options as compared to total nuclear power capacity of 10.7 GW by 2030. Moreover, energy efficiency mitigate issues associated with the development of power plants such as land occupied, displaced communities, emissions which raise social disparities throughout the country.

Chapter 8. Conclusions

The PhD study has examined energy consumption activities of households in HCMC from dwelling type, stock of appliances, determinants of energy consumption, energy saving potential ultimately to power plant development and its consequences on spatial development in future. The systematic research method proposed in the PhD study covers available and surveyed data in the household sector of HCMC aiming for in-depth investigation of energy consumption and energy saving potential. Bearing in mind the need for efficient use of energy to tackle climate change, energy consumption of household was analyzed properly in the linkages with dwelling types. Different dwelling types of household sector in HCMC characterized by different energy consumption patterns, consumption behaviors, income levels, demography, and stock of appliances. Modeling works, which used important results from its previous parts, in the last step of the PhD study allowed showing impacts of energy efficiency promotion on economic, resource, climate and spatial development of power sector. The PhD study has successfully analyzed energy consumption from the balance between demand and supply and proposed proper energy efficiency measures in households of HCMC. The PhD had achieved its research objectives. Major conclusions, which have been withdrawn from the PhD study, are discussed next.

8.1 Energy Consumption Pattern of Households in Ho Chi Minh City

The PhD study started with the analysis of energy consumption data from series of living standard surveys from 2002 to 2010. Data on energy expenditures were converted to physical energy consumption amounts by using energy prices in the past. Understanding the fuel mixes of urban and rural areas help design future strategies as well as appropriate tariff design to reduce regional inequalities.

During this time, Ho Chi Minh City economy grew remarkably, quickly urbanized, increased living standard. Energy consumption by household sector rose significantly as consequences. Households had been substituting from non-commercial energy types (i.e. firewood, agricultural residues) to commercial types (i.e. electricity, LPG, etc…). According to estimation from the living standard surveys, a household in HCMC consumed averagely 1509.4 MJ in 2002 and 1,866.9 MJ monthly in 2008. This increase in total energy consumption comes from electricity and gasoline. The results show a decrease in energy consumption between 2002 and 2004, significant increases in 2004 and 2008, and a small increase between 2008 and 2010.

Fuel mixes for households in HCMC between 2002-1010 were characterized with large shares of electricity, gasoline and LPG. Kerosene and other biomass energies made up small parts of total energy consumption. The shares for electricity, gasoline and LPG for households in HCMC are some 40, 40 and 20 percent respectively. That contrasts with households in the rest of Vietnam, which still consumed much non-commercial energy for cooking. Fuel mix for households in HCMC did not change much during 2002-2010 thanks to the better living standard of households of the City as compared to other regions. Gasoline demand rose quickly in the meantime to meet increased transport demand.

By applying index decomposition analysis, determinants for the increase in energy consumption of households in HCMC were activity effect during 2002-2008 and intensity effect in 2008-2010. These effects mainly represented the increases in household income and energy prices. In households of HCMC, structure effect had negative impact on energy consumption indicating that households switching to modern and efficient energies. In the current context of energy price volatility, it is useful to see price impacts on household energy consumption. Variations of income and fuel prices are possibly the main determinants for the changes of energy consumption pattern in households.

8.2 Inelastic Energy Demands for Electricity and LPG in Households

The PhD study employed a panel data analysis of electricity and LPG demand in households. The estimation used data from the series of household living standard surveys. These energy demands were averaged for urban and rural households in 64 provinces of Vietnam during 2002-2010. Explanatory variables in demand equations consist of own-price, substitute price, income, demography, living area, and other regional aspects. Fixed effects, random effects, population averaged and Hausman-Taylor estimator were employed to estimate coefficients in the demand equations. Hausman-Taylor model was proved as proper estimator for the panel data due to its capacity of dealing with time-invariant variables during the analysis horizon (i.e. dummy variables for regions in the demand equations).

The panel data analysis showed expected signs of elasticities of electricity and LPG demand, two main energy types in households, with respect to its own-prices, income, and other variables. Elasticities with respect to income have positive signs while the ones with respect to own-prices negative signs. Own-price elasticities for both demands are less than unity indicating both products are inelastic demands. It indicates that, both electricity and LPG in households are necessary goods. Demands for these goods decreases less than the increase in its own-prices.

Elasticities for electric demand are estimated at -0.611, 0.470, and 0.221 with respect to electric price, household income and LPG price. Elasticities for LPG demand are -0.533 and 0.452 with respect to LPG price and household income. Own-price elasticities for both demands are less than unity indicating both products are inelastic demands. The estimation show also significant differences for different regions, including Ho Chi Minh City.

In the context of quick increase in energy consumption and frequent adjusts of energy prices in Vietnam, the results for the panel analysis has significant implications in coming years. Calculations of elasticities of household energy demand suggest a proper scheme for setting energy price and projections of energy demand in future. In circumstance of lacking microeconomic data in Vietnam, the panel estimation is the first effort for estimating elasticities for energy demand in households.

8.3 Significant Differences in Energy Use Intensity by Dwelling Type and High Energy Saving Potential

After examining available household data, a household questionnaire survey was conducted within the scope of this PhD study. The survey was implemented during March to June 2011 in for some 500 households of Ho Chi Minh City. These households covers all five types of dwelling in the City, they are rudimental, shop house, row house, apartment, and villa. Contents of questionnaire include demographic, economic, dwelling type, energy consumption, stock of appliance, and attitude towards energy efficiency activities.

In examination of energy consumption and saving by four main end-uses, namely lighting, air conditioner, refrigerator and water heater, high potential for energy saving can be gained by replacing current inefficient devices with efficient ones. Energy efficiency options in households are therefore very promising in conserving energy and tackling climate change. Percentage of energy saving is quite high in houses in well-planned areas such as row house and villa. Air conditioner consumed up to 50 percent of total electricity consumption in villas. Lighting and refrigerator accounted for some 10 percent of electricity consumption.

Data and information from the survey were analyzed properly to get output on economic condition, living area, energy consumption, energy use intensity, appliance usage, and other important information related to energy use in households. Analysis of variance of energy and electricity use intensity was carried out to check the significant differences among different dwelling types. As can be seen in the analysis, results of ANOVA showed the significant differences in both monthly energy (MJ/m^2) and electricity use intensities (kWh/m^2) in all pairs of dwelling type except the pair of rudimental versus apartment and row house versus villa.

Monthly electricity use intensity from the survey are 4.63 kWh/m2 for rudimental houses, 3.41 for shop houses, 2.40 for row houses, 4.14 for apartments and 2.14 for villas. Monthly energy density from the survey are 26.33 MJ/m2 for rudimental houses, 18.20 for shop houses, 13.45 for row houses, 22.74 for apartments and 11.27 for villas. The intensities are almost significantly different in group means according to ANOVA results. Income and having air conditioner have significant impacts on electricity and energy consumptions. Electricity and energy consumption are different significantly for three income groups. Households with air conditioner consumed significantly 1.6 times higher households without air conditioner. Results of ANOVA points out factors, which should be paid adequately attention in estimation of energy consumption and energy demand forecast.

In all five types of dwelling, electricity and gasoline contribute the two largest shares followed by LPG uses for cooking. Coal and firewood are being used for cooking and heating in some low-income level dwelling types. Results from statistical analysis show that energy consumptions for household purposes are significantly different in dwelling type. The differences in the intensities are good basis for energy demand projections in future taking into account of spatial changes of urban development. In case of Ho Chi Minh City, large area of rudimental houses are planned to replace with well-planned urban districts characterized by apartment building and row houses. This has important implications in dealing with energy supply development of the City in future.

Estimation of energy saving potential for different dwelling types was the second task of this part. Options for energy saving were built for four main energy uses, such as lighting, air conditioner, refrigerator, and water heating. The four main energy uses make up from 30 percent to 70 percent of total energy use in different dwelling types. Electric use for cooling purpose is quite high in shop houses and villas. Lighting and refrigerator account for about 10 percent while water heating small share of total electricity use. In the energy efficiency case, the current appliances will be replaced with best available appliance in the market in order to examine energy saving potential.

Estimated energy efficiencies of current appliances were much lower than efficiencies of best available technologies. Villas may save up to 36 percent of total energy consumption while apartment more than 8 percent. The City would save an electricity amount of 1,820 GWh, an energy amount of 7 million GJ and cut more than 1.2 million tons of CO2 annually.

In this static analysis (in contrary to dynamic analysis by employing long-term energy model), the appliances are characterized by different efficiency with the usage data from the survey. Results of estimation show promising energy saving potential in households for these stock changes of appliances. This will be more impressed when taking into account the increased trend in future of these appliances in households, especially stock of air conditioner in both rural and urban areas.

8.4 Energy Efficiency Options in Households: Cost-effective and Significant Impacts on Economic, Resources, Climate and Spatial Development

Energy efficiency has been proved cost-effective measures in dealing with the increased demand as compare to other supply-side options. Employing an energy system model; that includes all energy end-uses, energy consuming appliances, energy conversion plants, and energy extraction resource; allows one to examine impacts of changes in demand side on the system. The impacts are possibly system cost, emissions, capacity of plants etc… The PhD study, therefore, employed MARKAL model for this purpose.

Energy efficiency options were input into model as alternatives for providing demands beside the conventional options. The Vietnamese energy system was modeled in detailed for this purpose. Demand sections for households in Ho Chi Minh City were also modeled specifically to examine energy saving potential of the energy efficiency options mentioned in the last part. Three different scenarios were built to compare the impacts of energy efficiency on different aspects. Outputs from the modeling work were then shown in the maps to examine spatial impacts of changes in power system. Major direct spatial impacts of power plants are land occupation, people resettled, and emissions to surrounding areas of the plants. Other possible impacts related to power plants development are fuel extraction (etc. coal, gas, oil).

By promoting energy efficient devices in household sector in HCMC, cost can be saved by more than EUR 1.32 billion. CO_2 emissions can be reduced also by about 425 million tons in 2010-2030. SO_2 emission, the main cause for acid rain, reduces by 1.4 million tons in the same period. In term of energy consumption, a large amount of coal can be avoided in energy efficiency scenarios. Coal consumption would reduce by 54 MTOE in the study horizon.

All five energy efficiency options included are cost effective without support measures. These options are lighting, air conditioner, window, refrigerator, and water heater. Efficient air conditioner contributes the largest energy saving amount. The second largest is contributed by efficient lamps. Efficient appliances in households are economic viable. To promote these efficient appliances, it needs to overcome the two main barriers, which are availability and quality.

About 1.2 GW can be reduced by 2020 and more than 6.6 GW by 2030 if energy efficient devices would be highly penetrated in households of HCMC. Avoided capacity is mainly coal fired power plants in the South of the country. It is estimated that about 3 big coal fired power stations with total capacity of 6GW can be avoided in the energy efficiency scenario. Moreover, one gas fired station with capacity of 630 MW would be avoided in the Central, which consumed expensive imported gas from abroad. In the output of the model, the largest impact of energy efficiency of household is coal power development, especially coal power plant in the South of the country, where energy efficiency options would take place. Reductions in coal power capacity also help country enhance its energy security by reducing coal import from abroad.

Energy efficiency activities reduce the land use for power development by 103 ha by 2020 and up to 467 ha by 2030. In the energy efficiency scenario, quantity of resettled people reduces by 315 persons by 2020 and 2,055 persons by 2030. CO_2 and SO_2 emissions can be saved in the energy efficiency scenario. Energy efficiency activities are able to reduce 7 million tons of CO_2 in 2020 and up to 78 million tons in 2030.

The results of modeling works show that significant reductions in total cost as well as emissions and energy consumption in case of promotion energy efficiency devices. In both cases of energy efficiency, cost and emissions can be cut. Due to increased capacity of coal power plants as planned in future, CO_2 emission in power sector may increase quickly. Coal power plants are projected to build in all three regions of the country, which uses local anthracite coal as well as imported steam coal. By reducing generating capacity in future, energy efficiency options, therefore, have remarkable impacts on spatial developments of power sector.

Increased energy efficiency of household appliances may help the country reduce lots of its energy consumption and power capacity building, especially removing potentially harmful nuclear power plants in future (more than 6.6 GW avoided by energy efficiency options as compared to total nuclear power capacity of 10.7 GW by 2030. Moreover, energy efficiency mitigate issues associated with the development of power plants such as land occupied, displaced communities, emissions which raise social disparities throughout the country.

8.5 Outlooks for Further Works

The PhD Study has formulated a systematic examination of household energy consumption from limited available data and an effective way of collecting data for specific research purpose. The PhD study achieved its four research objectives by following four major research steps: (1) analysis of current available data, (2) design of survey to get proper data for further examination, (3) organization and analysis of surveyed data, and (4) modeling works for data collected. As looking back to the study procedure, the study had limitations, which may influence the research outputs.

Bearing in mind the importance of data in any research activity, building a detailed and consistent energy database is an indispensable task. The current data collection system, especially microeconomic data on energy consumption are rather limited. The current data collection scheme should be designed appropriately for energy researches as well as monitoring and evaluation of energy efficiency efforts. Energy database for every economic sector including households should be well organized and frequently updated.

Energy in households plays an important part in total energy consumption. Domestic energy therefore should be adequately focused in energy policy measures. Main determinants of variations in household energy are energy price and income. It is therefore worth to get interactive impacts of these factors on energy price consumption. In the PhD study, panel data estimation for energy demands works efficiently for this purpose. However, due to lack of consistent data on micro level (i.e. household level) the PhD employed data at provincial level for the estimation. Panel data estimation will be improved in case of using household-level data instead of provincial average energy consumption.

For investigating energy efficiency measures for households, it needs a specifically designed survey, which includes appropriate contents on energy consumption and all other related factors such as income, dwelling type, living area, household size, appliance stock etc… The questionnaire survey in the PhD study was designed carefully and effectively, however due to limits on human capacity, time and budget; the sample size of some 500 households may be still small for analysis. The survey should be expanded and carried out frequently.

Energy efficiency measures in households ranges in appliances, behavior, building envelope, and renewable energy options. Promotion of energy efficiency in households is expected to bring about significant benefits for households and economy. In the PhD Study, limited number of energy efficiency options was examined due to lack of technical information on energy consuming market in Vietnam. More alternatives for energy efficiency and supporting measures should be added to the model, such as building envelope, cooking to improve further researches.

Energy efficiency and energy development have significant impacts on spatial development in terms of land use, displaced people, building envelope, urban form and emissions. Research on the linkages between energy efficiency and spatial development is needed. However, lack of spatial information of dwelling type of HCMC for efficient mapping limits spatial analyses for the purpose.

The PhD has been the first effort for Vietnam to do research in this field. The PhD study suggests an overall way for further study of household energy consumption. With the enhanced data collection scheme, future studies in the field will bring promising benefits for the country and contribute more for the study context.

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Chapter 10. Annex

EIDESSTATTLICHE VERSICHERUNG

Hiermit versichere ich an Eides statt, dass ich die vorliegende Dissertationsschrift zum Thema

"Examination of Energy Supply-Demand Balance and Measures for Energy Efficiency and Conservation in Household Sector of Ho Chi Minh City – Impact on Spatial Development"

selbstständig verfasst und keine anderen als die angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus Quellen entnommen wurden, habe ich als solche gekennzeichnet.

Des Weiteren wurde diese Arbeit weder in gleicher noch in ähnlicher Fassung einer akademischen Prüfung vorgelegt.

Dortmund, 13.05.2014 Nguyen Ngoc Hung

10.1 Household Living Standard Surveys

Table 10-1: Descriptive Statistics of Variables in the Household Living Standard Surveys

Variable	Observation	Mean	Std. Dev.	Min	Max
Province	66,597	455.6	267.5	101.0	823.0
District	66,597	79.8	200.8	1.0	973.0
Commune	66,597	2,592.8	7,322.0	1.0	32,248.0
Quantity of house	66,485	1.0	0.2	-	14.0
Living area	66,376	61.3	45.8	4.0	4,169.0
Dwelling type	56,985	4.0	0.8	1.0	5.0
Ownership	56,985	1.1	0.4	1.0	9.0
Sources for lighing	66,491	1.2	0.6	1.0	4.0
Household size	66,489	4.3	1.7	1.0	20.0
Income	66,492	2,706.3	4,534.1	-	721,295.8
Expenditure	57,090	1,719.3	1,661.5	28.4	62,730.4
Coal expenditure	57,195	8.9	18.8	-	420.0
Kerosene expenditure	66,597	2.8	10.6	-	600.0
Gasoline expenditure	66,597	63.9	163.1	-	11,500.0
Electricity expenditure	66,597	48.7	81.1	-	8,500.0
LPG expenditure	66,597	23.5	50.6	-	1,680.0
LPG price	66,597	12.9	6.8	6.0	27.3
Electricity price	60,098	0.6	0.2	0.5	2.0
Gasoline price	66,597	9.2	4.5	5.4	18.0
Kerosene price	66,597	7.9	4.9	4.1	20.0
Coal price	66,597	1.3	0.4	1.0	2.0
Electricity consumption	66,597	237.2	233.0	-	15,059.1
Coal consumption	66,597	370.2	487.4	-	18,768.8
LPG consumption	66,597	71.4	140.9	-	3,687.9
Kerosene consumption	66,597	17.3	61.0	-	2,281.8
Gasoline consumption	66,597	185.2	377.0	-	23,407.3
Total energy consumption	66,597	671.7	737.8	-	24,499.7
Year of survey	66,597	2,004.8	3.0	2,002	2,010

10.2 Panel Regression Outputs

Fixed-effects model for electricity demand

```
Fixed-effects (within) regression               Number of obs      =       640
Group variable: tinhttnt                        Number of groups   =       128

R-sq:  within  = 0.7977                         Obs per group: min =         5
       between = 0.8472                                        avg =       5.0
       overall = 0.6674                                        max =         5

                                                F(4,508)           =    500.87
corr(u_i, Xb)  = 0.4585                         Prob > F           =    0.0000

------------------------------------------------------------------------------
     lttdien |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  ltbthunhap |   .4640164   .0342435    13.55   0.000     .3967402    .5312927
      lgdien |   -.613543   .0518198   -11.84   0.000    -.7153505   -.5117355
     lgiaga  |   .2324842   .0410737     5.66   0.000      .151789    .3131794
  ltyledien  |   .4507285   .0355457    12.68   0.000     .3808939    .5205631
    _Ivung_2 |          0  (omitted)
    _Ivung_3 |          0  (omitted)
    _Ivung_4 |          0  (omitted)
    _Ivung_5 |          0  (omitted)
    _Ivung_6 |          0  (omitted)
    _Ivung_7 |          0  (omitted)
    _Ivung_8 |          0  (omitted)
    _Ittnt_2 |          0  (omitted)
       _cons |  -.2529263   .2133923    -1.19   0.236    -.6721662    .1663137
-------------+----------------------------------------------------------------
     sigma_u |  .32224766
     sigma_e |   .1374628
         rho |  .84604784   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(127, 508) =     9.09            Prob > F = 0.0000
```

Random-effects model for electricity demand

```
Random-effects GLS regression                   Number of obs      =       640
Group variable: tinhttnt                        Number of groups   =       128

R-sq:  within  = 0.7842                         Obs per group: min =         5
       between = 0.9133                                        avg =       5.0
       overall = 0.8781                                        max =         5

                                                Wald chi2(12)      =   3508.53
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
     lttdien |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  ltbthunhap |   .6189491   .0330444    18.73   0.000     .5541833    .6837149
      lgdien |  -.4941029   .0571305    -8.65   0.000    -.6060766   -.3821291
      lgiaga |   .1283793   .0438358     2.93   0.003     .0424627    .2142959
   ltyledien |    .609932   .0343135    17.78   0.000     .5426788    .6771852
    _Ivung_2 |   .1393535   .0341433     4.08   0.000      .072434    .2062731
    _Ivung_3 |   .1383094   .0298839     4.63   0.000     .0797381    .1968807
    _Ivung_4 |    -.03095   .0414324    -0.75   0.455    -.1121559    .0502559
    _Ivung_5 |   .2869186   .0440994     6.51   0.000     .2004854    .3733518
    _Ivung_6 |   .0509404     .03136     1.62   0.104    -.0105242    .1124049
    _Ivung_7 |   .5779375   .0855089     6.76   0.000     .4103431    .7455318
    _Ivung_8 |   .5087237    .087437     5.82   0.000     .3373503    .6800971
    _Ittnt_2 |  -.3632616   .0256287   -14.17   0.000     -.413493   -.3130302
       _cons |  -1.007074   .2138987    -4.71   0.000    -1.426308   -.5878402
-------------+----------------------------------------------------------------
     sigma_u |  .08005413
     sigma_e |   .1374628
         rho |  .25325996   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Hausman-Taylor model for electricity demand

```
Hausman-Taylor estimation                       Number of obs      =       640
Group variable: tinhttnt                        Number of groups   =       128

                                                Obs per group: min =         5
                                                               avg =         5
                                                               max =         5

Random effects u_i ~ i.i.d.                     Wald chi2(12)      =   2680.35
                                                Prob > chi2        =    0.0000
```

lttdien	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
TVexogenous						
lgdien	-.6110853	.0509809	-11.99	0.000	-.7110061	-.5111645
lgiaga	.220747	.0402325	5.49	0.000	.1418927	.2996013
ltyledien	.4811084	.0337062	14.27	0.000	.4150455	.5471714
TVendogenous						
ltbthunhap	.4702616	.0336439	13.98	0.000	.4043208	.5362025
TIexogenous						
_Ivung_2	.1803785	.0602892	2.99	0.003	.0622139	.2985431
_Ivung_3	.1670773	.0528736	3.16	0.002	.063447	.2707077
_Ivung_4	-.0001744	.0738005	-0.00	0.998	-.1448208	.144472
_Ivung_5	.3815406	.0754893	5.05	0.000	.2335844	.5294968
_Ivung_6	.1044273	.0545158	1.92	0.055	-.0024216	.2112762
_Ivung_7	.7057028	.1497735	4.71	0.000	.4121522	.9992534
_Ivung_8	.6717082	.1510001	4.45	0.000	.3757535	.967663
TIendogenous						
_Ittnt_2	-.6154044	.0488259	-12.60	0.000	-.7111015	-.5197074
_cons	-.096172	.2187664	-0.44	0.660	-.5249463	.3326024
sigma_u	.19626636					
sigma_e	.13692479					
rho	.67262506	(fraction of variance due to u_i)				

```
Note:  TV refers to time varying; TI refers to time invariant.
```

LM test for random effects of electricity demand

```
Breusch and Pagan Lagrangian multiplier test for random effects

        lttdien[tinhttnt,t] = Xb + u[tinhttnt] + e[tinhttnt,t]

        Estimated results:
                         |       Var     sd = sqrt(Var)
                ---------+-----------------------------
                 lttdien |   .2901971       .5386995
                       e |    .018896       .1374628
                       u |   .0064087       .0800541

        Test:   Var(u) = 0
                             chibar2(01) =   125.84
                          Prob > chibar2 =   0.0000
```

Hausman test for fixed- and random-effects of electricity demand

	(b) efe	(B) ere	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
	Coefficients			
ltbthunhap	.4640164	.6189491	-.1549327	.0089824
lgdien	-.613543	-.4941029	-.1194402	.
lgiaga	.2324842	.1283793	.1041049	.
ltyledien	.4507285	.609932	-.1592035	.0092779

```
                        b = consistent under Ho and Ha; obtained from xtreg
            B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(4) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =      232.23
                Prob>chi2 =      0.0000
                (V_b-V_B is not positive definite)
```

Hausman test for fixed- and Hausman-Taylor of electricity demand

	(b) efe	(B) eha	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
ltbthunhap	.4640164	.4702616	-.0062452	.0063798
lgdien	-.613543	-.6110853	-.0024577	.0092864
lgiaga	.2324842	.220747	.0117372	.0082698
ltyledien	.4507285	.4811084	-.0303799	.0112865

```
                           b = consistent under Ho and Ha; obtained from xtreg
            B = inconsistent under Ha, efficient under Ho; obtained from xthtaylor

    Test:  Ho:  difference in coefficients not systematic

                  chi2(4) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        7.29
                Prob>chi2 =      0.1211
```

Fixed-effects model for LPG demand

```
Fixed-effects (within) regression               Number of obs      =       629
Group variable: tinhttnt                        Number of groups   =       128

R-sq:  within  = 0.1740                         Obs per group: min =         4
       between = 0.4285                                        avg =       4.9
       overall = 0.2619                                        max =         5

                                                F(2,499)           =     52.54
corr(u_i, Xb)  = 0.2098                         Prob > F           =    0.0000
```

lttga	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ltbthunhap	.4518346	.0580562	7.78	0.000	.3377698	.5658993
lgiaga	-.5331761	.0584674	-9.12	0.000	-.6480487	-.4183035
_Ivung_2	0	(omitted)				
_Ivung_3	0	(omitted)				
_Ivung_4	0	(omitted)				
_Ivung_5	0	(omitted)				
_Ivung_6	0	(omitted)				
_Ivung_7	0	(omitted)				
_Ivung_8	0	(omitted)				
_Ittnt_2	0	(omitted)				
_cons	-.8671063	.4291627	-2.02	0.044	-1.710295	-.0239177
sigma_u	.19918873					
sigma_e	.29995413					
rho	.30602831	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(127, 499) =     2.01            Prob > F = 0.0000
```

Random-effects model for LPG demand

```
Random-effects GLS regression                   Number of obs      =       629
Group variable: tinhttnt                        Number of groups   =       128

R-sq:  within  = 0.1738                         Obs per group: min =         4
       between = 0.5633                                        avg =       4.9
       overall = 0.3368                                        max =         5

                                                Wald chi2(10)      =    258.58
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
       lttga |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  ltbthunhap |   .4861481   .0499691     9.73   0.000     .3882105    .5840857
      lgiaga |  -.5490551   .0570011    -9.63   0.000    -.6607751    -.437335
    _Ivung_2 |   .1802801   .0486162     3.71   0.000      .084994    .2755661
    _Ivung_3 |   .1277203   .0485183     2.63   0.008     .0326262    .2228145
    _Ivung_4 |    .110501   .0650525     1.70   0.089    -.0169997    .2380016
    _Ivung_5 |   .2730411   .0645835     4.23   0.000     .1464598    .3996224
    _Ivung_6 |   .1509253   .0491692     3.07   0.002     .0545555    .2472951
    _Ivung_7 |   .2449178   .1248119     1.96   0.050     .0002909    .4895447
    _Ivung_8 |   .3209953   .1260999     2.55   0.011     .0738439    .5681466
    _Ittnt_2 |  -.1534335   .0317433    -4.83   0.000    -.2156491   -.0912178
       _cons |  -1.163996   .3824493    -3.04   0.002    -1.913583   -.4144089
-------------+----------------------------------------------------------------
     sigma_u |  .10242307
     sigma_e |  .29995413
         rho |  .10442141   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Hausman-Taylor model for LPG demand

```
Hausman-Taylor estimation                       Number of obs      =       629
Group variable: tinhttnt                        Number of groups   =       128

                                                Obs per group: min =         4
                                                               avg =       4.9
                                                               max =         5

Random effects u_i ~ i.i.d.                     Wald chi2(10)      =    143.98
                                                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
       lttga |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
TVexogenous  |
      lgiaga |  -.5331761   .0571833    -9.32   0.000    -.6452533   -.4210988
TVendogenous |
  ltbthunhap |   .4518346   .0567812     7.96   0.000     .3405455    .5631236
TIexogenous  |
    _Ivung_2 |   .1782334   .0557434     3.20   0.001     .0689783    .2874885
    _Ivung_3 |   .1254352   .0559416     2.24   0.025     .0157916    .2350787
    _Ivung_4 |   .1096323   .0745072     1.47   0.141    -.0363991    .2556636
    _Ivung_5 |   .2776305   .0741387     3.74   0.000     .1323213    .4229398
    _Ivung_6 |   .1542048   .0564259     2.73   0.006      .043612    .2647976
    _Ivung_7 |   .2520194   .1432541     1.76   0.079    -.0287534    .5327921
    _Ivung_8 |   .3357955   .1447189     2.32   0.020     .0521516    .6194393
TIendogenous |
    _Ittnt_2 |  -.0748778   1.455341    -0.05   0.959    -2.927293    2.777538
             |
       _cons |  -.9673846   .8275375    -1.17   0.242    -2.589328     .654559
-------------+----------------------------------------------------------------
     sigma_u |  .14494651
     sigma_e |  .29935482
         rho |  .18992008   (fraction of variance due to u_i)
------------------------------------------------------------------------------
Note:  TV refers to time varying; TI refers to time invariant.
```

LM test for random effects of LPG demand

```
Breusch and Pagan Lagrangian multiplier test for random effects

        lttga[tinhttnt,t] = Xb + u[tinhttnt] + e[tinhttnt,t]

        Estimated results:
                         |       Var     sd = sqrt(Var)
                ---------+-----------------------------
                   lttga |   .1471365       .3835838
                       e |   .0899725       .2999541
                       u |   .0104905       .1024231

        Test:   Var(u) = 0
                             chibar2(01) =     6.43
                          Prob > chibar2 =   0.0056
```

Hausman test for fixed- and random-effects of LPG demand

```
                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |      lfe          lre         Difference          S.E.
-------------+----------------------------------------------------------------
  ltbthunhap |    .4518346     .4861481       -.0343135        .0295569
      lgiaga |   -.5331761    -.5490551         .015879        .0130121
------------------------------------------------------------------------------
                           b = consistent under Ho and Ha; obtained from xtreg
            B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(2) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        1.52
                Prob>chi2 =      0.4682
```

Hausman test for fixed- and Hausman-Taylor of LPG demand

```
                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |      lfe          lha         Difference          S.E.
-------------+----------------------------------------------------------------
  ltbthunhap |    .4518346     .4518346       -2.06e-11        .0121005
      lgiaga |   -.5331761    -.5331761        1.61e-11        .0121862
------------------------------------------------------------------------------
                           b = consistent under Ho and Ha; obtained from xtreg
        B = inconsistent under Ha, efficient under Ho; obtained from xthtaylor

    Test:  Ho:  difference in coefficients not systematic

                  chi2(2) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        0.00
                Prob>chi2 =      1.0000
```

10.3 Questionnaire Form

Questionnaire for household energy

All questions contained in this questionnaire are strictly confidential and will be served for a science research on energy efficiency.

Name of interviewer: …………………………………………………. .	Code: ………………
Date of interview: …………………………………………………. .	

Name of respondent: ………………………………… ………………		Code: ………………
Address: …………………………………………………………………………………………………….. Ward/Commune: ………………………………………………………. District:……………………………………………………….		
Telephone number: ………………………………………	E-mail: ………………………………………	

Section 100: Dwelling characteristics

101. Dwelling type

Shop house	☐	Old apartment	☐	Vila	☐
	☐	New apartment	☐		☐
	☐		☐		☐
	☐		☐		☐
	☐		☐		☐
	☐		☐		☐

102. Main outer wall material

Brick or cement block	☐	Sun dried brick	☐	Wood	☐
Stone or sillar	☐	Bamboo	☐	Other:…………………………	

103. Insulation for roof/wall

Tree	☐	Penthouse	☐	Sheet-metal with spongy	☐
Sun block paint	☐	Lean-to	☐	Other:…………………………	

104. Main roof material

Concrete	☐	Tiles	☐	Bamboo	☐

Wood ☐	Fiber of cement ☐	Other:…………………………

105. Main floor material

Parquet ☐	Ceramic tiles ☐	Cement ☐
Earth, sand ☐	Bare wood planks ☐	Other:…………………………

106. Window

Single-glazed, Glass, Metal ☐	Multiple-glazed, Glass, Metal ☐	No window ☐
Single-glazed, Glass, Wood ☐	Multiple-glazed, Glass, Wood ☐	Other:…………………………

107. Shading method

Window drape ☐	Window film ☐	Mobile eaves ☐
Window shade ☐	Paperhanging ☐	None ☐
Other:………………………		

108. For shop house:

Land area (m^2): ………..	Living area (m^2): ………..	Number of floor ……….
Number of room (excluding kitchen and bathroom)	………..	

109. For apartment in building:

Living area (m^2): ………..	Number of building floor ………..	Floor number ……….
Number of room (excluding kitchen and bathroom)	………..	

110. For villa/detached house:

Land area (m^2): ………..	Living area (m^2): ………..	Number of floor ……….
Number of room (excluding kitchen and bathroom)	………..	

111. Year of completing construction:……………………

112. The house that your household occupied is:

Rented ☐	Own, hire purchase ☐	Other:…………………………
Own, totally paid ☐	Yielded by institution ☐	

113. Distance to:

Work place (km): ………..	School (km): ………..	Market (km) ……….

Section 200: Household characteristics

201. Number of people that are living in the house:……………………………..

202. Ages and professions of people that are living in the house

No.	Age	Sex	Profession
1		M ☐ F ☐	Employer ☐ Independent ☐ Employee ☐ Household ☐ Retired ☐ Student/Pupil ☐
2		M ☐ F ☐	Employer ☐ Independent ☐ Employee ☐ Household ☐ Retired ☐ Student/Pupil ☐
3		M ☐ F ☐	Employer ☐ Independent ☐ Employee ☐ Household ☐ Retired ☐ Student/Pupil ☐
4		M ☐ F ☐	Employer ☐ Independent ☐ Employee ☐ Household ☐ Retired ☐ Student/Pupil ☐
5		M ☐ F ☐	Employer ☐ Independent ☐ Employee ☐ Household ☐ Retired ☐ Student/Pupil ☐
6		M ☐ F ☐	Employer ☐ Independent ☐ Employee ☐ Household ☐ Retired ☐ Student/Pupil ☐
7		M ☐ F ☐	Employer ☐ Independent ☐ Employee ☐ Household ☐ Retired ☐ Student/Pupil ☐
8		M ☐ F ☐	Employer ☐ Independent ☐ Employee ☐ Household ☐ Retired ☐ Student/Pupil ☐

204. Do you use a space in the house to perform an activity that provides income to the home:

Production		Business	
Type of production	Hour/day	Model of business	Hour/day
Mechanical		Shop	
Handicraft		Guest-house	
Ice production		Leased-shop	
Others:………………………………………		Others:……………………………	

Section 300: Energy consumption and purposes of use

301. Energy consumption in 2010:

Type of fuel	Unit	Average monthly consumption in 2010	
		Quantity	Cost (VND)
Electricity			
Coal			
Gas			
Kerosene			
Gasoline			

Firewood			
Solar			
Biogas			
Other:……………			

302. Purpose of energy use:

Type of fuel	Purpose of use						
	Water heating	Cooking	Heating	Drying	Lighting	Cooling	Electricity generating
Electricity							
Coal							
Gas							
Kerosene							
Gasoline							
Wood							
Solar							
Biogas							
Other:…………							

303. In case of power failure, what backup equipment does the household use, if any?

Candle	☐	Gas lamp	☐	Generator	☐
Kerosene lamp	☐	Battery	☐	Other:…………………………..	

Section 400: Energy consuming appliances

401. Lighting

Type of lamp	Watts (W)	Quantity	Usage (hour/day)	Operation at 18:00 – 21:00	With automatic control (Y/N)
Incandescent	25W				
	40W				
	60W				

	75W				
	100W				
	>100W				
Fluorescent	"Big tube" 40W				
	"Big tube" 20W				
	"Thin tube" 36W				
	"Thin tube" 18W				
	Ballast-M				
	Ballast-E				
Compact fluorescent	< 10W				
	> 10W				
Halogen					
LED lamp					
Sodium vapor lamp					
Mercury vapor lamp					
Other:……………………					

Note: If the household has 3 lamps with each of 25 W, two lamps uses1 hour per day per lamp and remain one uses in 3 hours per day, then total used time of all three lamps will be 5 hours.

402. Air conditioners

No.	Type *	Manufacturer	Model	Watts(W)	Ratting (BTU)	Temperature setting (^{o}C)	Year of purchase
1							
2							
3							
4							

* 2W for two-way window unit; 1W for one-way window unit; 1S for one-way split unit and 2S for two-way split unit

Use of air conditioner

	Monthly use (day/month)	Daily use (hour/diurnal slice)

No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day time	Evening	Night time	Rarely
1																
2																
3																
4																

403. Refrigerator

No.	Type *	Manufacturer	Model	Watts(W)	Usage (h/d)	Usage (d/y)	Year of purchase
1							
2							
3							
4							

* 1 for 1-door; 2 for 2-door; 3 for side-by-side and F for freezer

404. Electric cooking

Type	Model	Watts(W)	Usage (hour/day)	Notes
Rice cooker				
Microwave				
Electric kettle				
Toaster				
Electric cooker				

405. Electric fan

No.	Type *	Watts(W)	Usage (hour/day)	Usage (day/year)	Year of purchase
1					
2					
3					
4					

5					
6					
7					
8					

* P: Pedestal; T: Table; F: Floor; C: Ceiling; B: Bathroom; V: Ventilator; W: Water steam

406. Audiovisual equipment and computer

Type	Number	Size (inches)	Model	Watt (W)	Usage (hour/day)
CRT television					
LCD television					
Plasma television					
CD, VCD, DVD player					
Stereo equipment					
Computer					
Printer					

407. Other electric appliance

Type	Number	Model	Watts (W)	Usage (h/d)	Usage (d/m)
Washing machine					
Dish washing machine					
Fresh water pump					
Vacuum cleaner					
Iron					
Cloth Dryer					
Voltage Stabilizer					
Other					

408. Water heater

No.	Type*	Manufacturer	Model	Capacity (l)	Watts (W)	Usage (h/d)	Usage (d/m)

1							
2							
3							
4							

* E: Electric; L: LPG; S: Solar

409. Other energy consuming appliances

Type	Number	Usage (h/d)	Purpose
Coal cook stove			Cooking ☐ Water heating ☐ Drying ☐
LPG cook stove			Cooking ☐ Water heating ☐ Drying ☐
Wood cook stove			Cooking ☐ Water heating ☐ Drying ☐
Bio gas cook stove			Cooking ☐ Water heating ☐ Drying ☐
Straw cook stove			Cooking ☐ Water heating ☐ Drying ☐
Other:………………………			Cooking ☐ Water heating ☐ Drying ☐

410. Use of solar PV home system

Manufacturer	Model	Watt (W)	Year of installation	Purpose
				Lighting ☐ Cooking ☐ Appliances ☐ Other:…………………..

411. Use of biogas power

Manufacturer	Model	Watt (W)	Year of installation	Purpose
				Lighting ☐ Cooking ☐ Appliances ☐ Other:…………………..

412. Mobility device

No.	Type*	Manufacturer	Model	Fuel**	Engine (l)	Average loading (person)	Usage (km/day)	Fuel consumption (l/month)	Year of purchase
1									
2									
3									

4									
5									
6									
7									
8									

* C: Car; M: Motorbike; E: Electric motorbike

** G: Gasoline; D: Diesel; G: LPG

Section 500: Movement and income

501. What was previous house type that the household occupied in the past?

Shop house	☐	Old apartment	☐	Vila	☐
	☐	New apartment	☐		☐
	☐		☐		☐
	☐		☐		☐
	☐		☐		☐
	☐		☐		☐

In Ho Chi Minh City or another province: in HCMC ☐ in another province ☐

How many years before:……………………….. years

503. What are reasons for the movement in the past?

Income increase	☐	New member of family	☐	Better environment	☐
New job	☐	Marriage	☐	Other:…………………….	

504. The house that your household occupied in the past is:

Rented	☐	Own, hire purchase	☐	Other:…………………………
Own, totally paid	☐	Yielded by institution	☐	

505. Do you have a plan to move to another house type in future?

Shop house	☐	Old apartment	☐	Vila	☐
	☐	New apartment	☐		☐
	☐		☐		☐
	☐		☐		☐

☐	☐	☐
☐	☐	☐

506. What can be reasons for the movement in future?

Income increase ☐	New member of family ☐	Better environment ☐
New job ☐	Marriage ☐	Other:……………………..

507. The house that your household may occupied in future is:

Rented ☐	Own, hire purchase ☐	Other:…………………………
Own, totally paid ☐	Yielded by institution ☐	

508. During the last 12 months, what is your household total cash income from wages, salaries, and overtime?

Less than VND 2 million ☐	VND 4-8 million ☐	VND 12-20 million ☐
VND 2-4 million ☐	VND 8-12 million ☐	More than VND 20 million ☐

509. During the last 12 months, what is your household total income from rental, agricultural, fisheries, production activities?

Less than VND 2 million ☐	VND 4-8 million ☐	VND 12-20 million ☐
VND 2-4 million ☐	VND 8-12 million ☐	More than VND 20 million ☐

Section 600: Attitude toward energy efficiency

601. Possibility of energy efficiency measures

No.	Measures	Implementation
1	Reducing time of using air conditioner	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
2	Reducing area of using air conditioner	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
3	Increasing temperature of A/C	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
4	Improving air leakage for windows	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
5	Applying effective shading methods	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
6	Installing sun block measures	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
7	Saving water	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
8	Effective cloth washing	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
9	Effective use of refrigerator	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐

10	Effective use of cooking device	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
11	Avoiding warming state of rice cooker	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
12	Avoiding standby consumption of appliances	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
13	Replacing bulbs with CFL	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
14	Installing automatic control for appliances if appropriate	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
15	Purchasing of energy efficient appliances	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
16	Avoiding use of heat sources (iron, hair dryer etc…) in air conditioning areas	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
17	Energy efficient design of new house	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
18	Purchasing of solar water heater	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
19	Purchasing of solar PB home system	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐
20	Installing bio gas digester	Being done ☐ Willing to do ☐ Possible to do ☐ Won't do ☐ Can't say ☐

602. Main barriers to energy efficiency measures

Initial cost	☐	Low electricity price	☐	Quality of appliances	☐
Lack of information	☐	Availability of appliances	☐	Don't care about efficiency	☐
Reliability of appliances	☐	Lack of incentives	☐	Other:……………………………	

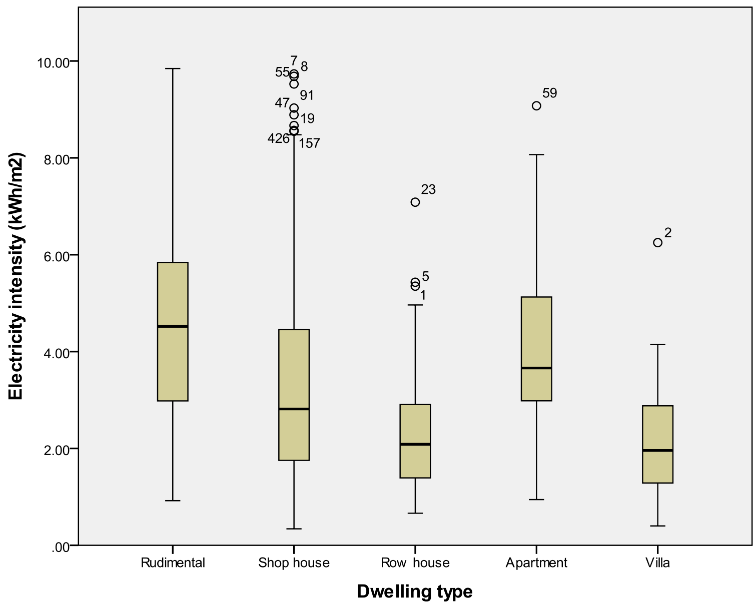
Thank you very much for your cooperation!

10.4 Analysis of Variance

Table 10-2: Descriptive Statistics of Main Variables from the Questionnaire Survey

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Household with airconditioner	461	.00	1.00	.2408	.42802	.183
Living area (m2)	461	15.00	525.00	91.1416	62.48882	3904.852
Dwelling type	461	1	5	2.57	1.344	1.806
Coal use (kg)	11	2	30	11.73	8.247	68.018
Gas use (kg)	461	.00	50.00	9.5961	5.53866	30.677
Kerosene use (l)	16	1.00	15.00	7.5000	4.81664	23.200
Gasoline use (l)	461	.00	159.00	31.3132	25.39879	645.098
Wood use (kg)	5	4.00	90.00	35.8000	35.11695	1233.200
Electricity consumption by air conditioner (kWh/month)	129	24.00	1260.03	274.4860	222.66819	49581.125
Electricity consumption by refrigerator (kWh/month)	339	21.00	81.00	33.9794	15.68409	245.991
Electricity consumption by water heater (kWh/month)	67	.45	216.00	23.8629	31.35902	983.388
Electricity use intensity (kWh/m2)	461	.34	9.84	3.5811	2.08754	4.358
Energy use intensity (MJ/m2)	461	2.22	72.82	19.6059	11.24534	126.458
Income level (1: Low, 2: Medium: 3: High)	461	1	3	1.93	.845	.714
Household energy use (MJ)	461	278.52	3675.00	1381.1873	608.59764	370391.093
Total energy use (MJ)	461	399.45	8499.55	2400.3172	1149.80443	1322050.233
Transport energy use (MJ)	461	.00	5174.86	1019.1298	826.63656	683328.004
Total monthly income (1000VND)	461	1000	96000	11758.69	8969.851	80458235.619

ANOVA of electricity use intensity by dwelling type



Descriptives

Electricity use intensity (kWh/m2)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Rudimental	105	4.6265	2.08170	.20315	4.2236	5.0293	.92	9.84
Shop house	183	3.4141	2.16775	.16024	3.0980	3.7303	.34	9.73
Row house	35	2.4048	1.47056	.24857	1.8996	2.9100	.66	7.08
Apartment	80	4.1510	1.74663	.19528	3.7623	4.5396	.94	9.07
Villa	58	2.1393	1.10267	.14479	1.8493	2.4292	.40	6.25
Total	461	3.5811	2.08754	.09723	3.3900	3.7722	.34	9.84

Test of Homogeneity of Variances

Electricity use intensity (kWh/m2)

Levene Statistic	df1	df2	Sig.
7.711	4	456	.000

ANOVA

Electricity use intensity (kWh/m2)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	314.830	4	78.707	21.240	.000
Within Groups	1689.761	456	3.706		
Total	2004.591	460			

Robust Tests of Equality of Means

Electricity use intensity (kWh/m2)

	Statistic[a]	df1	df2	Sig.
Welch	34.215	4	158.658	.000

a. Asymptotically F distributed.

Multiple Comparisons

Electricity use intensity (kWh/m2)

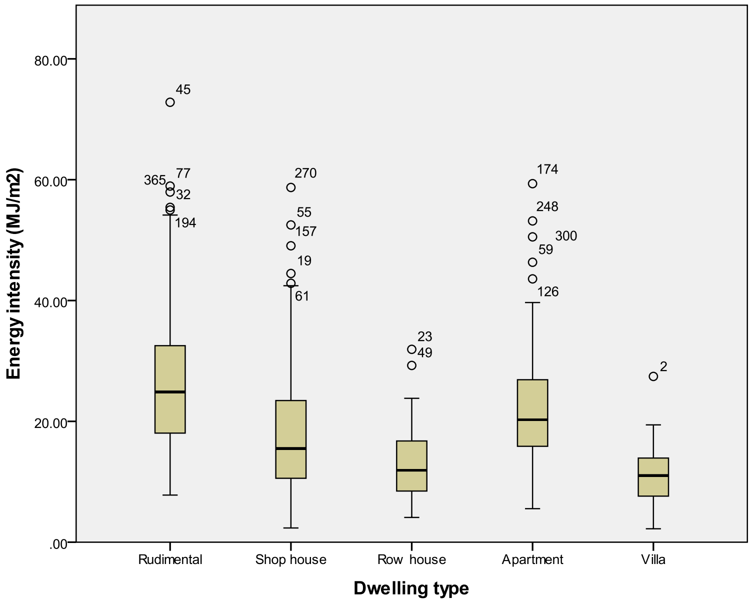
Games-Howell

(I) Dwelling type	(J) Dwelling type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Rudimental	Shop house	1.21235*	.25875	.000	.5008	1.9239
	Row house	2.22168*	.32103	.000	1.3263	3.1170
	Apartment	.47553	.28179	.444	-.3009	1.2520
	Villa	2.48721*	.24947	.000	1.7989	3.1755
Shop house	Rudimental	-1.21235*	.25875	.000	-1.9239	-.5008
	Row house	1.00933*	.29575	.009	.1799	1.8388
	Apartment	-.73681*	.25261	.032	-1.4327	-.0409
	Villa	1.27487*	.21597	.000	.6801	1.8696
Row house	Rudimental	-2.22168*	.32103	.000	-3.1170	-1.3263
	Shop house	-1.00933*	.29575	.009	-1.8388	-.1799
	Apartment	-1.74615*	.31610	.000	-2.6293	-.8630
	Villa	.26553	.28766	.887	-.5448	1.0759
Apartment	Rudimental	-.47553	.28179	.444	-1.2520	.3009
	Shop house	.73681*	.25261	.032	.0409	1.4327
	Row house	1.74615*	.31610	.000	.8630	2.6293
	Villa	2.01168*	.24310	.000	1.3394	2.6839
Villa	Rudimental	-2.48721*	.24947	.000	-3.1755	-1.7989

	Shop house	-1.27487*	.21597	.000	-1.8696	-.6801
	Row house	-.26553	.28766	.887	-1.0759	.5448
	Apartment	-2.01168*	.24310	.000	-2.6839	-1.3394

*. The mean difference is significant at the 0.05 level.

ANOVA of energy use intensity by dwelling type



Descriptives

Energy use intensity (MJ/m2)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Rudimental	105	26.3252	12.33256	1.20353	23.9385	28.7118	7.80	72.82
Shop house	183	18.1987	10.42109	.77035	16.6787	19.7186	2.35	58.71
Row house	35	13.4480	6.61073	1.11742	11.1771	15.7188	4.09	31.92
Apartment	80	22.7447	10.38509	1.16109	20.4336	25.0558	5.55	59.35
Villa	58	11.2681	4.83322	.63463	9.9973	12.5390	2.22	27.43
Total	461	19.6059	11.24534	.52375	18.5766	20.6351	2.22	72.82

Test of Homogeneity of Variances

Energy use intensity (MJ/m2)

Levene Statistic	df1	df2	Sig.
8.642	4	456	.000

ANOVA

Energy use intensity (MJ/m2)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11250.423	4	2812.606	27.335	.000
Within Groups	46920.136	456	102.895		
Total	58170.558	460			

Robust Tests of Equality of Means

Energy use intensity (MJ/m2)

	Statistic[a]	df1	df2	Sig.
Welch	43.374	4	161.240	.000

a. Asymptotically F distributed.

Multiple Comparisons

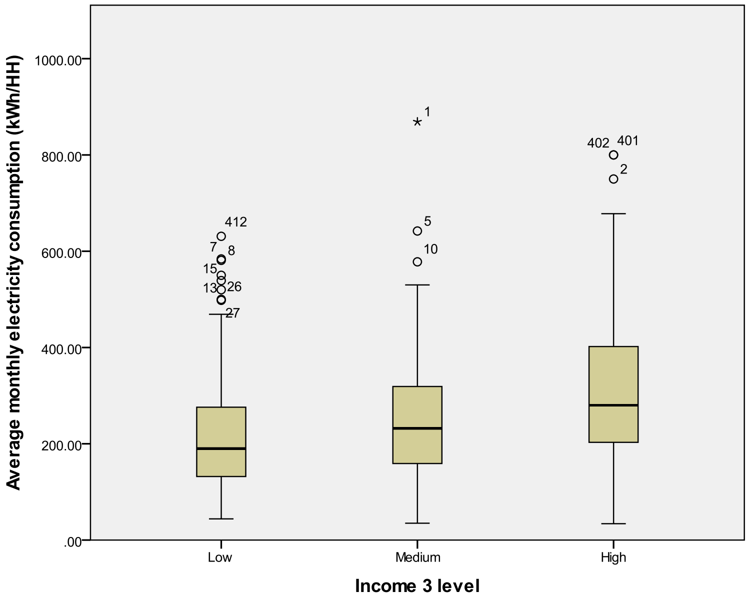
Energy use intensity (MJ/m2)

Games-Howell

(I) Dwelling type	(J) Dwelling type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Rudimental	Shop house	8.12651*	1.42896	.000	4.1906	12.0624
	Row house	12.87723*	1.64229	.000	8.3224	17.4321
	Apartment	3.58051	1.67231	.207	-1.0275	8.1885
	Villa	15.05704*	1.36061	.000	11.2997	18.8144
Shop house	Rudimental	-8.12651*	1.42896	.000	-12.0624	-4.1906
	Row house	4.75073*	1.35723	.007	.9517	8.5498
	Apartment	-4.54599*	1.39340	.012	-8.3932	-.6988
	Villa	6.93053*	.99810	.000	4.1839	9.6772
Row house	Rudimental	-12.87723*	1.64229	.000	-17.4321	-8.3224
	Shop house	-4.75073*	1.35723	.007	-8.5498	-.9517
	Apartment	-9.29672*	1.61144	.000	-13.7753	-4.8181
	Villa	2.17980	1.28506	.445	-1.4423	5.8019
Apartment	Rudimental	-3.58051	1.67231	.207	-8.1885	1.0275
	Shop house	4.54599*	1.39340	.012	.6988	8.3932
	Row house	9.29672*	1.61144	.000	4.8181	13.7753
	Villa	11.47652*	1.32321	.000	7.8110	15.1421
Villa	Rudimental	-15.05704*	1.36061	.000	-18.8144	-11.2997
	Shop house	-6.93053*	.99810	.000	-9.6772	-4.1839
	Row house	-2.17980	1.28506	.445	-5.8019	1.4423
	Apartment	-11.47652*	1.32321	.000	-15.1421	-7.8110

*. The mean difference is significant at the 0.05 level.

ANOVA for Electricity Consumption by Income Level



Descriptives

Average monthly electricity consumption (kWh/HH)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Low	182	212.6484	112.10728	8.30994	196.2515	229.0452	44.00	631.00
Medium	130	250.7077	123.35462	10.81892	229.3022	272.1132	35.00	869.00
High	149	318.0604	149.77056	12.26968	293.8140	342.3068	34.00	800.00
Total	461	257.4512	135.74380	6.32222	245.0272	269.8752	34.00	869.00

Test of Homogeneity of Variances

Average monthly electricity consumption (kWh/HH)

Levene Statistic	df1	df2	Sig.
7.776	2	458	.000

ANOVA

Average monthly electricity consumption (kWh/HH)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	918587.309	2	459293.654	27.834	.000
Within Groups	7557546.843	458	16501.194		
Total	8476134.152	460			

Robust Tests of Equality of Means

Average monthly electricity consumption (kWh/HH)

	Statistic[a]	df1	df2	Sig.
Welch	25.313	2	282.263	.000

a. Asymptotically F distributed.

Multiple Comparisons

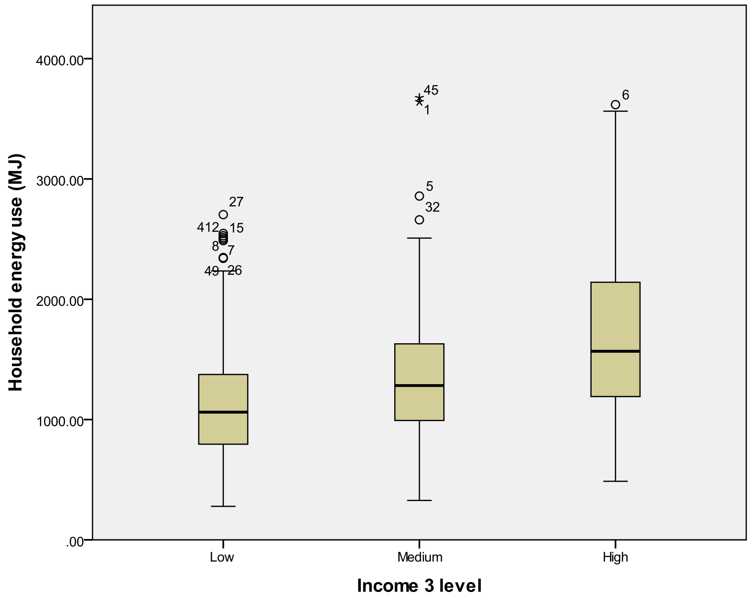
Average monthly electricity consumption (kWh/HH)

Games-Howell

(I) Income 3 level	(J) Income 3 level	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Low	Medium	-38.05934*	13.64200	.016	-70.2156	-5.9031
	High	-105.41205*	14.81892	.000	-140.3369	-70.4872
Medium	Low	38.05934*	13.64200	.016	5.9031	70.2156
	High	-67.35271*	16.35830	.000	-105.8998	-28.8056
High	Low	105.41205*	14.81892	.000	70.4872	140.3369
	Medium	67.35271*	16.35830	.000	28.8056	105.8998

*. The mean difference is significant at the 0.05 level.

ANOVA for Household Energy Consumption by Income Level



Descriptives

Household energy use (MJ)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Low	182	1122.1330	480.97282	35.65208	1051.7859	1192.4802	278.52	2703.80
Medium	130	1370.7692	546.64583	47.94401	1275.9108	1465.6276	327.45	3675.00
High	149	1706.7057	646.94689	52.99995	1601.9713	1811.4401	486.80	3617.60
Total	461	1381.1873	608.59764	28.34522	1325.4852	1436.8895	278.52	3675.00

Test of Homogeneity of Variances

Household energy use (MJ)

Levene Statistic	df1	df2	Sig.
8.539	2	458	.000

ANOVA

Household energy use (MJ)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	28016337.847	2	14008168.924	45.066	.000
Within Groups	1.424E8	458	310837.478		
Total	1.704E8	460			

Robust Tests of Equality of Means

Household energy use (MJ)

	Statistic[a]	df1	df2	Sig.
Welch	42.474	2	280.501	.000

a. Asymptotically F distributed.

Multiple Comparisons

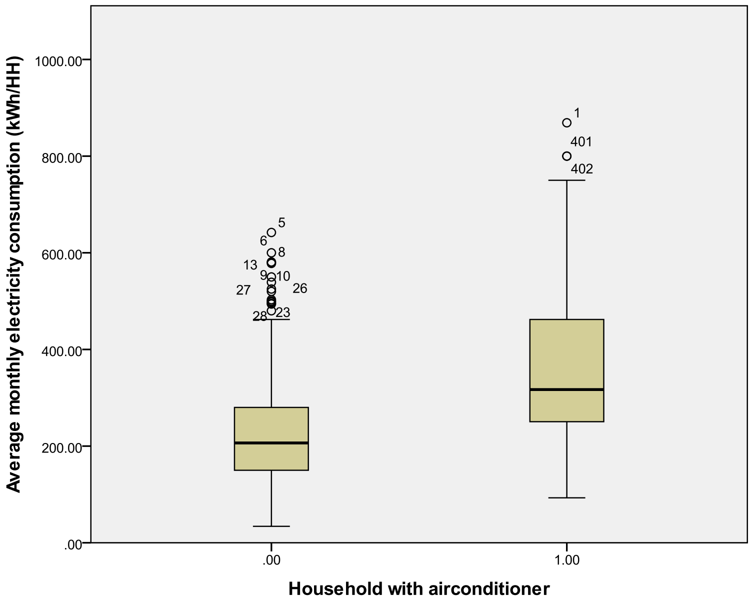
Household energy use (MJ)

Games-Howell

(I) Income 3 level	(J) Income 3 level	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Low	Medium	-248.63619*	59.74696	.000	-389.4871	-107.7853
	High	-584.57264*	63.87539	.000	-735.1165	-434.0288
Medium	Low	248.63619*	59.74696	.000	107.7853	389.4871
	High	-335.93645*	71.46764	.000	-504.3424	-167.5305
High	Low	584.57264*	63.87539	.000	434.0288	735.1165
	Medium	335.93645*	71.46764	.000	167.5305	504.3424

*. The mean difference is significant at the 0.05 level.

ANOVA for Electricity Consumption by Ownership of Air Conditioner



Descriptives

Average monthly electricity consumption (kWh/HH)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
.00	350	225.9057	109.60988	5.85889	214.3825	237.4289	34.00	642.00
1.00	111	356.9189	160.58496	15.24205	326.7128	387.1251	93.00	869.00
Total	461	257.4512	135.74380	6.32222	245.0272	269.8752	34.00	869.00

Test of Homogeneity of Variances

Average monthly electricity consumption (kWh/HH)

Levene Statistic	df1	df2	Sig.
26.441	1	459	.000

ANOVA

Average monthly electricity consumption (kWh/HH)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1446505.993	1	1446505.993	94.450	.000
Within Groups	7029628.159	459	15315.094		
Total	8476134.152	460			

Robust Tests of Equality of Means

Average monthly electricity consumption (kWh/HH)

	Statistic[a]	df1	df2	Sig.
Welch	64.372	1	143.917	.000

a. Asymptotically F distributed.

10.5 MARKAL Model

Table 10-3: Energy price forecast

Fuel	Unit	2010	2015	2020	2025	2030
Antracite 4b	EUR/ton	23.14	59.50	65.71	72.54	80.07
Anthracite 5	EUR/ton	18.57	47.75	52.71	58.21	64.25
Imported coal	EUR/ton	70.97	74.67	82.06	86.50	94.63
Fuel oil	EUR/ton	470.94	519.74	573.71	633.59	700.13
Diesel oil	EUR/ton	580.36	640.99	707.53	781.46	862.04
Natural gas	EUR/MBTU	3.07	4.04	4.71	5.43	6.06
Natural gas from South Con Son	EUR/MBTU	2.62	2.88	3.17	3.49	3.84
Natural gas from Cuu Long	EUR/MBTU	2.85	4.15	4.58	5.06	5.58
Natural gas from Ca Mau	EUR/MBTU	2.62	4.15	4.58	5.06	5.58
Natural gas from Block B	EUR/MBTU	4.44	5.52	6.10	6.74	7.43
Nuclear fuel	EUR cent/kWh	0.00	5.21	5.81	6.48	7.22

Capacity of power plants under EEC scenario

Table 10-4: Gas and oil fired power plants (GW)

Province	District	Power plant	Capacity in 2020	Capacity in 2030
Bà Rịa - Vũng Tàu	Bà Rịa	Ba Ria CCGT	0.37	0.37
Bà Rịa - Vũng Tàu	Tân Thành	Dam Phu My GT	0.02	0.02
Bà Rịa - Vũng Tàu	Tân Thành	New Gas Turbine (South)	2	2
Bà Rịa - Vũng Tàu	Tân Thành	Phu My 2-1 CCGT	0.89	0.89
Bà Rịa - Vũng Tàu	Tân Thành	Phu My 1 CCGT	1.09	1.09
Bà Rịa - Vũng Tàu	Tân Thành	Phu My 2-2 CCGT	0.72	0.72
Bà Rịa - Vũng Tàu	Tân Thành	Phu My 3 CCGT	0.72	0.72
Bà Rịa - Vũng Tàu	Tân Thành	Phu My 4 CCGT	0.45	0.45
Bà Rịa - Vũng Tàu	Tân Thành	New CCGT (South)	0.15	9
Cà Mau	U Minh	Ca Mau CCGT	1.5	1.5
Cần Thơ	Bình Thủy	Can Tho Oil Steam	0.12	0.12
Cần Thơ	Bình Thủy	Can Tho GT	0.03	0.03
Cần Thơ	Ô Môn	O Mon CCGT (South)	1.5	2.25
Cần Thơ	Ô Môn	O Mon Gas Steam	0.66	0.33
Đồng Nai	Nhơn Trạch	Nhon Trach CCGT	1.2	1.2
Quảng Ngãi	Bình Sơn	New Gas Turbine (Central)	0	0
Quảng Ngãi	Bình Sơn	New CCGT (Central)	0	0.69
HCMC	Nhà Bè	Hiep Phuoc Oil Steam	0.78	0.78
HCMC	Thủ Đức	Thu Duc Oil Steam	0.15	0.15
HCMC	Thủ Đức	Thu Duc GT	0.12	0.12

Table 10-5: Nuclear power plants (GW)

Province	District	Power plant	Capacity in 2020	Capacity in 2030
Ninh Thuận	Ninh Hải	Vinh Hai NPP	0.00	4.00
Ninh Thuận	Ninh Phước	Phuoc Dinh NPP	4.00	4.00
Phú Yên	Tuy Hòa	New NPP (Central)	0.00	2.70

Table 10-6: Coal fired power plants (GW)

Province	District	Power plant	Capacity in 2020	Capacity in 2030
An Giang	Châu Thành	Song Hau Coal PP	4.43	5.20
Bắc Giang	Lục Nam	Luc Nam Coal Steam	0.00	0.10
Bắc Giang	Sơn Động	Son Dong Coal Steam	0.22	0.22
Bắc Giang	Yên Dũng	Bac Giang Coal Steam	0.00	0.30
Bình Thuận	Hàm Tân	Son My Coal PP	2.40	2.40
Bình Thuận	Tuy Phong	Vinh Tan Coal Steam	1.20	4.38
Bình Thuận	Tuy Phong	New Coal Steam 1 (South)	0.00	8.00
Hà Tĩnh	Kỳ Anh	Vung Ang Coal Steam	1.20	3.60
Hải Dương	Chí Linh	Pha Lai Coal Steam	0.44	0.44
Hải Dương	Chí Linh	Pha Lai Coal Steam	0.60	0.60
Hải Dương	Kinh Môn	Hai Duong Coal Steam	0.00	0.00
Hải Phòng	Thủy Nguyên	Hai Phong Coal Steam	3.60	3.60
Khánh Hòa	Ninh Hòa	Van Phong Coal PP	0.00	2.64
Kiên Giang	Kiên Lương	Kien Giang Coal PP	0.00	3.60
Lạng Sơn	Lộc Bình	Na Duong 1 FBC	0.11	0.11
Long An	Cần Đước	Long An Coal PP	0.00	1.20
Nam Định	Hải Hậu	Nam Dinh Coal Steam	0.00	2.40
Nghệ An	Quỳnh Lưu	Quynh Luu Coal Steam	0.00	1.20
Ninh Bình	Ninh Bình	Ninh Binh Coal Steam	0.10	0.10
Quảng Bình	Quảng Trạch	Quang Trach Coal Steam	0.00	2.40
Quảng Nam	Quế Sơn	Nong Son Coal Steam	0.03	0.03
Quảng Ngãi	Bình Sơn	Dung Quat Coal Steam	0.11	0.11
Quảng Ngãi	Đức Phổ	New Coal PP (Central)	0.00	4.00
Quảng Ninh	Cẩm Phả	Cam Pha Coal Steam	0.60	0.60
Quảng Ninh	Đầm Hà	Dam Ha Coal Steam	0.00	2.40
Quảng Ninh	Đông Triều	Mao Khe Coal Steam	0.44	0.44
Quảng Ninh	Đông Triều	Cam Thinh Coal Steam	0.00	0.27
Quảng Ninh	Đông Triều	Mong Duong Coal Steam	1.00	2.20
Quảng Ninh	Hạ Long	Quang Ninh Coal Steam	1.20	1.20
Quảng Ninh	Hoành Bồ	Thang Long Coal Steam	0.00	0.60
Quảng Ninh	Uông Bí	Uong Bi Coal Steam	0.11	0.11
Sóc Trăng	Long Phú	Long Phu Coal Steam	4.40	4.40
Thái Bình	Thái Thụy	Thai Binh Coal Steam	0.00	1.80
Thái Nguyên	Phổ Yên	An Khanh Coal Steam	0.00	0.10
Thái Nguyên	Thái Nguyên	Cao Ngan FBC	0.10	0.10
Thanh Hóa	Tĩnh Gia	Cong Thanh Coal Steam	0.00	0.30
Thanh Hóa	Tĩnh Gia	Nghi Son Coal Steam	0.60	1.80
Trà Vinh	Duyên Hải	New Coal Steam 2 (South)	0.00	2.00
Trà Vinh	Duyên Hải	Duyen Hai Coal Steam	4.20	4.20

Table 10-7: Hydro power plants (GW)

Province	District	Power plant	Capacity in 2020	Capacity in 2030
Bình Định	Vĩnh Thạnh	Vinh Son HPP	0.07	0.07
Bình Phước	Lộc Ninh	Srok Phu Mieng HPP	0.05	0.05
Bình Phước	Phước Long	Thac Mo HPP	0.15	0.15
Bình Phước	Phước Long	Can Don HPP	0.07	0.07
Bình Thuận	Bắc Bình	Bac Binh HPP	0.04	0.04
Bình Thuận	Bắc Bình	Dai Ninh HPP	0.3	0.3
Bình Thuận	Hàm Thuận Bắc	Ham Thuan HPP	0.3	0.3
Bình Thuận	Tánh Linh	La Ngau HPP	0.04	0.04
Bình Thuận	Tánh Linh	Da Mi HPP	0.18	0.18
Đăk Lăk	Buôn Đôn	Srepok 3 HPP	0.22	0.22
Đăk Lăk	Buôn Đôn	Srepok 4 HPP	0.08	0.08
Đăk Lăk	Buôn Đôn	Srepok 4A HPP	0.06	0.06
Đăk Lăk	Krông Ana	Buon Kuop HPP	0.28	0.28
Đăk Lăk	Lắk	Buon Tua Srah HPP	0.09	0.09
Đăk Nông	Đăk Glong	Dong Nai 3+4 HPP	0.52	0.52
Đăk Nông	Đăk Glong	Dak Rtih HPP	0.07	0.07
Đăk Nông	Đăk R'Lấp	Dong Nai 5 HPP	0.14	0.14
Đồng Nai	Vĩnh Cửu	Tri An HPP	0.4	0.4
Gia Lai	An Khê	An Khe-Ka Nak HPP	0.17	0.17
Gia Lai	Chư Păh	Se San 3 HPP	0.26	0.26
Gia Lai	Ia Grai	Se San 3A HPP	0.11	0.11
Gia Lai	Ia Grai	Se San 4 HPP	0.36	0.36
Gia Lai	Ia Grai	Se San 4A HPP	0.06	0.06
Gia Lai	Kbang	Vinh Son 2 HPP	0.11	0.11
Gia Lai	Krông Pa	Song Ba Ha HPP	0.22	0.22
Hà Giang	Bắc Mê	Bac Me HPP	0.05	0.05
Hà Giang	Đồng Văn	Nho Que 1 HPP	0.04	0.04
Hà Giang	Mèo Vạc	Nho Que 3 HPP	0.11	0.11
Hà Giang	Mèo Vạc	Nho Que 2 HPP	0.07	0.07
Hà Giang	Quản Bạ	Thai An HPP	0.04	0.04
Hà Tĩnh	Hương Sơn	Huong Son 1 HPP	0.03	0.03
Hoà Bình	Hoà Bình	Hoa Binh HPP	1.92	1.92
Kon Tum	Kon Plông	Thuong Kon Tum HPP	0.22	0.22
Kon Tum	Sa Thầy	Pleikrong HPP	0.1	0.1
Kon Tum	Sa Thầy	Yaly HPP	0.72	0.72
Lai Châu	Mường Tè	Lai Chau HPP	1.2	1.2
Lai Châu	Than Uyên	Ban Chat HPP	0.22	0.22
Lâm Đồng	Bảo Lộc	Bao Lam HPP	0.11	0.11
Lâm Đồng	Bảo Lộc	Dam Bri HPP	0.07	0.07
Lâm Đồng	Cát Tiên	Dong Nai 6 HPP	0	0
Lâm Đồng	Di Linh	Dong Nai 2 HPP	0.07	0.07
Lâm Đồng	Đơn Dương	Da Nhim HPP	0.16	0.16
Lâm Đồng	Lâm Hà	Da Dang 2 HPP	0.03	0.03
Lào Cai	Bảo Thắng	Ta Thang HPP	0.06	0.06
Lào Cai	Bát Xát	Ngoi Phat HPP	0.04	0.04
Lào Cai	Sa Pa	Coc San HPP	0.04	0.04

Province	District	Power plant	Capacity in 2020	Capacity in 2030
Lào Cai	Sa Pa	Su Pan HPP	0.04	0.04
Nghệ An	Quế Phong	Hua Na HPP	0.18	0.18
Nghệ An	Quế Phong	Nhan Hac HPP	0.05	0.05
Nghệ An	Tương Dương	Ban Ve HPP	0.3	0.3
Nghệ An	Tương Dương	Khe Bo HPP	0.1	0.1
Phú Yên	Sông Hinh	EaKrong Hnang HPP	0	0
Phú Yên	Tuy Hòa	Song Hinh HPP	0.07	0.07
Quảng Nam	Bắc Trà My	Song Tranh 2 HPP	0.16	0.16
Quảng Nam	Đông Giang	A Vuong HPP	0.21	0.21
Quảng Nam	Đông Giang	Song Con 2 HPP	0.05	0.05
Quảng Nam	Nam Giang	Song Bung 4 HPP	-	-
Quảng Nam	Nam Giang	Song Bung 5 HPP	0.09	0.09
Quảng Nam	Phước Sơn	Dak Mi 4 HPP	0.19	0.19
Quảng Nam	Tây Giang	Song Bung 2 HPP	0.11	0.11
Quảng Ngãi	Sơn Hà	Dak Drinh HPP	0.12	0.13
Sơn La	Mường La	Huoi Quang HPP	0.52	0.52
Sơn La	Mường La	Nam Chien HPP	0.2	0.2
Sơn La	Mường La	Nam Chien 2 HPP	0.03	0.03
Sơn La	Mường La	Son La HPP	2.4	2.4
Thanh Hóa	Bá Thước	Ba Thuoc HPP	0.12	0.12
Thanh Hóa	Quan Hóa	Trung Son HPP	0.25	0.25
Thanh Hóa	Quan Hóa	Hoi Xuan HPP	0.1	0.1
Thanh Hóa	Thường Xuân	Cua Dat HPP	0.1	0.1
Thừa Thiên - Huế	A Lưới	A Luoi HPP	0.17	0.17
Thừa Thiên - Huế	Hương Trà	Binh Dien HPP	0.04	0.04
Tuyên Quang	Tuyên Quang	Tuyen Quang HPP	0.34	0.34
Yên Bái	Văn Chấn	Van Chan HPP	0.04	0.04
Yên Bái	Yên Bình	Thac Ba HPP	0.12	0.12

End-use devices

Lamps

	Unit	Bulbs	CFL	Fluorescent lamp	Efficient fluorescent lamp
Price	EUR/pc	0.22	1.,51	0.50	0.49
Lumen	Lm/W	14	60	55	68
Lifetime	hrs	1,000	6,000	12,000	15,000
Reference Model	Rang Dong	A60-60	CFLST314W	FLT1040W	FLT836W
Capacity	W	60	14	40	36

Air conditioner

	Unit	Current air conditioner	Efficient air conditioner	Efficient air conditioner
EER		2.80	3.40	5.6
Price	EUR/pc	296.30	407.41	561.85
Lifetime	Yrs	10	10	10
Capacity	BTU/hour	12,000	12,000	12,000

Refrigerator

	Unit	Current refrigerator	Efficient refrigerator
Capacity	l	400	400
Consumption	kWh/m	31.92	15.96
Price	EUR/pc	222.22	370.37
Lifetime	yrs	10	10
Reference Model			EnergyStar
Efficiency increase	%	0.0%	50.0%

Water heater

		Electric water heater	LPG water heater	Solar water heater
Price	EUR/pc	111.11	51.85	370.37
Lifetime	yrs	10	10	10
Capacity	W	2,500		
Consumption rate	kg/hr		0.5	