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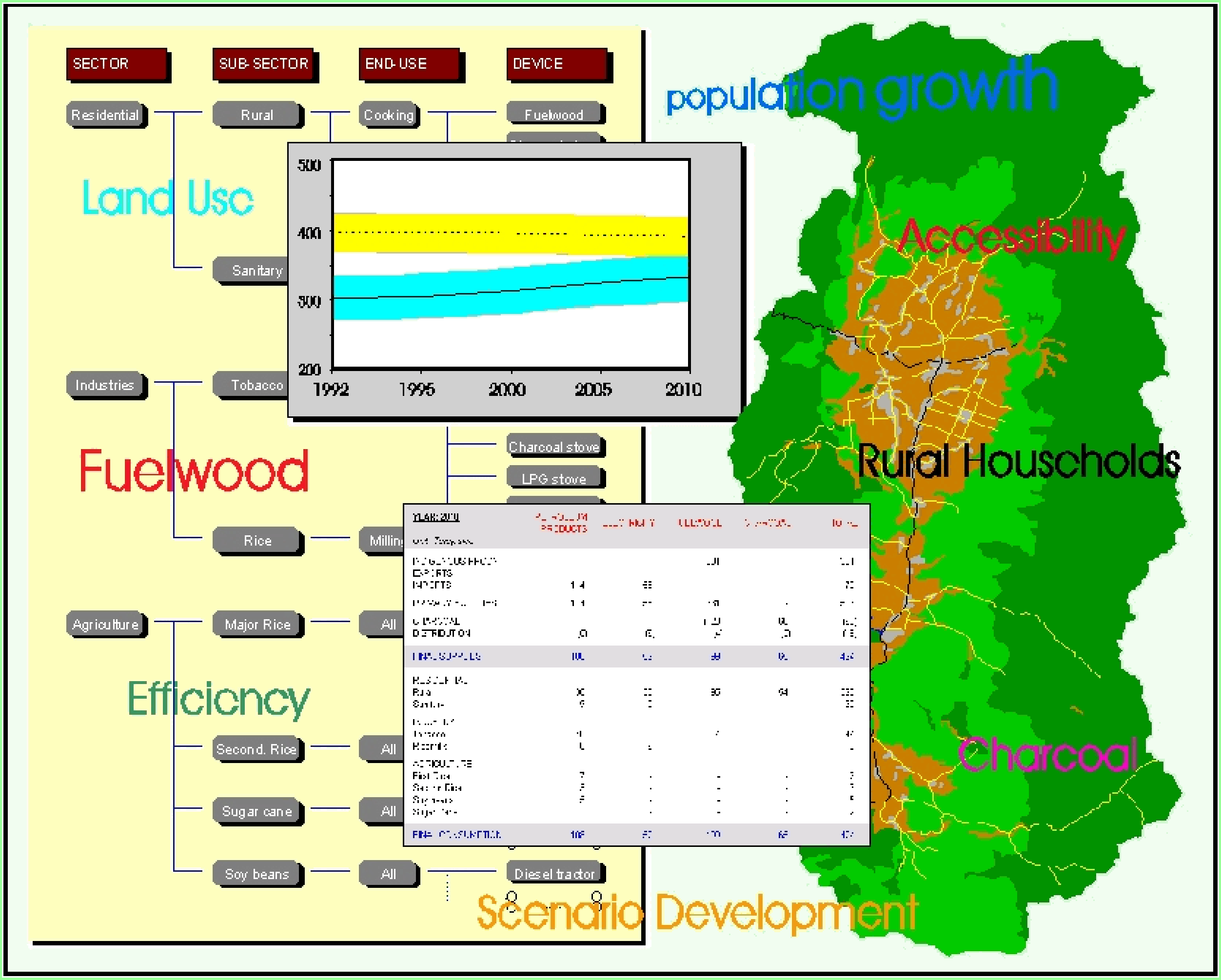
REGIONAL WOOD ENERGY DEVELOPMENT PROGRAMME IN ASIA
GCP/RAS/154/NET

DATA COLLECTION & ANALYSIS FOR AREA-BASED ENERGY PLANNING

A Case Study in Phrao District, Northern Thailand

Joost Siteur



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FOREWORD

In most countries, energy planning is concentrated at the national level and focuses mainly on commercial fuels. Common practices of national energy planning do not accommodate site-specific issues of supply and demand. However, in South and South-east Asia, wood and other biomass fuels constitute large parts of national energy consumption and this is not likely to change for many years to come. The characteristics of these fuels are site-specific and, consequently, scenarios and effective interventions should be adapted to local conditions. This calls for an area-based approach in energy planning.

The Long-range Energy Alternatives Planning model (LEAP) provides a methodology which can be applied to any smaller or larger area and accommodate wood and biomass fuels as well as environmental impacts. However, few if any real-life cases applying LEAP have yet been documented. Therefore, RWEDP conducted a case study applying LEAP, for which Phrao District in Northern Thailand was selected. The study also incorporated aspects of local fuelwood accessibility.

The results of the case study illustrate the adequacy of the methodology for area-based energy planning. They also elaborate on aspects of data availability and collection, which are common obstacles to area-based planning. An examination of the process of data collection and analysis provided suggestions for a 'minimal approach' to nation-wide area-based energy planning under certain conditions.

It is a pleasure to thank the many agencies in Thailand as well as international experts who have contributed directly or indirectly to this study. The report on the case study is a field document which is being circulated to stimulate further applications in area-based energy planning. RWEDP would be interested in any comments and eager to hear of experiences in other areas or countries.

W.S. Hulscher,
Chief Technical Adviser.

SUMMARY

The importance of wood fuels in RWEDP member countries, with shares varying from 30 to 80 % of the total energy consumption, and the fact that for all RWEDP member countries woodfuel consumption is still growing, asks for the incorporation of wood energy in the formulation and implementation of energy policies, plans and projects. This requires the assessment and forecasting of the demand and supply of all forms of energy to identify (future) problems and to allow for the evaluation of intervention options. For this purpose data on several factors that have an impact on an energy system are needed. However, in most developing countries these data are hardly available to energy planners. Data that are required for wood energy planning may exist, but these usually have to come from different sources. Hence differences in objectives, definitions and scale may complicate comparison and integration.

The site-specific nature of rural energy asks for the area-based planning, i.e. demand and supply assessment, forecasting and plan formulation and implementation for a distinct area, defined either by administrative boundaries or by factors such as agro-ecology, economy, social or cultural characteristics. Unfortunately, at present energy planning in most RWEDP member countries occurs mainly at national level, with an emphasis on conventional fuels. Little if any practical experience of area-based energy planning has been documented. Therefore the possibilities and limitations of area-based energy planning with respect to data collection and analysis are hardly known.

In order to gain insight into the problems related to the availability, collection and analysis of data for energy planning at area-based level, a case study was conducted in Phrao District, Northern Thailand that followed and documented the planning process from the identification of data requirements to the impact analysis of future trends and intervention options. Energy planning hardly is performed at this level as yet and it is desirable to perform planning at area-based level. Therefore the possibilities and limitations of coming up with an energy plan using available data and analysis tools were studied, considering the effort and skill required for data collection and analysis. The study only used secondary data that are available from government agencies such as ministries, provincial and local administration offices and other organisations involved.

Several woodfuel demand and supply scenarios were developed, based on available data and background information. Uncertainty assessment was applied to evaluate the reliability and usefulness of the analysis. It was concluded that data collection was a time-consuming process because data had to be obtained from a wide variety of agencies, and some data were lacking. Nevertheless the assessment of the energy situation and forecasting through scenario development is possible and feasible at district level in the case of Thailand.

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Abbreviations

Organisations in Thailand:

CDD	Community Development Department, Interior Ministry
DEA	Department of Energy Affairs
DEDP	Department of Energy Development and Promotion
DLD	Department of Land Development, Ministry of Agriculture
EGAT	Electricity Generation Authority of Thailand
MEA	Metropolitan Electricity Authority
NEA	National Energy Administration
NEPO	National Energy Policy Office, Office of the Prime Minister
NESDB	National Economic and Social Development Board
NSO	National Statistical Office
OAC	Office of Agriculture and Co-operatives (Chiang Mai)
PEA	Provincial Electricity Authority
PIO	Provincial Industry Office (Chiang Mai)
PSO	Provincial Statistical Office (Chiang Mai)
PTT	Petroleum Authority of Thailand
RFD	Royal Forest Department, Ministry of Agriculture
TMT	Tobacco Monopoly Thailand

Others:

APDC	Asian and Pacific Development Centre
ESMAP	Energy Sector Management Assistance Programme
FAO	Food and Agriculture Organisation of the United Nations
GAP	Agricultural share of GPP
GIS	Geographic Information System
GPP	Gross Provincial Product
ITC	International Institute of Aerospace Survey and Earth Science
LEAP	Long-range Energy Alternatives Planning model
NGO	Non-Governmental Organisation
RWEDP	Regional Wood Energy Development Programme in Asia
SEI-B	Stockholm Environment Institute - Boston

1. INTRODUCTION

Many households, industries and other enterprises in developing countries depend on wood and other biomass as an energy source. Estimates of woodfuel consumption vary from 30 to 80% of the total energy consumption for most countries. It has been shown that for all RWEDP countries woodfuel consumption is still growing (WEN, 1996). Therefore it can be assumed that the dependence on woodfuels will not change in the near future. However, with an increasing population the need for agricultural land is also increasing, which may conflict with the need for wood. It is necessary to assess if these trends are sustainable and if not, what interventions are required. Therefore it is important to incorporate wood energy in the formulation and implementation of energy policies, plans and projects.

Policy formulation and planning requires the assessment and forecasting of the demand and supply of all forms of energy to identify (future) problems and to allow for the evaluation of intervention options. For this purpose data on several factors that have an impact on an energy system are needed. However, in most developing countries these data are hardly available to energy planners. Data that are used for energy planning are often based on information about sales of conventional fuels, supplied by their respective producers, and estimates of demand and supply of traditional fuels. Data that are required for wood energy planning may exist, but these usually have to come from different sources, hence differences in objectives, definitions and scale may complicate comparison and integration.

The production, distribution and consumption of biomass fuels occur usually at local level, on a small scale and often outside the monetary economy. Due to the local nature of energy, the rural energy system is site-specific. As the environment, the level of income, the type of settlement and the existence and accessibility of resources vary among areas, the supply of biomass fuels and energy consumption patterns also vary. Likewise, within an area, patterns of energy demand and supply can vary by sub-area, town or village, depending on cultural, social, geographic, agro-ecological and climatic conditions. Apart from the influence of energy on the environment (e.g. in the form of CO_2 emissions), environmental factors can influence the energy system in a certain area. The distribution of conventional fuels to an area and among consumers within the area depends on the infrastructure. The availability of biomass fuels depends on geographic factors such as the location of consumption and resources, the infrastructure, slope, land use and land ownership. Existing resources may be inaccessible to certain types or groups of consumers, due to landownership, distance or land use.

The development of energy planning since the early seventies has shown the need for an integrated analysis of the demand and supply of all energy forms (including traditional) in relation to a country's economy and environment, considering inter-sectoral relations and social impacts of energy trends and policies (APDC, 1985). More recently it has become apparent that rural energy, due to its site-specific nature, requires a decentralised approach, i.e. demand and supply assessment, forecasting and plan formulation and implementation for a distinct area, defined either by administrative boundaries or by factors such as agro-ecology, economy, social or cultural characteristics (FAO, 1990).

Unfortunately, at present energy planning in most RWEDP countries occurs mainly at national level, with an emphasis on conventional fuels. Energy planning at the local level is usually not conducted because it is assumed that data are not available and decentralised (energy) institutions do not exist or they lack the capabilities and responsibilities to formulate and implement decentralised energy plans. Little if any practical experience of area-based energy planning has been documented. Therefore the possibilities and limitations of area-based energy planning with respect to data collection and analysis are hardly known.

Objectives of the Study

In order to gain insight into the problems related to the availability, collection and analysis of data for energy planning at area-based level, a case study was conducted in Phrao District, Northern Thailand that followed and documented the planning process from the identification of data requirements to the impact analysis of future trends and intervention options. Energy planning is hardly performed at this level as yet and it is desirable to perform planning at area-based level. Therefore the possibilities and limitations of coming up with an energy plan using available data and analysis tools were studied, considering the effort and skill required for data collection and analysis. The study only used secondary data that are available from government agencies such as ministries, provincial and local administration offices and other organisations involved.

The present case study aims to serve only as an example of the required data collection and analysis steps, in order to assist government agencies involved in rural energy planning, since hardly documentation of this kind is available at present. It may not be feasible to conduct studies like this for all districts in Thailand or comparable areas in other countries. The present case study aims to be an example of data collection and analysis using secondary data that are already available at present for planning at area-based level, in order to identify problems related with these data. It was aimed to identify the minimum amount of data required to assess the present and future energy situation at area-based level.

In short the objectives of the case study are:

1. to identify possibilities and limitations in the formulation of energy plans at area-based level, based on data collection and analysis using secondary data;
2. to identify possibilities and limitations of the use of existing secondary data from government agencies and other organisations, in particular the integration of various scattered data;
3. to identify what can be done with a minimal amount of data to assess the present and future energy situation at area-based level.
4. to evaluate the applicability of existing planning tools such as LEAP and GIS for (area-based) energy planning.

The method of the case study is to apply the different steps of energy planning in an iterative way, i.e. in several stages of data collection and analysis. The initial stage will lead to the identification of data gaps, which will be followed by a another stage of data collection and analysis, and so forth. During the subsequent stages problems related to the requirements, availability, collection and processing of secondary data for area-based energy planning will be identified. The case study covers the assessment of the current energy demand and supply situation, the development of several forecasting scenarios, supply-demand balancing, the identification of intervention options, and the assessment of impacts of future trends and interventions in economic and environmental terms. Uncertainty assessment will be included in supply-demand balancing, because decisions to intervene in the energy system generally will be based on the ratio of wood demand and supply.

It should be stressed that the methods followed in this case study are not the only possible ones. Other options may be feasible depending on the area, data, available tools, institutional set-up, etc. The case study only intends to provide an insight into area-based planning through practical experience, and therefore it cannot be complete. A better understanding of limitations and opportunities in area-based planning requires more case studies conducted for other areas, using other approaches.

The study area was selected because information was already available from reports of ITC students who have done research in the area. These reports cover energy related topics, such as residential and industrial energy consumption and land use evaluation. This information will generally not be available for other areas. The case study tried to use information available from institutions in Thailand as much as possible and the ITC reports were used to identify which site-specific information is required for area-based energy planning in addition to existing information.

2. ENERGY PLANNING & MODELLING

2.1. Energy Planning

The objective of energy planning is to find solutions to match demand for and supply of energy sources. Solutions can be demand-oriented (e.g. price policy), supply-oriented (e.g. new supply technologies) or mixtures of supply- and demand-oriented solutions (CEC, 1988). Figure 2.1 shows the framework of rural energy planning as described by Hulscher (1990).

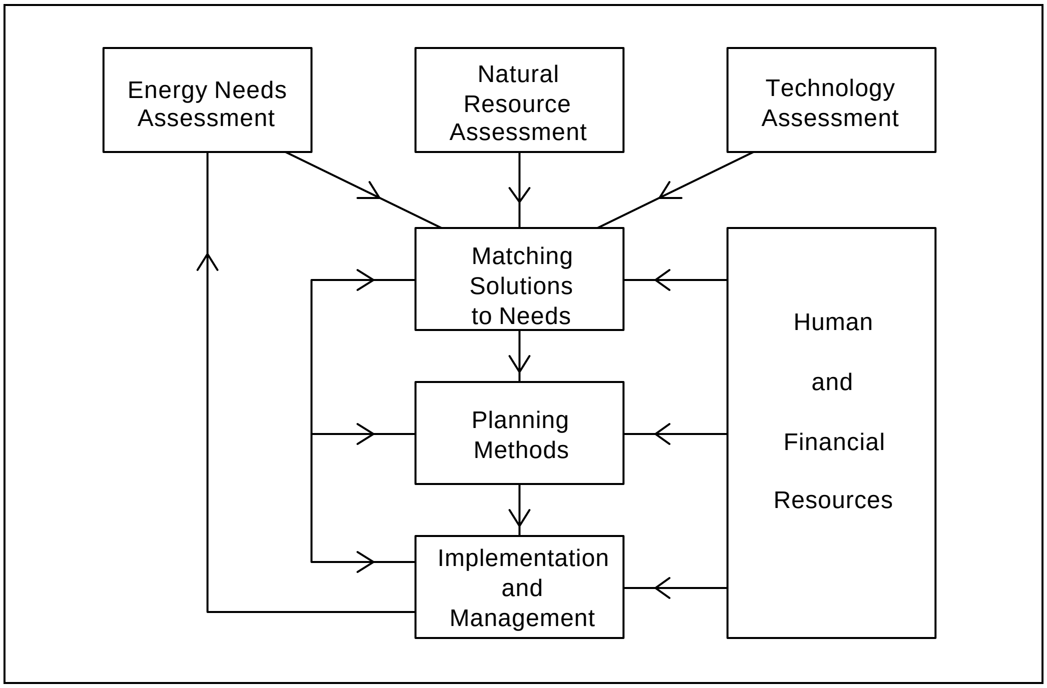

Figure 2.1 *Framework of Rural Energy Planning and Management*

The primary objective of energy planning is to arrive at a set of agreed, feasible and consistent targets for energy policy or an energy plan. The second stage is a set of policy actions to implement such a plan (APDC, 1985).

Levels of Planning

Energy planning can vary in objectives, levels of disaggregation and time span. We can distinguish between, on the one hand, project or programme planning, and on the other, development or perspective planning, which should provide a framework for projects and programmes (Hulscher, 1995). Perspective planning covers a longer time span and it considers more sectors and processes than project planning.

Several levels of disaggregation can be distinguished for perspective energy planning. Strong integration and interaction between the different levels should exist for energy planning to be successful.

- National level: this covers the whole country. Planning objectives are the formulation of broad and long-term policies, strategies and intervention options in relation to national economy

planning. National energy planning is usually supply-oriented with a focus on conventional fuels;
- Sub-national or intermediate level: sub-division occurs according to administrative boundaries. Planning objectives include the formulation of sub-national policies, strategies and intervention options in relation to sub-national planning and environmental issues;
- Area-based level: the area is a distinct zone defined either by administrative boundaries or by factors such as agro-ecology, economy, demography, social and cultural characteristics. Planning objectives include the formulation of site-specific policies, strategies and intervention options in relation to other local development objectives. Area-based energy planning is multi-sectoral with strong emphasis on traditional fuels.

Components of Energy Planning

Energy planning is an iterative and continuous process. Results are continuously reviewed and new information leads to new analyses. Although there is no rigid sequence of steps to be carried out for energy planning, several components of the planning process can be distinguished, and these are discussed below. The process can be applied at all levels of disaggregation (APDC, 1985).

Data Base Development

The objective of data base development is to identify, generate and assemble information required for energy analysis. There is an interdependent relationship between data base development and energy planning. Energy planning depends on the availability and quality of data, and gaps and deficiencies in the data base can be identified as a result from planning. The data base serves as input to demand and supply analysis, but its development does not have to precede these steps. Data base development is part of the iterative and continuous process of energy planning.

The first step is the identification of data requirements, depending on the planning objectives and the issues to be addressed. The data refer to activities of production, transformation, distribution and consumption of energy and parameters that influence these activities. The second step is the collection of required data, from secondary data sources or by energy surveys. A lot of the required data may be available from existing statistics and reports, but these secondary data sources should be critically reviewed because usually they are not generated for energy planning purposes and they may vary in time periods, scale and definitions. When surveys are necessary, they should be designed carefully because they are time consuming and expensive. The third step is the assembling of the data of tables or other formats.

Energy Demand Analysis

The objective of energy demand analysis is to develop a set of projections of future energy consumption. Energy demand analysis plays a sequential, intermediate and iterative role in energy planning. Firstly, it follows the phase of data base establishment. Secondly, it is an intermediate step in the planning process. Its outputs serve as inputs to energy policy analysis. Thirdly, demand analysis occurs iteratively. In the process of formulating policy decisions its results are re-examined and sometimes reset.

Two major approaches to energy demand analysis are macro and sectoral demand analysis. Macro demand analysis considers demand as a function of population, income and prices. Sectoral demand analysis examines the structure of sectors and sub-sectors and their energy consuming activities, including the equipment. Developing demand projections requires a joint and parallel approach.

Energy Supply Analysis

The objective of supply analysis is to generate and assemble information on the present energy supply system and its potential for the future. An energy supply system includes amongst others oil wells, refineries, pipelines, power plants and charcoal kilns, but not end-use devices such as cookstoves, cars and boilers. Supply analysis comprises two categories: the assessment of energy resources and the evaluation of fuel distribution and supply technologies. Resource assessment generates information on the quantity and costs of energy resources.

This requires information on:

- location, class and quantity of resources;
- production rates: the rate at which a resource can be extracted, considering economic, technical and physical parameters;
- economics of production: the opportunity cost of the resource for non-renewable resources, based on the annually consumption of renewables.

Technology evaluation provides information on the various technologies used for the processing of raw energy into energy forms that are useful to end consumers. It assesses various transformation steps with respect to the availability of technology, cost and environmental and social implications.

Supply - Demand Balancing

The objective of supply-demand balancing is to match iteratively demand scenarios and supply options in order to evaluate the consistency of the data, to identify gaps and to evaluate energy demand and supply options. Energy flows are traced from each source to each end-use, assessing intermediate uses, losses and other factors. Because an interdependence exists between demand and supply, supply cannot be studied independently of demand (and vice-versa). The output of supply-demand balancing is a number of alternative energy balances.

Impact Assessment

Impact assessment means the analysis of impacts of alternative scenarios and policy measures, such as economic impacts (e.g. inflation, external trade and foreign exchange balance), environmental impacts (e.g. water, soil and air, health aspects, safety, deforestation), and social impacts (e.g. employment, gender, development, poverty alleviation). It can serve both as an input for and as an evaluation of policy formulation.

Energy Policy Analysis

The output of supply-demand balancing can reveal problems or undesirable trends in the present or future energy system such as shortages, unequal distribution of fuels or sub-optimal use of existing resources that require interventions, either on the demand side, the supply side, or a combination of both. Interventions can be implemented either by policies, such as pricing, subsidies, promotion of conservation or technologies, or by projects such as improved cookstoves and community forests.

The objective of policy analysis is to formulate an energy plan. Crucial points are the degree of detail as compared to other planning efforts, and the degree of centralisation or decentralisation adopted for implementing the plan. Energy policy analysis has two aspects. Firstly as an information assembly and co-ordination stage, which places demand scenarios and supply options in an economy-wide framework. Secondly as a forum for assessing energy management tools, which covers the policy tools available for closing energy supply-demand gaps and for overcoming imbalances between the energy sector and the economy as a whole.

2.2. Energy Modelling

For energy planning, models are used to assist planners to perform demand and supply analysis, to make forecasts for the future and to identify gaps in the demand and supply and options for intervention. Several models have been developed and used in recent years for planning, mostly at national level. They vary from econometric models using linear programming to techno-economic models that analyse sectoral energy consumption at detailed level. Of these models, the Long-range Energy Alternatives Planning model (LEAP) seems to be the one most known and used in developing countries mainly because it includes the supply of biomass as an energy source and several countries are willing to adopt it for data storage and planning purposes. Because of its flexible data structure it can be applied at different levels of disaggregation; e.g. for national planning or area-based planning. However, at present its use is severely constrained by the present lack of a comprehensive energy data base in most countries. It is used in the case study for the development and evaluation of energy demand and supply scenarios. A brief description of the model follows below.

LEAP follows an end-use, demand driven approach which means that energy demand is viewed from the consumption of energy for each end-use. The analysis of energy consumption and supply occurs through scenario development to simulate alternative energy scenarios under a range of user-defined assumptions. The impact of the alternative scenarios can be evaluated in economic and environmental terms. The Energy Scenario programs (Demand, Transformation, Biomass, Environment and Evaluation) of LEAP are discussed below (SEI, 1995a).

The demand program divides the society in a hierarchical structure of four levels: sectors, sub-sectors, end-uses and devices. An example of one branch of this structure could be households (sector), rural households (sub-sector), cooking (end-use) and charcoal stove (device). The demand variables can change according to explicitly specified values, growth rates or drivers and elasticities. The total demand is calculated by summing up the consumption for all sub-sectors and sectors.

Energy conversion processes with their efficiencies and losses can be incorporated in the transformation program, so for every requested fuel type, the total amount of required primary energy can be calculated from the demanded final energy. Different levels of complexity of transformation processes can be distinguished, from simple (i.e. single input and single output with only one efficiency factor, e.g. wood as input of a kiln and charcoal as output) to more complex processes with multiple inputs and outputs and efficiencies (e.g. power plants).

The biomass program divides the area in sub-areas, zones and land use types. For each land use type the acreage, stock and yield of woody biomass is to be specified, after which the total biomass supply can be calculated. Forecasts are based on land conversion by indicating how much area of a land use type is converted to another land use type. The accessibility of wood resources can be incorporated by specifying an access fraction for each land use type, which represents the maximum fraction of yields and stock that can be used for energy purposes.

The model contains an Environmental Data Base (EDB) which contains data on environmental effects water, soil and air for several types of end-use and transformation devices. This can be used to evaluate the environmental impact for the alternative demand and transformation scenarios. The evaluation program can be used to compare physical, energy and cost differences between alternative demand, transformation and biomass scenarios.

For the energy supply analysis a Geographical Information System was used to process geographic data (such as land use, infrastructure) and to assess the accessibility of the wood resources (see section 6.2). A Geographical Information System (GIS) comprises a set of powerful tools for collecting, storing, retrieving, transforming and displaying spatial data. By interactively accessing, transforming and manipulating these data, environmental processes, past trends and the possible impacts of planning decisions can be studied. Input data can be information from existing maps, field observations, aerial photographs, satellite imagery, tables and reports (Burrough, 1986).

2.3. Data Uncertainty

Data always contain uncertainty due to measurements errors, sampling errors and errors during data processing such as copying, counting and transferring, and sometimes even by manipulation of data (Jacob, 1984). The uncertainty of data influences the reliability of the results of energy analysis and modelling. The integration of different data sets, each with an uncertainty, leads to error propagation, which may increase the overall uncertainty. This does not only apply to forecasts, which are uncertain by nature, but also to the analysis of the present or past situations. The use of uncertain data implies a risk of decision-making, because decisions are taken under the assumption of a certain reliability of available data. The uncertainty of data and modelling results, in fact, defines the margin in which decisions can be taken. Therefore data uncertainty and risks should be quantified and incorporated into decision-making, to evaluate the usefulness of the analysis and to ensure sound decision-making. This requires the quantification of uncertainties of data sets and risks, and the evaluation of the propagation of uncertainties in results of the analysis.

The impact of data uncertainty in the case of energy planning can be illustrated by the following example. Suppose that for an area the demand for fuelwood and the sustainable supply of the existing forest resources are studied, without accounting for data uncertainty. The total demand appears to be 1000 GJ/year in the first year of the analysis, increasing to 1400 GJ/year over the coming 20 years, and the sustainable supply of forest resources can account for 1500 GJ yearly. This would mean that for the coming 20 years enough supplies are available, but interventions may be required to prevent likely problems after this period. Now suppose that the uncertainty of data is incorporated in the analysis, which shows that both the demand and supply value have an error estimate of ±10%, which means that the true value for the variable most probably lies between 90 and 110% of the given value. The values for demand and supply and their uncertainties are shown in Figure 2.1. This shows that the uncertainty can have a serious impact on the results and thus on the decisions to be taken. In the worst case, i.e. highest demand and lowest supply, the total demand will outgrow the supply in about six years, in another case the demand may even decrease at the end of the scenario period, so intervention would not be required.

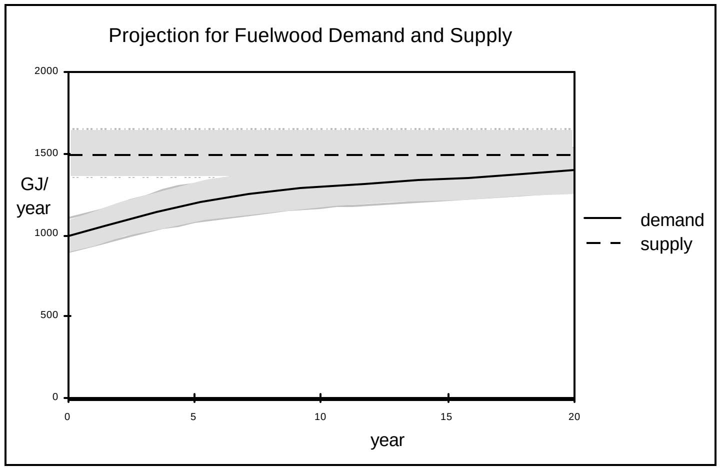

Figure 2.1 *Example of Data Uncertainty*

Methods to incorporate uncertainty assessment in the analysis include the assessment of error propagation and sensitivity analysis. The former refers to the determination of the uncertainty of a variable that is a function of two or more variables, which requires a series of observations for these variables (or an estimate of their uncertainty), and knowledge about the distribution of the uncertainty. The latter method refers to the evaluation of the responsiveness of conclusions or analysis results to changes or errors in parameter values or assumptions. In other words, the stronger the outcome reacts to changes in a certain input parameter, the more accurate information about this parameter is required. The reader is referred to Appendix A1 for a more detailed description of these methods. Both methods will be applied in the case study for uncertainty assessment.

3. ENERGY IN THAILAND

3.1. Energy Planning in Thailand

Several institutions and organisations are involved in energy planning and management activities in the country (Chantavorapap, 1993). The most important are discussed below.

Governmental Agencies

The responsibility of formulating and implementing energy plans is divided among several agencies. Their responsibilities and powers tend to overlap because they are located in different ministries.

The National Economic and Social Development Board (NESDB) formulates the overall national development plan in the form of 5-year development plans of which the present one is the seventh (1992-1996). The plan sets the direction and strategy for national development during the planning period. More elaborate and detailed plans are subsequently drawn up by the implementing agencies, such as ministries (Tingsabadh et al., 1991). NESDB is located in the Office of the Prime Minister and is a central coordinating body for other government agencies.

The national energy plan is formulated by the National Energy Policy Office (NEPO), located in the Office of the Prime Minister, and respective production companies, i.e. EGAT (Electricity Generation Authority Thailand), PEA (Provincial Electricity Authority), MEA (Metropolitan Electricity Authority), PTT (Petroleum Authority Thailand) and the Department of Mineral Resources of the Ministry of Industry in cooperation with NESDB. It mainly focuses on conventional energy and it is mostly supply oriented. There is little concern for traditional energy. Special policies for rural areas are limited to the electrification of villages and subsidies for LPG and electricity.

The Department of Energy Development and Promotion (DEDP), formerly the National Energy Administration (NEA), is located in the Ministry of Science, Technology and Energy. Since the reorganisation, when planning responsibilities were transferred to NEPO, it has been mostly involved in technical research and compilation of energy data, water pumping and irrigation. It publishes a national energy balance yearly. Since 1980 it has conducted a survey on energy consumption by rural households at five year intervals. It has several regional energy centres which develop and promote rural energy technologies in cooperation with local authorities, universities and other agencies.

The National Statistical Office conducts several kinds of survey, such as a population census, socio-economic survey, etc. It also conducts a bi-annual household energy survey.
Specialised agencies exist that are responsible for the extraction and/or production and distribution of oil, gas and electricity. No equivalent agency exists for renewable energy sources. The Royal Forestry Department (RFD) has a role in the supply of fuelwood by control of forest areas through licenses for wood cutting and charcoal making. Also it does some research on fuelwood related issues, e.g. the production of charcoal, improved cookstoves.

Private organisations

The private sector is involved in refining and distributing oil and gas, and since recently privately generated electricity can be supplied to the grid. The commercial banking system is the major source of credit for energy investments. Private companies and universities are involved in the research and development of equipment for rural energy projects. Most Non-Governmental Organisations (NGO) are concerned with rural development in a broad sense, and not with energy issues in particular. Some are involved in the development of community forests as a means to conserve the natural forest and the rural way of life (Tingsabadh et al., 1991).

3.2. The Energy System in Thailand

In 1994 total energy consumption was 43.8 Mtoe, of which 26% was provided by biomass fuels (DEDP, 1994). Due to the rapid economic growth during the 80's and early 90's the demand for energy has risen sharply, more than the domestic production of energy, so dependence on imported fuels has increased to 60%. The country's primary energy resources are lignite, crude oil, natural gas, hydro-electricity and biomass.

Development Objectives

The Energy Development Plan during the Eighth National Economic and Social Development Plan (1997-2001) of NEPO aims to speed up the development of domestic energy production to prevent a further increase of the import dependency. Specific targets of energy development are:

- Increasing the commercial energy production at a rate of 5% per year;
- Keeping the growth rate of commercial energy consumption abreast of the GNP growth rate;
- Maintaining the energy import dependence at no more than 70% by 1996;
- Limiting emission of sulphur dioxide from commercial energy consumption;

Strategies to reach these goals include speeding up exploration and production of domestic petroleum, increasing refinery capacity and electricity generation, encouraging the efficient use and conservation of energy, promoting private sector role and developing public organisations. With respect to biomass energy the plan aims to promote reforestation activities, to develop the woodfuel industry, to encourage the plantation of trees on empty land and to promote the production and utilisation of improved biomass energy equipment (NEPO, 1996).

3.3. Description Of The Study Area

Phrao district is located in Chiang Mai Province in the Northern Region of Thailand, with its centre about 90 km north of Chiang Mai city. The area is a floodplain of 30,000 hectares, surrounded by a mountain range of 100,000 ha. It has a tropical monsoon climate with two distinct seasons, a rainy season from May to October and a dry season from November to April. Total annual rainfall is 1200 mm. The average annual temperature in the floodplain is approximately 25° C.

The district consists of eleven sub-districts (tambon) and 100 villages, most of which are located in the floodplain. Total population was 48,867 in 1990, with an average annual growth rate of 0.72% between 1980 and 1990. The main occupation is farming, with rice as the major crop.

Industries in the area include agriculture related industries such as tobacco curing and rice-milling, and pottery and brick-making.

The major energy consumer sectors in rural areas in Thailand are the residential, agricultural and industrial sector. The main energy end-uses of rural households are cooking, lighting, water supply, the use of electrical appliances, space heating and fumigation (protection from insects). Major fuels for cooking are fuelwood and charcoal, with an increasing role for LPG and electricity (for rice cooking) over the last two decades. Pumps for water supply use modern fuels (electricity, gasoline or diesel) or animate power (human, animal). For lighting, kerosene was the traditional fuel in rural areas. Due to the scale of rural electrification in the last decades this has been replaced by electricity in many households. Also the use of electric appliances has increased, although mainly by higher income groups. Space heating, in the cool season or mountainous areas uses mostly fuelwood and agricultural residues. The same fuels are used for fumigation.

The main end-uses of the agricultural sector are land preparation, irrigation and machinery for sowing, threshing, drying and others. The main energy source is animate power, though, increasingly this is being replaced by diesel and gasoline (Raengkhum, 1990).

In the Northern Region the main industries in rural areas are tobacco curing, brick-making, pottery and rice-milling. Cottage industries, that produce food products and household goods require very little fuel in comparison with household energy consumption and are very labour-intensive. For tobacco curing coal lignite and fuelwood are the main fuels. Pottery industries, of which most are located in the Northern Region, use mostly fuelwood and in some cases rice husks or LPG. Brick-making industries can be found in the whole country. They use fuelwood, rice husks or diesel as fuels (Chantavorapap, 1993).

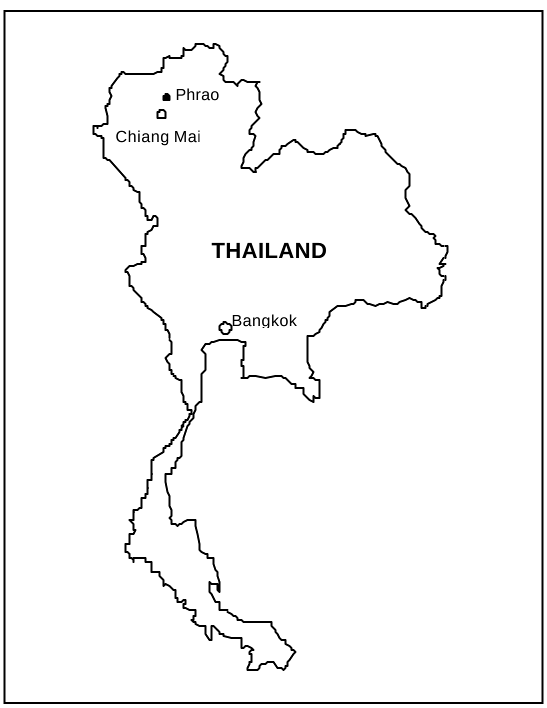

Figure 3.1 *Location of Phrao District*

4. DATA BASE DEVELOPMENT

Data base development occurs in three stages. It starts with the identification of the required data, followed by data collection and data assembling.

4.1. Identification of Data Requirements

Data base development starts with the identification of required data for demand and supply. The data requirements are identified separately for demand and supply analysis.

Data Requirements For Demand Analysis

Data requirements for demand analysis are divided into two groups; (1) factors affecting energy consumption and (2) actual consumption. The first group refers to population, industrial and agricultural production, Gross Domestic Product for the area or at higher aggregated level, etc. The second refers to actual energy consumption per sector.

Factors Affecting Energy Consumption:

- Population and number of households;
- Average annual population and household growth;
- Average annual income per capita or household;
- Gross Domestic Product for the Phrao district or Chiang Mai province;
- Production per type of industry (tobacco curing, pottery, brick-making, rice-milling);
- Agricultural production per type of crop;

Energy Consumption:

- Energy consumption per type of household;
- Energy consumption per type of industry;
- Energy consumption by type of crop;

Data Requirements For Supply Analysis

Data requirements for supply analysis are separated into two groups; data on resources and data on the supply technology. No resources of conventional fuels are existing in the area so the supply analysis will only cover wood and other biomass energy. The data requirements for supply technology include geographical data such as infrastructure and slope of the terrain to evaluate the accessibility of the biomass resources.

Resources:

- Land use;
- Types of forest in the mountainous areas;
- Standing stock and annual yield per hectare for the present forest types;
- Standing stock and annual yield per hectare for trees in non-forest areas (orchards, home gardens);
- Production and utilisation of agricultural residues;

Supply Technology:
- Infrastructure;
- Height and slope of the terrain;
- Collection patterns;
- Conversion technology (charcoal kilns);

4.2. Data Collection

Data collection started with a review of statistical reports and other government publications, because it was assumed these would provide relevant data at regular time intervals. No data were available from NGOs or educational institutes in Thailand. Some data were provided by private organisations (e.g. tobacco production). More data may be available from NGOs and private organisations but time was lacking to further continue the data collection.

At central level data were provided by several divisions or sections of five government agencies (CDD, DLD, DEDP, NSO, RFD). Four provincial offices provided data (RFD, PSO, PIO, OAC), while at district level the district office could provide data on several issues.

Other important data sources were RWEDP publications and MSc theses of the ITC students who have studied related issues in the area. Furthermore, several government offices in Bangkok were visited in an attempt to collect additional data that is not published.
An overview of the initial collection of data for demand and supply follows below.

Demand: Energy Affecting Factors

Data collection for demand started with a review of reports compiled by different government agencies. These included statistical reports of the National Statistical Office (NSO) on population.
Population data were retrieved from the population censuses of 1980 and 1990 (NSO 1980 & 1990). Population and the number of households are given per type of area (rural or sanitary) (see table 4.1). The sanitary area is an intermediate classification between rural and municipality. Usually, as in the case of Phrao, it is the centre of a district, where the district office is located. It is different from villages and it could be called a town.
A report on the projection of the population and the number of households for the whole country was available from NSO (1992).

Area	***1980***		***1990***		***Annual Growth Rate 1980-90***	
	Population	*Households*	*Population*	*Households*	*Population*	*Households*
Total	45,485	11,283	48,867	14,436	0.72	2.49
Sanitary	2,750	741	3,569	1,122	2.64	4.24
Rural	42,735	10,542	45,298	13,314	0.58	2.36

Table 4.1 *Population and Households in Phrao District (NSO 1980 & 1990)*

The statistical reports for Chiang Mai Province provide information on several issues, some per district, some for the whole province (NSO, 1983 & 1993). An overview of the relevant information is given below:

- Population in Phrao district (1981, 1992);
- Number of households per income group in Phrao district (1979, 1992);
- Average monthly income per household by source of income for the Northern Region (1992);
- Gross Provincial Product (GPP) by industrial origin for 1987-1991 at market prices (corrected for inflation) and at constant 1988 prices;
- Gross Provincial Product (GPP) by industrial origin for 1976-1980 at market prices and at constant 1972 prices;
- Electricity sales per consumer group in Phrao district (1982, 1992);
- Number of electrified villages in Phrao district (1992);
- Area and production of rice in Phrao district (1992/3);

The Statistical Reports of the Northern Region (NSO, 1991) gives the GPP by industrial origin at constant 1972 market prices for 1981-1987 so the GPP for 1988-1991 at constant 1972 market prices can be calculated. Information on other crops and industries for Phrao district was not available from statistical reports.

The Community Development Department (CDD) of the Interior Ministry was contacted about a survey that is conducted every two years for all villages in the rural areas, the NRD-2C Village Survey. The objective of these surveys is to evaluate implemented projects and to identify target areas for project implementation. For every village the data are collected in a group interview with the village committee by the tambon working group of the sub-district. The village committee consists of the village headman and several others. The tambon working group consists of local representatives of the sub-district, the district office, the Public Health Department, the Agriculture Extension Office and one teacher. For each village the data are classified according to 37 indicators in three classes, backward, intermediate and progressive. These indicators are compiled to one final village classification (CDD, 1995). Since the survey only considers rural areas, the sanitary area of Phrao is not included.

The computer centre of CDD in Bangkok provided the original survey data for the years 1992 and 1994. It contains data on a wide range of issues, such as population, occupation, income, economy, infrastructure and education. With respect to energy issues, data on the main fuel used for cooking, the source and time for collection of fuelwood and the number of households having electricity are included.

Demand: Energy Consumption

Both NSO and DEDP conduct surveys to estimate the household energy consumption with different objectives, sampling rates, intervals and methods.

The energy consumption surveys conducted by NSO are a by-product of other surveys. The first two (1984, 1985) were conducted with the labour force survey. Since 1986 they are conducted bi-annually with the socio-economic survey on household income and expenditure. For 1986, 1990 and 1992 separate energy reports are available, for 1988 the survey was conducted but no energy report was published. The report of the 1994 survey was not available during the course of the case study.

The sampling rate of the surveys varies per year. In 1992 the number of households interviewed was 16,000 out of 12.2 million for the whole country (0.13%), and 3,000 out of 2.6 million for the Northern Region (0.12%). Annual energy consumption per household is given by fuel, region, socio-economic and income classes, household size and community type (municipal area, sanitary areas and villages). It focuses on petroleum products and, of biomass fuels, only wood and charcoal are included. During the survey the consumption is measured by the expenditure for every fuel and converted to energy units using the local fuel prices. This is also done for charcoal and fuelwood, which means that only purchased woodfuels are accounted for in the consumption figures (NSO, 1995).

The objective of the DEDP surveys is to get an indication of the household energy consumption in rural areas. Municipalities and sanitary areas are not included in the surveys. The first survey was conducted in 1980 by DEDP (then NEA) for the preparation of the Energy Master Plan. The following surveys of 1985 and 1991 were conducted by regional universities and external consultants respectively. On request DEDP provided figures on the per household energy consumption in the Northern Region from the 1985 and 1991 surveys. Unfortunately the same data from the 1980 survey could not be obtained. Several persons and divisions were approached but none could provide the requested information. It was said that only 20 copies of the report have been produced and they could not be traced anymore. From an article discussing the 1980 and 1985 surveys only the final and useful energy consumption per capita for the whole country was available (Raengkhum, 1990).

The number of sample households was 2800 out of 9.9 million for the whole country (0.03%), and 779 out of 2.4 million for the Northern Region (0.03%) in 1991. Average annual consumption is given by region, household, capita, fuel and end-use. Several kinds of biomass fuels are included. Consumption is measured in physical units: kilogram for fuelwood and charcoal and other biomass fuels; litres for kerosene; number of bottles for LPG; number of electricity units from monthly bill. The consumption of electricity for different end-uses is estimated from the number and power of devices and the estimated time that these are used (DEDP, 1995).

The DEDP surveys of 1980 and 1985 include also energy consumption by the agricultural sector. For several crop types the fuel consumption per rai is given[1]. The 1980 survey distinguishes between land preparation and other activities, whereas the 1985 survey gives only the total energy consumption but it includes more types of crops. Both surveys recognise human and animal labour as an energy source, which gives options for fuel substitution evaluation, e.g. the replacement of buffaloes by diesel tractors (Raengkhum, 1990).

A separate agricultural energy survey was carried out from June 1988 to June 1990 by the Mahidol University for DEDP. Six major economic food crops were distinguished, namely rice, maize, cassava, sugar cane, soy bean and sorghum, amounting to 75% of the total field crop in Thailand in 1988. Data collection was achieved using secondary data analysis, farm interviews and farm tests and measurement. The survey was carried out in 17 agro-economic zones in 51

[1] rai is a Thai unit of measurement for land area; 1 rai = 0.16 hectare

of the 76 provinces. Energy use is presented per agro-economic zone for several activities, such as soil preparation, plantation, weeding, fertilising and irrigation (DEDP, 1992b).

Supply: Resources and Technology

The Forest Resources Assessment Division of the Royal Forestry Department (RFD) was contacted for data on standing stock and annual yield but these were not available.

Topographic maps with a scale of 1:50,000 of 1969 with 1982 road information were found to exist at the Thai Military Survey Office, but they could not be obtained because they are classified. They are available for government agencies but not for public and foreign organisations.

It was expected to collect more data on biomass resources required for supply analysis at institutions in Chiang Mai and Phrao.

A literature review of several publications provided adequate information on different methods of charcoal-making, their functioning, construction and efficiencies. Panya and Lovelace (1988) give a good description of the most common methods used in north-east Thailand but do not provide information on efficiencies. A report on charcoal prepared by RFD and published by NEA (NEA, 1984) provides information of yields and efficiencies measured during tests of different types of charcoal kilns used in Thailand. As these tests are performed under ideal circumstances these figures can be assumed to be rather high. Three types of kilns which are common in Thailand were identified:

1. Earth mound pit: This type is constructed by first digging a small pit in the ground. Then the wood is placed in the pit and lit from the bottom, after which the pit is covered with rice husks, saw dust or earth. The process takes up to 3 days. Yield 27.3 - 35.5%, average 31.1% (NEA, 1984);
2. Mud Beehive or Baked Clay Kiln: This is a semi-spherical or parabolic shaped kiln made of mud or clay, above the ground or partially underground. Sizes vary from kilns with a 30 kg fuelwood capacity to large kilns with 6-10 ton output capacity, with varying production time. It produces better quality charcoal than the earth mound pit at a higher efficiency. Yield 28.4 - 45.8%, average 37.2% (NEA, 1984);
3. Brick Beehive: This kiln is similar to the mud beehive except that it is made of bricks. Yield 32.2 - 43.6%, average 37.5% (NEA, 1984);

The yield of a kiln is the ratio of the weight of input and the weight of output, as opposed to the efficiency which is the ratio of the energy content of the input and the energy content of the output. Since the energy content of charcoal is higher than the energy content of fuelwood the efficiency of charcoal making kilns is higher than the yield.

4.3. Data Assembling

All collected information was assembled in comprehensive tables and overviews to allow for comparison and analysis. To allow comparison of data from different sources these have to be assembled in comparable units. This is important especially for the energy content of fuels, expressed as the heating value per physical unit (e.g. megajoule per kilogram). The moisture and ash content influence the energy content of a fuel. A part of the weight or volume of the fuel can be water, which has no heating value. Also, energy is required for the conversion of water to steam during fuel use, which reduces the energy directed to the end-use. The ash content refers to the non-combustible materials in the fuels which reduce the heating value (Ryan and Openshaw, 1991).

A standard set of values for the energy content of fuels was compiled from the default fuel list and standard conversion factors provided by LEAP (SEI, 1995a). All physical energy consumption figures (in kilograms or litres) of energy consumption surveys were converted to energy units using these standard values.

5. DEMAND ANALYSIS

Demand analysis occurred in several stages of data collection and analysis through the identification of further data requirements after each stage. During the first stage, use was made of data available from reports and publications of government offices in Bangkok.

5.1. Forecasting

Forecasting for demand analysis distinguishes economic growth forecasting, population forecasting, and consumption pattern forecasting. Scenarios for the total energy situation will be developed from these forecasts.

Economic Growth Forecasting

From the statistical reports of Chiang Mai province the Gross Provincial Product is known from 1981 up to 1991. For most of the components of the GPP it can be assumed that they are dominated by Chiang Mai city, which is experiencing rapid economic growth. Since agriculture is the main occupation in Phrao the agriculture share of the GPP is chosen as a measure of income.

Since farming is mainly a household activity in Phrao the Gross Agricultural Product (GAP) per household could serve as the driver for crop production, but because data on the number of households in Chiang Mai Province in 1981-1991 were not available, the GAP was chosen instead. For agro-related industries like tobacco curing and rice milling the GAP was also chosen as driver as these are less related to individual households.

The Gross Agricultural Product at constant 1988 market prices increased with an average annual growth rate of 3.8% between 1981 and 1991 (NSO, 1991 & 1993). The national growth rate of the agriculture sector was 3% per year during the sixth economic plan (1987-1991). The seventh economic development plan aims to continue this growth during the period 1992-1996.

Population Forecasting

Different methods were used to give forecasts for the population and number of households. Firstly, it was assumed that average annual growth will remain the same as that recorded between 1980 and 1990. The growth rate for population is lower than for households (see table 4.1) so the number of households will increase more than the population, which means that the average household size will decrease. Different growth rates were used for the sanitary area and the rural area. Since the former is higher it means that the sanitary population will increase faster than the rural population. This can be contributed to the faster development of the sanitary area which stimulates migration from the villages to the district centre.

The second method was to relate the past population growth (1980-1990) for the whole country with the past population growth of Phrao, in order to forecast the population in Phrao based on the available national forecasts. As in the previous option the sanitary and rural area are distinguished. The national forecast gives the total population and the number of households from 1990 - 2010 with a five year time interval (NSO, 1992). From this the average household

size, and the growth rates for every 5 year interval could be calculated. For Phrao the future growth rates were calculated assuming a stable ratio between the national growth rate and the growth for Phrao. So the growth rate for Phrao in 1990-1995 is equal to the national growth rate multiplied by the ratio of the past Phrao growth to the past national growth rate. From the future growth rates of Phrao the total population, the number of household and the average household size for both the sanitary and rural area were calculated.
Table 5.1 shows the population and the number of households according to the different methods of forecasting.

	Stable Population Growth				***Population & Households Projected***			
	Sanitary district		**Rural Area**		**Sanitary district**		**Rural Area**	
Year	*Population*	*Households*	*Population*	*Households*	*Population*	*Households*	*Population*	*Households*
1980	2,750	741	42,735	10,542	2,750	741	42,735	10,542
1990	3,569	1,122	45,298	13,314	3,569	1,122	45,298	13,314
1995	4,066	1,381	46,627	14,961	4,172	1,223	46,909	13,975
2000	4,631	1,700	47,995	16,812	4,583	1,434	47,901	15,281
2005	5,276	2,092	49,403	18,891	4,966	1,651	48,764	16,538
2010	6,010	2,574	50,852	21,228	5,298	1,867	49,470	17,715

Table 5.1 *Population and Households Forecasts*

Forecasting Industrial and Agricultural Production

As stated in the previous section, no data on industries in Phrao were available from reports or government agencies in Bangkok so no forecasts could be developed at this stage.
For agriculture, only data on rice production and area in 1992 in Phrao were available. Data from previous years were not available because the statistical report of 1983 (NSO, 1983) does not give rice data per district so the change in area and production could not be related to the Gross Agricultural Product. For the whole province the rice production for 1982-1990 and 1992, and the GPP and GAP at constant 1972 prices are available. Elasticities between rice production and the GAP could be calculated for the whole province and used to forecast rice production in Phrao. However, this would not be realistic since the agricultural circumstances may be site-specific. This is especially true for the area of rice production which is a major driving factor for agricultural energy consumption. Therefore assumptions will be made about the area and production of rice during scenario development (see section 5.2).

Household Energy Consumption Forecasting

Considering the method of measurement and the included fuels for both surveys, it was concluded that the DEDP surveys are more useful than the NSO surveys, because the former consider more types of biomass fuels, and energy consumption is measured in physical units instead of monetary expenditure as done by NSO. In the latter way collected woodfuels are not included in the measurement. Since biomass is often a non-commercial fuel. the given consumption figure cannot be taken as realistic. Comparison of the two types of surveys shows that the woodfuel consumption figures of the NSO surveys for the Northern Region are lower for charcoal (44%), but higher for fuelwood (120%). This is surprising since charcoal is usually a more commercially traded fuel than fuelwood. The reason for this could not be found. End-uses are not distinguished in the NSO surveys (except for LPG) so options for fuel switching are difficult to evaluate.

On the other hand, the NSO surveys distinguish different types of households, such as urban, sanitary and rural, and they give consumption per household income group, which can be useful for consumption forecasting. Energy consumption forecasts could be based on the forecasts for the population of the different groups and the change of behaviour. However, the income groups used for the subsequent energy surveys are not consistent and they do not match with those used in the households statistics which complicates comparison.

The energy consumption in the Northern Region of the DEDP survey will be used for the demand analysis since data at more disaggregated level are not available. Using raw survey data to obtain more disaggregated data on average household energy consumption (e.g. for Chiang Mai province or Phrao district) would not be feasible because the sample size for these areas is too small.

Comparing the energy consumption in the Northern Region in 1985 and 1991 of the DEDP surveys, it can be seen that the use of the conventional fuels LPG and electricity has increased sharply. This is probably more because of the increase of supply of both electricity and LPG than the increase of consumption in households that already used these fuels. The number of electricity customers in Phrao has increased from 1,722 in 1982 to 11,346 in 1992. This includes households, industries and government offices (NSO, 1983 & 1993). LPG was introduced around 1970, but it remained virtually inaccessible to rural villages up to 1980. After that the supply increased and many people adopted it for cooking due to its convenience; it has no start up time and it is very responsive to control (Chirarattananon and Chomcharn, 1985). So it can be concluded that more people started to use LPG and electricity, instead of people using more of these fuels. Furthermore, other great changes cause doubt on the comparability of the surveys. For example, the energy consumption for space heating increased by more than 100% according to the surveys. This may be contributed to different weather conditions in the survey years and the different month of data collection (May-June in 1985, September-October in 1991). These factors may have an influence on other consumption patterns as well.
Therefore it is difficult to base forecasts for future consumption patterns on the DEDP surveys. Data on the number of households that use electricity are available from the village survey but not for LPG, so the change of consumption cannot be related to the change of the number of customers. The Gross Provincial Product could be used to calculate income elasticities but this would not be realistic because income was not the main driving factor. The surveys do not distinguish income groups or other classes, otherwise forecasting could be done based on an assumed shift in the distribution of households among income groups.

During scenario development assumptions will be made about the change of per household energy consumption.

Agriculture Energy Consumption Forecasting

For agriculture, the energy consumption per hectare is available from the DEDP surveys. The driving factor of energy consumption used in the surveys is the area of land used per crop. From

comparison of the surveys it can be concluded that these are hardly consistent. The 1980 energy consumption is given per region, for 7 crop types, distinguishing between land preparation, water pumping and other activities, whereas the 1985 survey distinguished 20 crop types but no end-use activities. The 1991 survey gives the energy consumption per agro-economic zone for 6 major economic crops (rice, maize, cassava, sugar cane, soybean, sorghum), distinguishing between soil preparation, planting, weeding, threshing, fertilising, transportation and others. The differences in disaggregation, crops and end-uses complicate comparison and trend analysis. Furthermore, comparison of the data for human and animal labour suggests that different methods and definitions have been used for the different surveys.
Since it is difficult to identify a trend in the agriculture energy consumption from the subsequent surveys, other forecasting methods are required. The 1990 survey will be used as the base for agriculture energy consumption. For scenario development, assumptions will be made regarding the change of energy consumption per hectare for the different crops and energy sources.

5.2. First Stage of Scenario Development

From the different forecasts for population, economic growth and energy consumption patterns different scenarios were developed. The scenarios are based on the data of the population from the population census (NSO, 1990), agriculture production in 1992, household energy consumption from the 1991 survey (DEDP, 1992a) and the agriculture energy consumption from the 1990 survey (DEDP, 1992b). In no way are the scenarios following below the only possible ones. Several assumptions were made for these scenarios, so other scenarios can be developed under different assumptions.

As the base year, 1991 was chosen because of the household energy survey of 1991. Variables for which no value for 1991 was available were projected (back or forth) depending on the projection method used for these variables in the different scenarios. For example, the number of households is given for 1990. If the growth rate for the number of households can be assumed constant, the value for 1991 is calculated from the 1990 value using this growth rate.

Although the household energy survey covers only the rural area and no sanitary areas, it was decided to use its results for the sanitary area as well since no other data were available. No consumer groups could be distinguished, so the total number of households represents the residential sector at this stage.

For industry, no data were available at this stage so it could not be included in the scenarios. For agriculture, only production data on major and secondary rice were available so the scenarios include only these crops.

Scenario 1: Population Growth and Consumption Patterns Stable

For the first scenario it was assumed that the number of households continues to grow according to the same rate as that prevalent between 1980-90 (2.49% per year). The energy consumption per household and end-use will be stable, so population increase is the only driving factor for the change of residential energy consumption in this scenario.
For agriculture it was assumed that the area of rice production and the energy consumption patterns are stable so the total energy consumption will remain the same.

Scenario 2: Population Projection and Change of Consumption Patterns

For this scenario the number of households was adopted from the population projection (see section 5.1, population forecasting). The per household energy consumption for cooking changes assuming that the total useful energy consumption remains the same. Figures on efficiencies of cooking devices used by NEA were found in NESDB (1985). It was assumed that some households will shift from fuelwood to charcoal and from charcoal to LPG and electricity. This results in a decrease of final energy consumption because the efficiencies of the different devices are not the same: wood stove (15%), charcoal stove (25%), LPG stove (40%), electricity stove (90%). Assumptions were made on the share of useful energy for every cooking fuel in the year 2010. From this the final energy consumption was calculated. The total final energy consumption per household is lower than in base year 1991. The consumption for the intermediate years was interpolated assuming a gradual shift. For agriculture, the area of rice production was still assumed to be stable but an increase in consumption of all fuels (including human and animal labour) per rai of 0.5% per year was assumed, so the total energy consumption will increase.

Scenario 3: Higher Efficiency, Modernisation of Agriculture

The change of per household energy consumption will be as in the second scenario but now it is assumed that the useful energy consumption will decrease slightly because of the shorter start-up and extinction time required for electricity and LPG devices. Assumptions were made for the amount of this conservation.

For agriculture, less area will be used for major rice growing, but the production and thus the area of secondary rice will increase due to the adoption of new technology like irrigation that is required for the production of rice during the dry season. The consumption of modern fuels per rai will increase by 0.7% per year, and human and animal labour per rai will decrease with 0.4% per year. Although modern machinery and fuels are often more efficient than animate energy it was assumed that the increase of modern fuel consumption is higher than the decrease of human and animal labour, since these fuels do not necessarily replace animate energy but they can be used for new and/or more end-use activities. Moreover, these end-uses still may require animal and (especially) human labour.

Scenario Results

The data and results of the last scenario are given in Appendix S1. Comparing the results for the three different scenarios it can be concluded that for all scenarios the total energy consumption increases. The first scenario shows the largest increase (60%) due to the stable growth of the number of households. For all scenarios the residential sector is the largest energy user, consuming up to 97% of the total energy. That this share is so high is due to the lack of data on industrial and agricultural production. The largest share of the household energy comes from biomass (82% in 1991).

For the residential sector no change occurs in the first scenario in the share of fuels because the consumption patterns are to be stable. The second scenario shows a lower increase in residential energy consumption due to the lower population growth and the change of cooking patterns. In the last scenario residential energy use increases slightly less because of the more efficient use of energy for cooking.

For the agriculture sector, the first scenario shows no change in energy consumption because the land and energy consumption patterns are stable. The second scenario shows an increase in consumption due to the increase of energy per rai but no change in the fuel share. The third scenario shows a decrease in energy consumption due to the decrease of land for rice cultivation and it shows a change in the share of energy forms due to an assumed increase of modern fuels and a decrease of the share of animate labour.

Furthermore it can be concluded that the DEDP household and agriculture surveys provide hardly any basis for scenario development and planning. For the household survey historical data were not useful because the main drivers in the change of household energy consumption patterns are not quantifiable (i.e. the number of LPG and electricity users are not known) and no consumer groups were distinguished (e.g. income groups). For the subsequent agriculture energy surveys different methods and (probably) definitions were used so comparison is difficult.

5.3. Second Stage: Additional Data Collection and Analysis

Several agencies in the study area and Chiang Mai city were visited in order to collect data that were lacking on industry, agricultural production for non-rice crops and population at disaggregated level.

The Provincial Industry Office in Chiang Mai provided data on industries in Phrao. These contain only industries that were registered in the past and do not mention anything about the present state. Also data on production are lacking for most industries.

The local office of the Tobacco Monopoly Thailand provided data on production of cured tobacco per station and energy consumption in 1994. In total there are eight stations consisting of several traditional kilns located in different sub-districts. The company reported that all tobacco grown in Phrao is cured in their kilns and that lignite is the only fuel used. Alvarado (1994) reports that small curers related to the Tobacco Monopoly Thailand use 15% fuelwood and 85% lignite, where as private curers mainly use fuelwood. The TMT forbids the use of fuelwood as main fuel but it can be assumed that more fuelwood is being used because it is cheaper than lignite.

During the time of the visit the company had just started the testing of a new type of tobacco curing station that uses electricity, gasoline and LPG. The station consists of several connected chambers and one engine to boil water and distribute the steam over the chambers. The tobacco is dried by the steam. LPG is used as a catalyst to light the gasoline which is used for boiling the water. Electricity is used for water pumping, injection of the gasoline into the engine, and the distribution of the steam. The process of curing one load of wet tobacco takes four or five days. Like the traditional kilns one chamber can dry 4000 kilogram of wet tobacco per process. Data on the energy consumption per turn during the tests were obtained but the consumption per kilogram of cured tobacco is likely to decrease when the station becomes fully operational. The company plans to transfer all curing in the area to the new station in 1996.

Information on the number and production of rice-milling industries was obtained from the district office, but these data do not distinguish electricity and diesel using mills. Information on tobacco curing by private curers not linked to TMT could not be obtained. Also data on brick-making and pottery were not available because these are mostly home-based industries so no central agency for these industries exists.

The statistical report for Chiang Mai province (NSO, 1993) gives production data of non-rice crops for the whole province. This information is collected and compiled by the Chiang Mai Provincial Statistical Office. When enquiring if more disaggregated data were available reference was made to the Office of Agriculture and Cooperative in Chiang Mai. Upon request this office provided data on area and production of non-rice crops in Phrao for 1992, i.e. soybean (dry and rainy season), sugar cane, sweet corn, peanut (dry and rainy season), tobacco, mango, longan and lychee.

A household energy survey was carried out in Phrao district in 1992 by an MSc student of ITC (Arriola, 1993). In the planning process of data collection, assembling and analysis this was considered as local data and therefore used in this stage of data collection and analysis, since it is a one-time-exercise, carried out by an outsider and this type of data may not be available for other districts. The survey was carried in August 1992. Out of 13,400 households in 1992, 50 in 19 villages were visited for the survey. The villages were selected according to the village classification of the NRD-2C village survey (see section 4.2), selecting 16 households in backwards villages, 16 in intermediate villages and 18 in progressive villages. Within the villages, the households were selected based on the structure of the house to reach an equal distribution of income classes among the selected households, although it was found out that this criterion is no indication of the level of income. Only 3 types of end-uses were distinguished (cooking, lighting, electric appliances) as opposed to 7 in the DEDP survey (cooking, lighting, fumigation, heating, water pumping, charcoal production and others, which mainly refers to electric appliances) but these three account for more than 90% of the energy consumption in the DEDP survey as well, so it can be assumed that the survey covers the major share of energy consumption in Phrao. Also, no use of agriculture residues was reported in the Phrao survey, which contributed 6% of total household biomass energy consumption in the DEDP survey. This is probably due to the abundance of wood in the district.

Consumption of LPG, electricity and kerosene was measured by monthly expenditure and converted to physical and energy units by using the local price for each value. For fuelwood and charcoal the consumption was measured in physical units and later converted to energy units using heating values adopted from literature. Since the heating values were not measured in the field and some of the used heating values differ from the ones in the LEAP fuel list, the consumption for every fuel was recalculated using the standard set of heating values.

The average household energy consumption is given per end-use and fuel type. No distinction is made between the sanitary and the rural area. The relationship between energy consumption on the one hand and household income, household size and other socio-economic variables on the other hand was studied. The study gives the calculated correlation coefficients between these factors.

Another MSc student of ITC conducted a study on energy use and conservation options for selected small-scale industries in Chiang Mai province (Hao, 1993). This provided data on energy consumption per production unit for tobacco, brick-making, pottery and rice-milling. For tobacco curing, only the typical consumption of lignite per kilogram of fresh tobacco leaves is given. A report of the International Forest Science Consultancy on the use of wood by the tobacco industry in Thailand provides data on the consumption of both fuelwood and lignite per kilogram of fresh tobacco leaves (IFSC, 1987). The health centre in Phrao provided data on population and number of households per village for 1992 - 1995, including the villages that form the sanitary area.

Data Analysis

As mentioned above the household energy consumption survey provides data on the average fuel consumption per household and the relation between fuel consumption on the one hand and factors such as income and household size on the other hand. The coefficients of these relations can be used as the elasticities between income and household size to forecast the residential energy consumption. Forecasts of the average household size are available from the extrapolation of the past growth rate or the projected population growth. As income, the agriculture share of the Gross Provincial Product per capita will be used.

Data on the area and production in 1992 in Phrao are available for nine crops. The crops that occupy the largest area are major and secondary rice, soy bean, sugar cane, peanut and fruits. Energy consumption data of the 1991 survey are available only for four of these, i.e. major and secondary rice, soy beans and sugar cane. The agriculture energy consumption survey of 1985 provides data for 20 crops, but not for peanut or other crops grown in Phrao.

For fruit production no data on energy consumption are available but it can be assumed that this is relatively low assuming that these fruits are grown on trees which last more than one season.

In his study on the energy consumption of small-scale industries, Hao reports a consumption of 11.7 kg lignite or 221 MJ per kg fresh tobacco leaves (Hao, 1993). The figure of 221 MJ is high compared to other studies cited by Hao, but the figure of 11.7 kg corresponds more or less with the amount reported by the TMT (12.5 kg). The difference is probably due to the high energy content of lignite used by Hao compared to the energy content provided by the LEAP fuel list (18.9 MJ/kg vs. 11.3 MJ/kg lignite). It is not clear where the former value was obtained. Therefore it was decided to use the figure given by TMT and the energy content value given by LEAP. For the consumption of wood for tobacco curing, only one source provided data (IFSC, 1987) so these were used for the demand analysis. Tobacco curers associated with the TMT are obliged to use at least 85% lignite of the total energy use. Also this value was adopted for the demand analysis. Data on the consumption of the new tobacco curing station during the test phase were obtained from the TMT but it can be assumed that the process will become more efficient when the station becomes fully operational because during the testing only one chamber is used.
No data were available on the share of electricity and diesel using rice-mills. In Chiang Mai province 70% of all rice-mills use diesel, and the remaining 30% use electricity. These figures will be used for the rice-mills in Phrao as well.

Scenario Development

1992 was selected as the base year for the scenarios in this stage because of the household energy survey conducted in 1992. As in the first stage, variables for which no value for 1992 was available were projected depending on the projection method used for these variables in the different scenarios.

The base year data for the residential sector consist of the population data of NSO (1990) and the data of the household survey in Phrao (Arriola, 1993).
For agriculture, four crops were distinguished, i.e. major and secondary rice, soy beans and sugar cane, for which both production and energy consumption data were available.
The scenarios developed in this stage are similar to the ones of the first stage except for the fact that different and more data were used. So the first scenario assumes a stable growth of the number of households (2.49% / year) and industrial production (1.5% per year), and a stable area for all crops grown as in 1992. Tobacco will only be cured in the traditional lignite and fuelwood using kilns. Lignite provides 85% of the energy and fuelwood the remaining share. Of the rice-mills, 70% use diesel. For all sectors it was assumed that no change occurs in energy consumption patterns.

In the second scenario the number of households grows according to the projection. The energy consumption per household changes according to the elasticities for income and household size. The agricultural share of the Gross Provincial Product per capita was used as a measure of income. This will increase at a rate of 3.0% per year. The household size varies according to the projection for the population and the number of households. The elasticities for income and household size and the energy consumption for all fuels are given in table 5.2. A positive value means that the consumption will increase when the driver increases, whereas a negative value means the consumption will decrease when the driver increases. Both the increase of income and the decrease of the household size lead to less consumption of fuelwood and more consumption of LPG. For electricity and charcoal the drivers cause opposite changes so it depends on the magnitude of the drivers' change and the elasticity if their consumption decreases or increases. The electricity consumption per household increases whereas for charcoal the per household consumption slightly decreases. The total final energy consumption per household decreases because of the switch to LPG and electricity, for which the end-use devices have a higher efficiency than woodfuel devices.

Fuel	Income Elasticity	Household Size Elasticity
Fuelwood	-0.30	0.33
Charcoal	-0.05	-0.15
LPG	0.49	-0.10
Electricity	0.44	0.60

Table 5.2 *Elasticities for Household Income and Size (Arriola, 1993)*

Industrial production will grow at a stable rate of 2.0% per year. From the year 2000 onwards 90% of the tobacco will be cured in the new station, increasing to 95% in 2010. The remaining share will be cured by private tobacco curers not associated with the TMT. These will only use fuelwood as an energy source since they are not obliged by the TMT to use lignite and fuelwood is cheaper. Both the modern and traditional kilns will use less energy per kilogram of fresh tobacco. The share of diesel rice-mills will gradually decrease from 70% in 1992 to 40% in 2010. The energy consumption per kilogram of rice is stable.

The area for major rice will decrease, whereas the area for secondary rice and other crops will increase. The total area for these crops will remain the same. The consumption of energy per rai will increase at a rate of 0.5% per year for all crops and fuels.

In the third scenario the income will increase faster (+ 3.5% per year), leading to a stronger increase of the consumption of LPG and electricity per household. From the year 2000 all tobacco will be cured in the new station. The share of diesel rice-mills will gradually decrease from 70% in 1992 to 20% in 2000. The area for major rice will decrease stronger, whereas the area for secondary rice will increase more and for other crops will increase less. The total area for these crops will decrease assuming that more land will be used for settlements and fruit trees. The consumption of energy per rai will increase at a rate of 0.7% per year for the modern fuels and decrease at a rate of 0.4% per year for human and animal labour for all crops. All other factors are the same as in the second scenario.

The data and results of the last scenario are given in Appendix S2. For all scenarios the total energy consumption increases, with the first scenario showing the largest increase (49%) due to the stable growth of the number of households. Also in these scenarios the residential sector is the largest energy consumer (78% in the base year), followed by the industrial sector (18% in the base year).

The largest increase of residential energy consumption (56%) occurs in the first scenario because of the stable growth of the number of households and stable consumption patterns per household. In the second scenario this is less (24%) because of the slower growth of the number of households and the decrease of final energy use per household. This decrease is due to the switching to more efficient fuels (LPG, electricity) and the decrease of biomass fuel use. The share of biomass fuel in the total residential household energy consumption decreases from 79% to 72% whereas the total biomass consumption increases by 13%. In the last scenario the residential energy consumption increases slightly less than in the second one due to the higher income growth, leading to a stronger switch to modern fuels.

The industrial energy consumption increases by 30% in the first scenario because of the growth of production. In the second scenario the consumption decreases because of the tobacco curing in the new station using more efficient fuels and the switch to electricity of some rice-mills. No more lignite is used for tobacco curing. In the last scenario the total energy consumption decreases even more because tobacco is only produced in the new plant and more rice-mills will use electricity.

Agricultural energy consumption will remain stable in the first scenario because the area of crop growth and the energy use per rai do not change. In the second scenario the consumption will increase because of the more energy intensive production. The share of fuels will remain stable because the change of energy use will be the same for all energy forms. The last scenario shows an increase of modern fuel consumption and a decrease in the use of human and animal labour. Overall, the energy consumption increases.

5.4. Third Stage: Processing of Original Survey Data

The data of the household energy survey conducted by Arriola as published in her report do not provide data on average energy consumption per income group or type of area. Upon request she provided the original survey data which give the fuel consumption, income and village for every selected household. From this the households in the rural and sanitary area were distinguished, although the number of samples in the sanitary area is very low (6). For both groups of households the average household energy consumption was calculated. The number of households per type of area is available from the population census.

Furthermore it was attempted to stratify the households according to household income. The statistical report on Chiang Mai province gives the number of households per income group in Phrao, but comparing these with the survey data it appeared that the income used by NSO is low, which would mean that most of the households would be classified in the highest income group. Arriola also reports problems with the estimation of income of farmer households due to the unequal spread of earnings throughout the year, gifts of other people and non-monetary income not included as income by official statistics, and the possibility that people are reluctant to tell the truth for one reason or another. Therefore the NSO household data could not be used for the stratification according to income.

The NRD-2C village survey provides data on average household income for each village. Also these values are relatively low compared to Arriola's data. One way to stratify the households according to income would be to classify villages according to the average household income and match this with consumption data per income group, but this would not be realistic because it would be difficult to match the consumption data with the income groups, income differences within villages would be ignored and the income data of the village were not considered reliable considering the method of obtaining these data (see section 4.2). No other data were available so no household income stratification could be made.

Scenario Development

Two scenarios were developed. The industrial and agriculture sector in these scenarios are the same as the second and the third scenario respectively of the second stage since no new data were available for these sectors.

For the residential sector the first scenario is similar to the second of the first stage except for the distinction between the rural and sanitary areas. The number of households grows according to the different projections for the rural and sanitary area. The energy consumption per household changes according to the elasticities for income and household size. The same elasticities were used for both area types. Calculating different rural and sanitary elasticities would not be feasible since the sample size in the sanitary area is too small. The change in household size is different for rural and sanitary areas. Income growth was assumed to be the same for both areas (+ 3.0% per year).

In the second scenario the household size changes according to the projection but the growth of the number of households in the sanitary area is higher than in the projection and stable (+ 5.0% per year). Also, the change of income in the sanitary area is higher (+ 5.0% per year).
Figure 3 gives the structure of sectors, sub-sectors, end-uses and devices as used in the scenarios of the third stage.

The results of the second scenario are given in Appendix S3. Comparing the results for the household sector in the two scenarios it can be concluded that for the rural areas energy consumption will increase by 18% between 1992 and 2010. In the sanitary area the energy consumption will increase by 82% in the first scenario and by 200% in the second scenario because of the higher growth of population and income. Consumption of all fuels will increase, with LPG experiencing the fastest increment. The total residential energy consumption will grow by 23% which is a little bit less than in the second scenario of the second stage. This is because of the different change of consumption patterns for the two types of area.

The different stages of data collection and analysis showed a gradual development of the data base and refinement of the scenarios. Naturally the analysis does not need to stop here since planning is a continuous process which requires continuous energy assessment and evaluation. Options to proceed with the demand analysis are the change of the demographic structure, e.g. due to migration to the district centre of urban centres outside the area, and the effect of income on energy consumption patterns for different groups of households. This would require a more in-depth knowledge of social processes within the area.

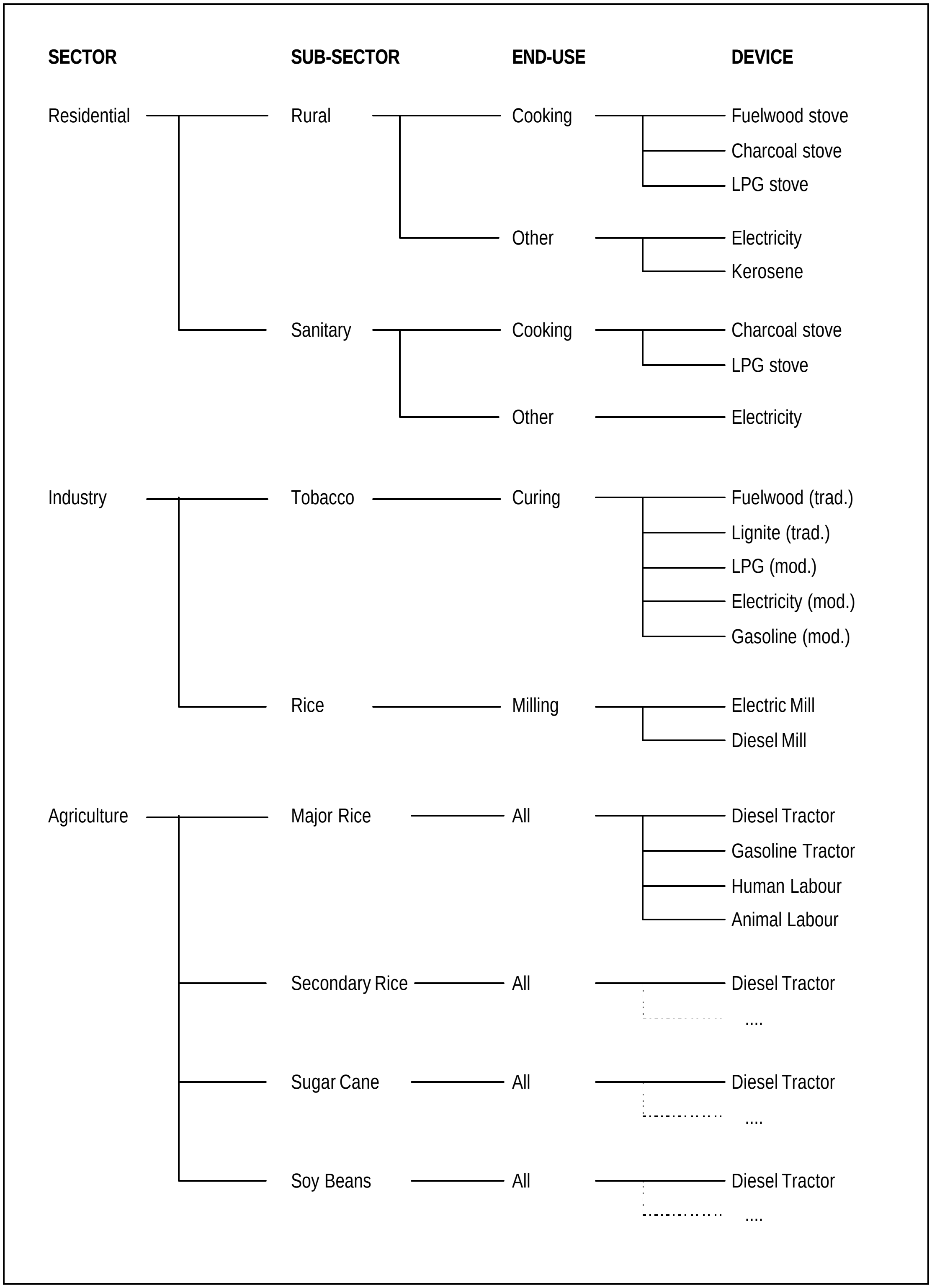

Figure 5.1 *Data Structure for Scenarios of Third Stage*[1]

[1] For the devices used for tobacco curing, 'trad.' refers to the traditional wood and lignite using kilns, 'mod.' to the new station using gasoline, electricity and LPG. For agriculture, the sub-sectors 'secondary rice', 'sugar cane' and 'soy beans' use the same device as the sector 'major rice'.

6. SUPPLY ANALYSIS

As with demand analysis, supply analysis occurred in several stages of data collection and analysis, but since not enough supply data were available for data analysis during the first stage, additional data collection was required. Since no agriculture residues are used for energy according to the household survey these will not be included in the supply analysis.

6.1. Additional Data Collection

As stated in section 4.2, hardly any information for the supply analysis could be traced from publications and government offices in Bangkok. Therefore several offices in Chiang Mai and Phrao were visited to try to collect the required data.

Energy Resources

Both the regional office and the provincial office of RFD were visited to request data on forest types in the area, standing stock and average annual yield for these forest types, but hardly anything of this was available. The regional office provided a copy of a report (in Thai, published by RFD Bangkok) which contains information on standing stock for forest types in the Northern Region. Information on present forest types in the area and yield could not be obtained. The forestry officers in the district centre of Phrao could not provide any information. They are mostly involved in projects that stimulate the plantation of trees by farmers along or on farm land. In Phrao it was learned that the surrounding area was declared a national park in 1988 – the Sri Lanna National Park. Its office was visited but no information was available.

The Regional Office of Land Development in Chiang Mai was visited for data on land use and land use planning. Land use planning maps for the highlands in Chiang Mai province with a scale of 1:50,000 were present but reference was made to Department of Land Development (DLD) Bangkok to obtain copies of these maps. DLD could indeed provide these maps together with land use maps for the whole province with a scale of 1:50,000 for 1989 and land use planning maps for all areas with a scale of 1:100,000. The land use maps also indicate the types of forest. They are printed on black and white copies of topographic maps of 1969 with road information updated in 1982.

The general impression after visiting the regional, provincial and district offices is that they are relatively ineffectual. Most of them refer to their head office in Bangkok for requested information. The organisation of the public sector seems to be centralised in the capital. Data at local level are hardly available but only at the head office in Bangkok. It could be that these data really are not available at local level or they are only provided to outsiders by the head offices located in the ministries. In general a lot of time will be required to learn to know the role and structure of different organisations.

Another impression is that the forestry sector is reluctant to provide forestry data to energy planners out of fear that wood energy causes destruction of the forest. Forest information received from the Department of Land Development was much more detailed and up to date than that provided by the Royal Forest Department. It was said that this was the most detailed information available from RFD. On the other hand it may well be true that RFD does not have better information and that they are not aware that DLD has forest data as well.

From the land use maps, the area for each land use type could be ascetained. Information on the standing stock and average annual yield of trees and other biomass on these land use types was hardly available. Standing stock figures for forest types in the Northern Region were obtained from RFD but it can be assumed that these refer to the stem only, commercially interesting for timber production. For trees on non-forest land no data could be found.

A rural household energy study in Vietnam, carried out by the Energy Sector Management Assistance Programme of UNDP and the World Bank presents stock and yield figures for trees on forest and non-forest land (ESMAP, 1994). Although they are based on rough estimates of tree volumes, densities and trees per hectare for each land use type these data are useful for an initial assessment of the woody biomass resources in Phrao. Data on stock and yield of trees were also available from the Household Energy Strategy Study in Pakistan of the World Bank but these data were considered less useful since climatic and agro-ecological conditions in Thailand are more similar to those in Vietnam than in Pakistan.

Supply Technology

The only energy conversion process that is relevant for this level of planning is the production of charcoal from wood, since no other resources are available in the area. Information on the types of charcoal kilns used in Phrao is not available. Charcoal is often a self-produced good so it is difficult to estimate the amount of produced charcoal and the used technology. Arriola (1993) found that 84% of the households purchase charcoal, mostly by delivery.

When asked about commercial charcoal production, several respondents in Phrao referred to a hill-tribe village located in the hills. During a visit to this village it was learned that they produce charcoal from wood in the forest area alongside the footpath between the village and the main road. They claim to use only dead wood collected from the ground. The charcoal is produced in an earth mound pit. First a pit of 50 cm and 2 metre across is dug in the ground, after which a pile of wood is placed in the pit and lit from the bottom. Then the stack is covered with leaves and earth. After three days the charcoal is packed in large bags and transported on foot to the main road and by bus to the sanitary area where it is sold to shops or households. It is permitted for one person to carry one large bag of charcoal without a license so the charcoal is transported by several people or one bag per time. According to the villagers it is not viable to sell the charcoal in other villages because, there, households produce their own charcoal or buy it from local producers. Another charcoal producer was found in a village near the sanitary area. He buys fruit trees that people want to remove from their land, hires people for felling and transport and produces the charcoal in a brick beehive kiln in his home garden. No other charcoal producers were identified but it can be assumed that more people engage in this business.

6.2. Data Analysis

This distinguishes land use forecasting, resource assessment, accessibility and technology.

Land Use Forecasting
The land use maps of 1989 of DLD distinguish several classes and combinations of crop fields, orchards, village and built up land, and forest. Comparing these classes with those in the land use planning maps, it appeared that these are mostly based on the conservation of the forest and reforestation of degraded forest areas. Two types of land use planning maps were received from DLD, one for the highlands only, and one for all areas. DLD indicated that the planning for the highlands will be implemented, and the planning for the other areas serves as a guideline for local authorities.

Although land use planning maps are available, it is difficult to give detailed land use forecasts since it is not known to what extent these plans will be implemented and not all aspects are under the control of the implementing agencies. The forest areas depicted in the land use maps were visually checked with satellite images of 1992 and 1995, which showed some changes in the forest areas with low slopes near existing agriculture fields, probably due to the conversion of forest land to crop fields. This process can be expected to continue if no measures are taken. Furthermore it can be expected that reforestation will take place on some degraded forest areas.

For the non-forest areas it is difficult to give any forecasts based on the available information, but it can be expected that the area of settlement will increase due to population growth. The land use maps show that this will come from agriculture fields, orchards and forest land.
During scenario development assumptions will be made on the amount of the land use change due to reforestation, forest encroachment, and settlement expansion.

Resource Assessment
For forest resources the standing stock was assumed by this study to be 20% higher than the RFD figures, because these probably only refer to the commercially valuable stem of trees. These data give figures for the three main forest types present in Phrao according to the DLD land use classification (mixed deciduous, dry dipterocarp, tropical evergreen), but also mixtures of types and degraded forms occur so, for these classes, assumptions on the standing stock had to be made from the RFD and ESMAP figures. The average annual yield for each forest type was obtained using the ratio of the stock and yield figures of the ESMAP study.
Since no other data were available for non-forest woody biomass resources, the ESMAP data were used.

Table 6.1 gives the area, the standing stock and average annual yield of the woody biomass resources in Phrao as used for the supply analysis. No changes are likely to occur in the yield and stock of the different land use types in the coming years.

Accessibility Assessment
Naturally, not all resources are available as fuel. Forest resources may be physically and legally inaccessible, privately owned resources may be inaccessible due to land-ownership, or they may be used for non-energy purposes and resources on common land may be inaccessible due to cultural and social constraints. The forest resources are located in the mountainous area ranging from 400 m to 1850 m elevation, so some parts will be difficult to access physically. The non-forest resources are all located in the flat area, so inaccessibility is not caused by physical

factors but rather by social and cultural factors, land-ownership and non-energy end-uses. For all land use types assumptions were made on their accessibility for fuelwood collection and production as follows:

All land use types in forest areas: 20%
All land use types in non-forest areas: 80%

Of the average annual yield in the accessible forest areas only 50% was thought to be available as fuel, due to the height of trees and the rotting of wood on the ground. This means a supply of 48.7 kton of wood from the forest, and 8.6 kton of the non-forest areas, and a total accessible, sustainable amount of wood for energy of 57.3 kton per year.

Land Use Type	**Area** *(ha)*	**Stock** *(ton/ha)*	**Yield** *(ton/ha/year)*
Mixed field crops	15,090.5	0.3	0.06
Mixed Orchards	838.1	20.0	5.00
Mixed Orchards/Mixed field crops	1,911.5	5.0	1.00
Village/Mixed Orchards	366.8	5.0	1.00
Swidden cultivation	8,810.4	10.0	0.20
Bushes and shrubs/mixed field crops	238.8	1.0	0.40
Town	75.6	-	-
Village	1,894.1	3.0	0.75
Institutional land	144.9	3.0	0.75
Built up water resources	181.2	-	-
Tropical evergreen forest	27,303.5	156.0	6.24
Tropical evergreen /Mixed deciduous forest	1,467.7	123.0	4.92
Mixed deciduous forest	18,520.2	90.0	3.60
Mixed deciduous forest/Dry dipterocarp forest	8,666.0	105.0	4.20
Dry dipterocarp forest	36,587.2	120.0	4.80
Forest plantation	2,469.4	50.0	10.00
Degraded tropical evergreen forest	2,753.8	50.0	2.00
Degraded dry dipterocarp forest	134.4	40.0	1.60

Table 6.1 *Area, Stock and Yield for Land Use Types*

The estimates on the accessibility of the biomass resources can be assumed not to be realistic. The household survey also provides some information on the patterns of wood collection which can be useful for a further evaluation of accessibility. Of the households who use fuelwood, 89% obtain this from collection, most of which comes from the forest (63%). About 60% of the households which collect fuelwood do this once a year, during the dry season, allocating some days for fuelwood collection in the forest. Most of the charcoal using households purchase this fuel (84%), either by delivery or in the neighbourhood.

From this pattern of fuelwood collection, the accessibility of forest resources can be evaluated spatially, assuming that for annual collection cars and motorcycles are used and that collection in the forest takes places near roads that are accessible by car or motorcycle. For the spatial assessment of the accessibility, a Geographical Information System (GIS) was used (see section 2.3). The evaluation of the accessibility will only be done for the forest areas since these are inaccessible mainly due to physical reasons. For the non-forest areas other factors, such as land-ownership will affect the accessibility. Since no data on this were available, this could not be further evaluated.

First the accessibility of the forest roads was studied. For each location in the area the time needed to reach that location by road from the district centre was calculated assuming an average speed of 40 km/hr. This was done by calculating the weighted distance from the district centre considering the road network and the slope of the terrain, i.e. access is possible only via roads and the slope causes a friction according to the equation below which 'increases' the distance. Using the average speed, the time needed to reach a location by road can be calculated.

$$F = 1 + a \cdot slope^{b} \qquad \text{(eq. 1)}$$

Where	F:	friction;
	a:	0.0003;
	b:	2.0
	slope:	percentage of slope

The equation is an exponential function with $b > 1$ because the growth of friction will be higher for higher slopes. With these values for a and b the friction will be 4 with a slope of 100%.

The calculation showed that all roads can be accessed within 30 minutes, except for the ones in the southern part of the district, since the district centre is located in the northern half. The accessibility of the roads from the villages will be similar to this, with southern villages having easier access to forest roads in the southern part of the district. Considering the fact that special days are allocated for fuelwood collection, the time needed to reach the collection point can hardly be seen as a constraint. Therefore the accessibility assessment will not further consider this and include only the accessibility of the forest areas from the roads. This was done in a similar way as for the forest roads.

Again the time needed to reach a certain location in the forest was considered a function of the distance, slope and average speed. For each point the shortest weighted distance to a road was calculated considering the slope of the terrain according to equation 1. As average speed for walking through the forest, 2 km/hr was chosen.

Those forest areas that are within 10 minutes walking distance, but not within 500 metres of main roads due to possible control by forest authorities, were considered accessible for fuelwood collection. This covers 7% of the total forest area. Again, only half of the average annual yield is available as fuel. For all the accessible areas the land use type and the stock and yield for these land use types were used to calculate the total accessible sustainable annual supply of biomass energy, being 16.3 kton of wood from the forest. For the non-forest areas the same estimates for accessibility were used (80%). So the total wood supply is 24.9 kton of wood.

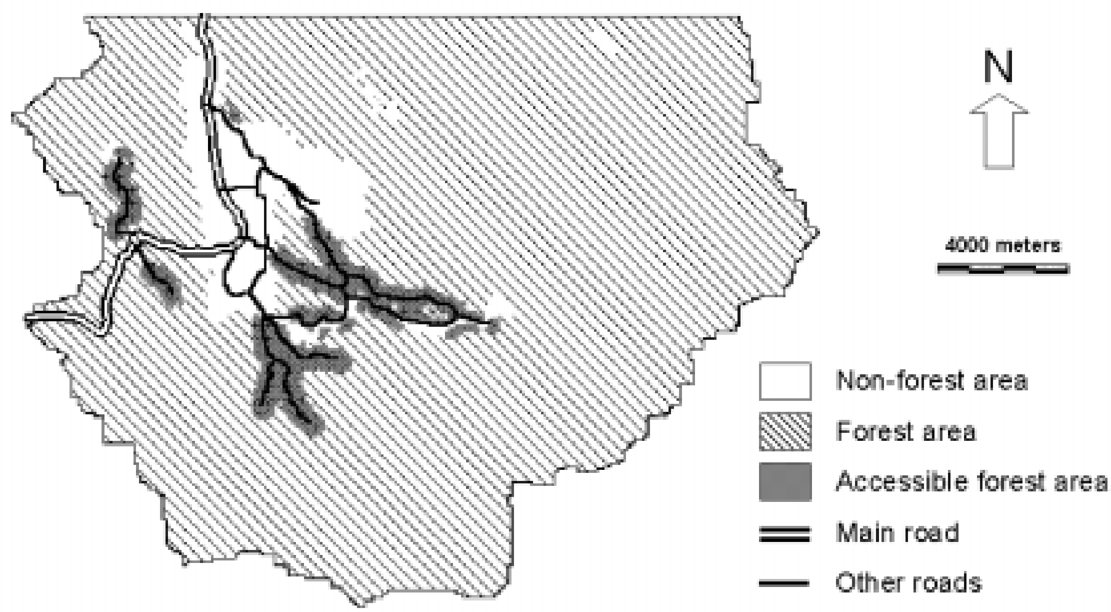

Figure 6.1 *Accessibility of Forest Resources for Fuelwood Collection*

Figure 6.1 shows the accessible forest area for a part of the district. It should be noted that the accessibility assessment does not take into account other possible collection patterns such as fuelwood collection by people working on crop fields near the forest or by people living in the forest, which increase the accessibility of the forest resources. Not enough data were available on the existence and scale of such patterns to allow for an evaluation of such collection patterns.

Technology Assessment

Based on the information on charcoal producers in Phrao and information on charcoal making in Thailand the following assumptions were made on the type, yield, efficiency and share of each type of charcoal kiln in Phrao. Furthermore, assumptions were made on the losses of fuelwood (2%) and charcoal (5%) during transport.

Name	Yield (%)	Efficiency (%)	Share 1992 (%)
Earth Mound Pit	25	45	60
Mud Beehive	31	56	30
Brick Beehive	33	60	10

Table 6.2 *Yield, Efficiency and Share of Charcoal Kilns*

Scenario Development

From the information on land use, resources, accessibility and technology, several supply scenarios were developed:

In the first scenario all factors remain constant, which means a stable sustainable supply of 24.9 kton of wood throughout the study period.

In the second scenario the area of the villages and the town will increase according to the rural and sanitary population respectively. For the town this will come from agriculture land (75%) and village land (25%), due to the development of the village adjacent to the town. New village area will come from agriculture land (60%), orchards (30%) and dipterocarp forest (10%). Furthermore the agriculture land near the forest with low slopes will be expanded resulting in a decrease of forest area. This will occur with 10 hectares per year. Of course this will have an impact an the amount of accessible forest area as well but since it is difficult to forecast where changes will occur the same percentages for the accessibility of each land use type as in the previous scenario will be used, which means a slight reduction of the accessible forest area and therefore of the accessible resources.
The share of charcoal kilns will gradually change to 30% earth mound pits, 35% mud beehive kilns, 35% brick beehive kilns in 2010.

In the third scenario the forest resources will not be accessible anymore starting from the year 2000 because of a ban imposed by the forest authorities. Changes in land use occur because of the expansion of the settlement areas at the cost of agriculture land. No changes will occur in the forest areas from the year 2000 onwards. Since at present a lot of charcoal originates from the forest this will have an impact on the share of the types of charcoal kilns as well. Charcoal from the forest is probably mostly produced in earth mound kilns, so the share of this kiln type will decline. It is assumed that the share of types of charcoal kilns will be 40%, 40%, 20% in 2000, and 45%, 50%, 5% in 2010 for mud beehive kilns, brick beehive kilns and earth mound pits respectively. Furthermore it is assumed that the accessibility of the non-forest wood resources will increase from 80 to 90% because more people will engage in the production of woodfuel. Then the total annual supply will decrease from 24.9 kton in 1992 to 9.7 kton of wood from the year 2000 onwards.

6.3. Further Data Collection and Analysis

As for energy demand analysis, the current stage of supply analysis can be followed by further data collection and analysis. Time was lacking in which to continue this but some further data requirements are given below.

- Stock and yield for the resources in Phrao district;
- Land-ownership to estimate the availability and distribution of non-forest wood resources;
- Additional information on patterns of woodfuel collection;
- Patterns of woodfuel trade (sources, distribution, prices, etc.);
- Present infrastructure;
- Share of types of charcoal kilns (since the used figures are rough estimates);

Probably most of these data will not be available and they will require surveys, which are beyond the scope of the present case study.

7. SUPPLY - DEMAND BALANCING

To evaluate the consistency of the data and the sustainability of the energy situation, energy balances were produced for several combinations of demand and supply scenarios.

The first balance combines the first demand scenario of the third stage (different consumption patterns and growth rates for the rural and sanitary area, income and household size elasticities, modernised industry, more cash crops and less rice – see section 5.4) and the second supply scenario (gradual change to use of more efficient charcoal kilns, expansion of settlement and agriculture area – see section 6.2). The wood energy balance for these demand and supply scenarios is given below. No other fuels are included since no supply and conversion data were available and these fuels are not available as a local resource.

From the energy balance it can be seen that the evaluated supply can meet the present and projected demand, although the demand for fuelwood is increasing and the supply slightly decreasing. It should be noted that the accessibility assessment is based on infrastructure data from 1982 so it can be assumed that changes have occurred in the accessibility, i.e. more areas have become accessible. On the other hand it may be true that not all areas which were considered accessible are visited for wood collection, because people do not drive up to the end of a forest road.

Unit: terajoule	1992		1995		2000		2005		2010	
	Wood	**Charc.**	**Wood**	**Charc.**	**Wood**	**Charc.**	**Wood**	**Charc.**	**Wood**	**Charc.**
Potential Supply	**396.8**		**396.3**		**394.4**		**392.7**		**390.7**	
Forest	259.1		258.0		255.6		253.3		250.8	
Non-forest	137.7		138.3		138.8		139.4		139.9	
Production	303.1	0.0	305.1	0.0	313.7	0.0	324.2	0.0	331.4	0.0
Primary Supply	**303.1**	**0.0**	**305.1**	**0.0**	**313.7**	**0.0**	**324.2**	**0.0**	**331.4**	**0.0**
Conversion	-103.5	50.8	-104.1	52.2	-111.3	57.7	-120.2	63.2	-128.2	68.4
Losses	-4.0	-2.5	-4.0	-2.6	-4.1	-2.9	-4.1	-3.2	-4.1	-3.4
Final Supply	**195.6**	**48.3**	**197.0**	**49.5**	**198.3**	**54.8**	**200.0**	**60.0**	**199.1**	**65.0**
Residential										
Rural	185.7	41.4	187.3	42.3	192.1	46.4	194.8	50.3	195.3	54.0
Sanitary	0.0	6.9	0.0	7.2	0.0	8.4	0.0	9.7	0.0	11.0
Industry	9.9	0.0	9.7	0.0	6.2	0.0	5.1	0.0	3.8	0.0
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Final Consumption	**195.6**	**48.3**	**197.0**	**49.5**	**198.3**	**54.8**	**200.0**	**60.0**	**199.1**	**65.0**

Table 7.1 *Wood Energy Balance*

To evaluate the reliability of the energy balance and the conclusions, uncertainty assessment was applied through evaluation of error propagation and sensitivity analysis. For detailed description of the assessment the reader is referred to Appendix A2. From the evaluation of the error propagation it appeared that during almost the whole scenario period the potential supply is higher than the projected demand, but that at the end of the period it becomes uncertain whether the demand will outgrow the sustainable supply. More precise information is required for those variables, for which the uncertainty has the greatest impact on the results. These include the average fuelwood and charcoal consumption per household, because both the consumption and the estimate for the relative deviation are high. Sensitivity analysis showed that the response of the energy balance was strongest for changes in the growth of the number of households and the agriculture share of the Gross Provincial Product, so a higher reliability for these factors would be required.

Supply-demand balancing was also conducted for the third supply scenario which assumes a non-availability of the forest resources for energy purposes. Naturally this will also have an impact on demand so a new demand scenario needs to be developed. It can be assumed that in case of an acute woodfuel shortage many households will switch to LPG for cooking earlier than they would have done otherwise, leading to sudden sharp increase in LPG consumption in the year 2000. It is assumed that the increase in LPG consumption is higher in the rural area since in the sanitary area more households use LPG already. Furthermore it is assumed that the decrease in fuelwood consumption will be higher than for charcoal, considering that fuelwood is mostly collected and charcoal mostly purchased. Consumption of woodfuels will also decrease due to conservation.
The available amount of wood for energy will decrease by about 65% in the year 2000. For the change in consumption of LPG, fuelwood and charcoal due to wood shortage, assumptions were made based on the projected values for average household energy use in the first demand scenario of the third stage (see energy balance above). The change in average household consumption in 2000 with respect to the projection for 2000 is -30% (fuelwood), -10% (charcoal), + 20% (LPG) in the rural areas, and - 10% (charcoal), +5% (LPG) for the sanitary area respectively. After the year 2000 consumption will change with a growth rate 10 times smaller than these values for each fuel and area respectively. In the first demand scenario of the third stage all independent tobacco curers used fuelwood. In this scenario in 2000, 50% of the energy needs will come from lignite, the remaining from wood. This will gradually change to 100% lignite in the year 2010.
The wood energy balance for these scenarios is shown below. This shows that although the wood requirements are decreasing the requirements cannot be met by the non-forest resources alone, leaving a gap of about 75 TJ in the year 2010. Considering the results of the uncertainty assessment for the first energy balance this conclusion will hold for the most probable deviations of measurements and assumptions.

Unit: terajoule	**1992**		**1995**		**2000**		**2005**		**2010**	
	Wood	**Charc.**	**Wood**	**Charc.**	**Wood**	**Charc.**	**Wood**	**Charc.**	**Wood**	**Charc.**
Potential Supply	**396.8**		**396.3**		**138.8**		**139.4**		**139.9**	
Forest	259.1		258.0		0.0		0.0		0.0	
Non-forest	137.7		138.3		138.8		139.4		139.9	
Production	303.1	0.0	304.3	0.0	235.1	0.0	224.7	0.0	214.2	0.0
Primary Supply	**303.1**	**0.0**	**304.3**	**0.0**	**235.1**	**0.0**	**224.7**	**0.0**	**214.2**	**0.0**
Conversion	-103.5	50.8	-103.3	52.2	-94.8	51.9	-95.5	53.9	-96.9	55.5
Losses	-4.0	-2.5	-4.0	-2.6	-2.8	-2.6	-2.6	-2.7	-2.4	-2.8
Final Supply	**195.6**	**48.3**	**197.0**	**49.5**	**137.6**	**49.3**	**126.7**	**51.3**	**115.0**	**52.7**
Residential										
Rural	185.7	41.4	187.3	42.3	134.5	41.7	125.0	42.9	115.0	43.7
Sanitary	0.0	6.9	0.0	7.2	0.0	7.6	0.0	8.3	0.0	8.9
Industry	9.9	0.0	9.7	0.0	3.1	0.0	1.7	0.0	0.0	0.0
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Final Consumption	**195.6**	**48.3**	**197.0**	**49.5**	**137.6**	**49.3**	**126.7**	**51.3**	**115.0**	**52.7**

Table 7.2 *Wood Energy Balance for Forest Ban Scenario*

8. OPTIONS FOR INTERVENTIONS

Several options exist for intervention, both on the demand and supply side. Some of them are discussed below.

8.1. Conservation & Plantation

The first intervention is the promotion of more efficient cookstoves and the plantation of trees in order to be able to cope with the lack of wood in case the forest resources cease to be accessible as in the third supply scenario. According to the energy balance the wood requirements will be 220 TJ in the year 2010. The non-forest resources can produce an annual sustainable supply of 140 TJ, which means a shortage of 80 TJ, equivalent to 5 kton of wood. Assuming an average annual yield of 5 ton/ha this would require 1000 hectare plantations of wood, which is about 3.5% of the total non-forest area.

It is assumed that in the year 2000 about 25% of households will use efficient wood and charcoal stoves, gradually increasing to 75% in 2010. The efficiency of these stoves increases from 15 to 20% for wood, and from 25 to 30% for charcoal respectively. The average household consumption for the improved stoves was calculated from the conventional stove consumption assuming that the useful energy consumption is constant.

With these conservation measures the requirements would be 200 TJ, still leaving a shortage of 60 TJ or 3.8 kton of wood, requiring 800 hectares of plantations. This amount of area may not be available due to the need for agricultural land unless the production of woodfuels is a commercially attractive option for farmers and/or land-owners. In case these measures are needed to cope with a woodfuel shortage the commercial production and trade of woodfuels should also be encouraged and supported.

8.2. Price Policy

Supply-demand balancing showed that the wood resources can easily meet the demand so there is no need for the stimulation of households and industries to switch to modern fuels or a strict ban of people from the forest. Therefore, another intervention option is to consider an increase in prices for electricity and LPG in order to slow down the increase in consumption of these fuels since they require costly equipment and infrastructure and they put a burden on the foreign trade balance. At district level this will not have a significant impact but on a nation-wide level this may be of major importance.

A price increase for LPG and electricity would probably lead to a decrease in consumption of these fuels, if no other factors are taken into account. People would use more fuelwood and charcoal for cooking and/or use LPG in a more efficient way. For most electric appliances no options for fuel switching exist so consumption could only decrease due to conservation. In reality however, people will not that easily switch back because of a price increase, so the price policy assumes only a slower growth of the consumption of LPG and electricity, simulated by a decrease due to the price increase, but an increase due to income and population growth.

No data are available on the impact of prices on fuel consumption but a typical price elasticity of -0.3 can be used as correlation between price and household fuel consumption of LPG and electricity (APDC, 1985). This means that the consumption of these fuels will decrease when the price increases. Naturally this means that the consumption of fuelwood and charcoal will increase to replace the modern fuels. Since the biomass end-use devices have a lower efficiency than modern devices the increase in final consumption of woodfuels will be higher than the decrease of final consumption of conventional fuels. The used elasticities are given below. Electricity consumption is less responsive to price increase because few options for replacement exist.

Fuel	Elasticity
LPG	-0.3
Electricity	-0.1
Fuelwood	0.4
Charcoal	0.3

The first demand scenario of the third stage was chosen as the basis for the price scenario (see section 5.4). Prices of LPG and electricity will increase by 30% in the year 2000. This will lead to a more modest increase of LPG and electricity consumption per household but not to a decrease because of the influence of income growth and household size according to the respective elasticities. The total residential consumption of LPG and electricity will increase by 66% and 62% respectively in the year 2010, as opposed to 80% and 66% respectively if no price increase were to occur.

8.3. Dendro-Thermal Electricity Generation

Another option to make use of the abundance of wood and to decrease imports would be to generate electricity for consumption in Phrao from wood grown in the district. From the demand scenarios it can be seen that in 2010 around 3 MW of electricity is required in Phrao. The generation of 1 MW requires 7,500 ton of wood per year (MacPherson, 1995). It is assumed that electricity generation will start in the year 2000. Furthermore it is assumed that the electricity power plant in the area will generate additional development due to extra employment for wood collection and others. This will lead to a higher income growth than in the last demand scenario, which will have an impact on the household consumption of electricity, LPG, charcoal and fuelwood according to the elasticities between the consumption of these fuels and income. More households will switch to LPG and electricity, whereas the share of fuelwood and charcoal will further decline.

The energy balance for fuelwood, charcoal and electricity for this scenario is given below. It shows that the resources which were assumed to be accessible can not meet the project demand. However it can be assumed that the accessibility of the forest resources will increase due to better organisation and management. The originally estimated area accessible for woodfuel collection (20% of the forest area) can easily produce the wood requirements in a sustainable manner, so considering the existing wood resources dendro-thermal electricity generation may be a feasible option for Phrao district. Naturally this would require further study on the existing resources, the efficiency and costs of wood-based electricity generation, other end-uses for the wood resources and the social and environmental impact before such a project can be implemented.

Unit: terajoule	1992			2000			2010		
	Electric	Wood	Charc.	Electric	Wood	Char	Electric	Wood	Charc.
Potential Supply		**396.8**			**394.4**			**390.7**	
Forest		259.1			255.6			250.8	
Non-forest		137.7			138.8			139.9	
Imports	35.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Production	0.0	303.1	0.0	0.0	493.1	0.0	0.0	609.2	0.0
Primary Supply	**35.2**	**303.1**	**0.0**	**0.0**	**493.1**	**0.0**	**0.0**	**609.2**	**0.0**
Dendro-Electricity	0.0	0.0	0.0	51.9	-197.5	0.0	78.4	-298.2	0.0
Conversion	0.0	-103.5	50.8	0.0	-113.4	58.7	0.0	-136.2	72.6
Losses	-3.5	-4.0	-2.5	-5.2	-3.6	-2.9	-7.8	-3.5	-3.6
Final Supply	**31.7**	**195.6**	**48.3**	**46.7**	**178.5**	**55.8**	**70.6**	**171.3**	**69.0**
Residential									
Rural	23.3	185.7	41.4	31.6	178.5	45.8	42.0	171.3	52.8
Sanitary	6.4	0.0	6.9	11.0	0.0	10.0	20.9	0.0	16.2
Industry	1.99	9.9	0.0	4.15	3.1	0.0	7.69	0.0	0.0
Agriculture	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Final Consumption	**31.66**	**195.6**	**48.3**	**46.74**	**178.5**	**55.8**	**70.59**	**171.3**	**69.0**

Table 8.1 *Energy Balance for Dendro-Thermal Power Plant Scenario*

The above described interventions illustrate the usefulness of the demand and supply analysis at area-based level. Several options for intervention can be identified, both at demand and supply side. The interventions are not only related to crises of fuel shortage and deforestation but the abundance of wood resources also offers opportunities for demand management and decentralised supply systems. The availability of local data allows for intervention at local level. In some cases there will be a strong relation with larger-scale or national planning (as in the last two options) which requires the evaluation of the intervention options for more areas. Naturally all interventions require impact assessment and feasibility studies before they can be implemented.

9. IMPACT ANALYSIS

The alternative demand and supply scenarios and interventions will have different impacts on the economic structure and the environment of the area. These need to be studied to identify the most desirable supply-demand balance in both economical and environmental terms.
At this stage not enough data are available to conduct an economic impact analysis so the following section contains a qualitative discussion only. For the environmental impact analysis it was possible to quantitatively evaluate the air emissions of materials for the alternative scenarios using the environmental data base of LEAP.

9.1. Economic Impacts

The economic impacts of a certain supply-demand balance include, among others, impacts on the local economic growth and structure (employment, household income, prices, gender relations, rural migration), impacts on major economic sectors and impacts on the trade balance and inflation. Naturally the latter two are hardly measurable at area-based level. Not enough data are available to evaluate the alternative scenarios in economic terms so only the major possible economic impacts will be discussed here.

In most scenarios household income will increase causing a change of household energy consumption patterns. More households will use conventional fuels, replacing biomass fuels. Conventional fuels are more efficient in the time needed to purchase and use them, so more time will be available for other activities, such as cottage industries or off-farm labour.

The use of modern equipment in farming and industries may decrease the labour requirements which will modify the economic structure of the area, i.e. from an agriculture-based economy to a more industrial and commercial economy, although it might also lead to migration, especially amongst the younger generation to urban areas in case no employment opportunities exist in the district itself.

The intervention scenarios will have different economic impacts. Employment and income generating opportunities may change due to the change of energy consumption patterns in the intervention scenarios. Employment may either increase, e.g. production of non-forest woodfuels and more efficient cookstoves (forest ban and conservation scenario), the use of traditional, more labour-intensive production methods because of price increase of conventional fuels (price policy scenario), employment needed for dendro-thermal plant (dendro-thermal plant scenario), or decrease e.g. decreased demand for woodfuels due to conservation and a switch to LPG (forest ban and conservation scenario), less labour hired to save on production costs (price policy scenario). Naturally household income is strongly related to employment and the economic structure. More industrial and commercial activities will most probably lead to an increase in income.

The change of energy prices will generally effect prices of products and services that use energy. In the forest ban and conservation scenario the price of commercially traded woodfuels will most probably rise due to the larger demand. In the pricing policy scenario the increase of

conventional fuel prices may also lead to a larger demand for commercial woodfuels and thus to an increase in its price. In the dendro-thermal plant scenario the increase in income will affect the demand for and the price of different fuels.
For all the above impacts the influence on gender relations should also be evaluated because men and women may not be equally affected due to their different roles, e.g. who benefits from the increase in income and the savings of labour-time. For a successful implementation of the intervention scenarios, the roles men and women play have to be equally considered.

9.2. Environmental Impacts

Apart from economic impacts, the alternative scenarios will have an impact on the local environment, through the air emissions of materials such as carbon dioxide (CO_2) and carbon monoxide (CO), emissions of pollutants to water and soil, impacts on land use (e.g. deforestation, settlement expansion) and others. These may influence the health and quality of life, so they are equally important as economic impacts and should be evaluated likewise.

As said in section 2.3 LEAP includes the Environmental Data Base (EDB) which contains data on emission coefficients for several end-use and transformation devices. This was used to evaluate the environmental impacts of alternative demand and supply scenarios. Each device used in the scenarios was linked with a typical device for which air emission data is stored in the EDB. A full description of these typical devices is lacking so the selection may be somewhat arbitrary but for a comparative analysis of the alternative scenarios it can still be useful. For Phrao district the air emissions of several materials were calculated from the fuel consumption and transformation for several scenarios, using one scenario as a reference to evaluate the intervention options. For other environmental effects not enough data was available to evaluate the alternative scenarios, although it can be expected that some deforestation will continue to occur at the border of the forest area, as assumed in the supply scenarios.

The first scenario that was evaluated was the combination of the first demand scenario of the third stage (different consumption patterns and growth rates for the rural and sanitary area, income and household size elasticities, modernised industry, more cash crops and less rice, see section 5.4) together with the transformation as in the second supply scenario (gradual change to the use of more efficient charcoal kilns, see section 6.2), for which the wood energy balance is given in chapter 7 (see table 7.1). The annual and cumulative (from the year 1992 onwards) emissions for carbon-dioxide and carbon-monoxide are given below. Biogenic carbon-dioxide is caused by the use of biomass fuels, whereas non-biogenic carbon dioxide is caused by the use of other fuels. Under the condition of sustainable use of biomass resources, biogenic emissions of carbon-dioxide do not constitute net additions of CO_2 to the atmosphere, since CO_2 can be recaptured during photosynthesis (SEI, 1995b).

From the table it can be seen that the emissions grow annually except for non-biogenic CO_2. The decrease in annual non-biogenic CO_2 after 1995 is caused by the switch to the new type of tobacco curing station which mainly uses gasoline instead of lignite. Also, the carbon-monoxide emissions due to industrial energy use decrease but this decrease is outweighed by residential and agricultural CO emissions. For the residential and agricultural sector all emission effects grow annually which leads to a new increase in annual non-biogenic CO_2 emission after the year 2000.

Unit: 1000 ton	1992		1995		2000		2005		2010	
	Annual	*Cumulat.*	Annual	*Cumulat.*	Annual	*Cumulat.*	Annual	*Cumulat.*	Annual	*Cumulat.*
Carbon Dioxide										
Non-Biogenic	7.5	*7.5*	7.6	*30.2*	6.1	*63.6*	6.7	*95.9*	7.4	*131.5*
Biogenic	22.6	*22.6*	22.8	*90.8*	23.4	*206.7*	24.1	*325.7*	24.5	*447.2*
Carbon Monoxide	1.7	*1.7*	1.7	*6.8*	1.8	*15.6*	1.9	*25.0*	2.0	*34.8*

Table 9.1 *Emission Effects for Reference Scenario*

The emissions effects for the interventions scenarios are given in table 9.2 below. From this it can be seen that the emission of biogenic and non-biogenic carbon-dioxide varies according to the a switch to conventional or biomass fuels in the alternative intervention scenarios. For the forest ban scenario the non-biogenic CO_2 emission is higher than in the reference scenario due to switch to LPG for cooking, whereas for the pricing scenario the non-biogenic CO_2 emission is lower than in the reference scenario due to a slower switch to LPG for cooking. In the dendro-thermal scenario the emission of biogenic CO_2 increases sharply in the year 2000 due to the local production of electricity leading to an increase of the cumulative emission in the year 2010 of 110% compared to the reference scenario. This does not necessarily mean a negative impact since in the reference scenario the electricity has to be generated elsewhere, and the emission of biogenic CO_2 does not constitute a net addition of CO_2 to the atmosphere when the biomass resources are used in a sustainable manner. Moreover, the emission of CO_2 and CO caused by residential energy use is less compared to the reference scenario because of the switch to LPG and electricity by more households due to a higher income growth. This means a reduction of indoor air pollution, which has a major health impact mostly on women and children (Smith, 1987).

Unit: 1000 ton	1992		1995		2000		2005		2010	
	Annual	*Cumulat.*	Annual	*Cumulat.*	Annual	*Cumulat.*	Annual	*Cumulat.*	Annual	*Cumulat.*
Forest Ban										
Carbon Dioxide										
Non-Biogenic	7.5	*7.5*	7.6	*30.2*	6.7	*65.5*	7.5	*101.3*	8.3	*141.0*
Biogenic	22.6	*22.6*	22.8	*90.8*	16.3	*185.4*	15.6	*264.9*	14.2	*338.9*
Carbon Monoxide	1.7	*1.7*	1.7	*6.8*	1.3	*14.1*	1.2	*20.2*	1.0	*25.6*
Price Increase										
Carbon Dioxide										
Non-Biogenic	7.5	*7.5*	7.6	*30.1*	5.9	*62.9*	6.5	*94.3*	7.2	*128.8*
Biogenic	22.6	*22.6*	23.7	*92.6*	25.8	*217.4*	26.5	*348.5*	26.9	*482.3*
Carbon Monoxide	1.7	*1.7*	1.8	*6.9*	2.0	*16.4*	2.1	*26.7*	2.2	*37.4*
Dendro-Thermal										
Carbon Dioxide										
Non-Biogenic	7.5	*7.5*	8.0	*30.8*	6.5	*66.2*	7.4	*101.4*	8.4	*141.4*
Biogenic	22.6	*22.6*	22.3	*89.9*	40.8	*256.9*	45.6	*475.1*	51.2	*719.7*
Carbon Monoxide	1.7	*1.7*	1.7	*6.7*	2.1	*16.3*	2.2	*27.0*	2.4	*38.5*

Table 9.2 *Emission Effects for Intervention Scenarios*

10. MINIMAL APPROACH TO DATA COLLECTION AND ANALYSIS

The process of identification of required data, data collection, assembling, analysis and scenario development as described in the previous chapters required approximately four man-months. This is a considerable amount of time, which may prevent similar studies being applied to all districts in Thailand. Therefore it was studied to what extent a minimal approach to data collection analysis can be followed that still produces relevant results.

Naturally this depends on the level at which the planning is actually conducted. Considering the present institutional set-up, data availability, responsibilities and skills at sub-national level it is more feasible to conduct such studies at central level. Probably not enough manpower and skill are available at provincial or district level. Furthermore, data is mostly collected, stored and published by national agencies with little involvement of sub-national agencies, so the latter may not have the data that are required. This does not mean that the central approach is the most desirable one. Preferably these studies should be conducted at local level, but initially this can be done at central level, while enhancing the capabilities of local agencies. Below, some options for minimisation of the data collection and analysis are discussed.

Assessment of Current Situation Only, No Forecasting

One of the main objectives of the assessment of the energy situation at area-based level is basically to identify crisis areas, i.e. where people (will) face shortages of biomass fuels and where biomass resources are threatened. The identification of existing crisis areas does not require extensive analysis because these areas can be identified in other ways, but the identification of future or possible crisis areas requires planning, i.e. assessment of the current situation and forecasting, and plan formulation and implementation. Therefore it is not a recommended option to limit the analysis to the current situation only.

Biomass Energy Only

The assessment could be limited to biomass resources only, but this would not be time-saving since data of energy consumption usually cover also conventional fuels. Furthermore, it is not realistic to assume a constant average fuel consumption per capita or per household so biomass fuel consumption should be studied in relation to other fuels in order to identify substitution among fuels.

Data from Central Agencies Only

To limit the time requirements it may be an option to use only data that are available from central agencies in the capital so a visit to the area itself (which is time-consuming and for which often no budget is available) is not necessary. For countries like China, India, Pakistan and other countries which have a partly decentralised administrative structure the capital could also be the state or provincial capital. These data can also cover data from local agencies which happen to be available in the capital (e.g. the Statistical Reports for Changwat Chiang Mai, prepared by the Provincial Statistical Office, published by NSO).

In the case study most of the essential data were obtained from national agencies in Bangkok, except for the household survey, and data on tobacco and rice-mill industries. However, the latter may be available in the capital as well considering the centralised nature of the public sector in Thailand.

The Phrao energy consumption survey is an exceptional data source which usually will not be available for other areas. Comparison with the NSO and DEDP surveys showed that the energy consumption in Phrao is considerably different from the average consumption in the Northern Region, i.e. fuelwood consumption is higher and charcoal consumption lower, probably because of the abundance of wood in the district which does not require conversion and transport over long distances. This shows the need for local surveys or the need to distinguish different user groups in national energy consumption surveys, e.g. per income group, type of area, agro-ecological, local economy and other parameters which allow the estimation of local energy consumption by linking these local parameters with the survey data. At present the survey results are presented basically as the average consumption per region. The NSO survey distinguishes income groups but these are hard to match with data on households income. More detailed, disaggregated data may be available in raw format which could be processed to be used at area-based level. Initially this may be time consuming, especially for past surveys, but the results will be applicable to all areas under consideration. Therefore it can be concluded that the use of central data only is a feasible option of minimisation.

Major Sectors Only

The study could be limited to the main energy consuming sectors, which will be different for each area, although they will usually include the residential sector. This also depends on the specific objectives of the study. For example, in the case of Phrao the agriculture sector does not use biomass fuels so no further study would be required, if the objective is to identify possible biomass fuel crisis areas. Likewise, industries that do not consume biomass fuels and the transport sector would not have to be considered.

Simple Forecasting Only

For the case study several forecasting methods were used such as the extrapolation of growth rates, the use of elasticities and the assumption of certain changes (e.g. consumption patterns) in the future. This could be limited to the forecasting of population and economic growth, assuming that the latter will cause changes in consumption patterns and production. Elasticities that describe the relation between economic growth on the one hand and changes in energy consumption patterns and industrial and agricultural production on the other hand can be used when available, otherwise assumptions can be made on these changes. It is strongly recommended not to apply national figures to economic growth and elasticities, but to use local figures. When data for the area itself are not available, sectoral data for a larger area data may be used. For example, for Phrao, economic growth data were not available. Therefore, the agriculture share of the Gross Provincial Product of Chiang Mai was used as the economic growth figure, since the economy is mostly agriculture-based.

No Accessibility Assessment
Accessibility assessment in the case study was quite detailed and required experience with the use of GIS, and therefore it required a considerable amount of time. The assessment of the biomass supply is definitely more than resource assessment only, but also requires study of the accessibility of these resources for different users, although it could be less detailed than in the present case study, i.e. through estimation of the accessibility from information on land use and collection patterns, as was done in the initial analysis. When it appears for a certain area that the accessibility may be a crucial factor in the energy supply system, further, more analytical assessment can be done.

Conclusion
In conclusion it can be said that the use of central data, limitation to major sectors, the use of simple forecasting methods, and accessibility assessment without spatial evaluation are all feasible options for minimisation.

The first stage of the demand analysis followed more or less this minimal approach because only central data were used and forecasts were based on assumptions for population growth and consumption pattern change (see section 5.2). Data on industries were still lacking at this stage but as said above, these may be available at central level as well.
Comparison with the later stages shows that household energy consumption is very site-specific. According to Arriola's household survey, fuelwood consumption in Phrao is higher than the average fuelwood consumption in the Northern Region, probably due to the abundance of wood in the area. The raw data of the NSO or DEDP were not available for processing so the method of relating the consumption data of these national surveys with site-specific factors such as type of area and household income could not be tested.
The supply analysis followed mostly the minimal approach, apart from the accessibility assessment which used information on collection patterns from Arriola's survey and evaluated the accessibility analytically with the use of GIS. All other data came from national agencies or international publications.
It is not feasible at this stage to develop scenarios but if the minimal approach had been followed from the start it could have produced useful results.

Naturally the level at which planning can be conducted relates to the required skills, since people with the required education and experience may not be available at local level. An indication of relevant skill requirements is listed below:
- Bachelor's degree in economy, statistics, administration, engineering or forestry;
- good analytical capabilities.

Required experience:
- experience with conducting surveys and/or using survey results;
- experience with project evaluation and implementation, preferably in the field of energy or rural development;
- knowledge of statistics;
- some experience with computers, data bases and spreadsheets.

11. CONCLUSIONS

Below the main conclusions are presented per main objective of the case study (see page 2).

Objective 1 (planning process):

1. The process of identification of required data, data collection, assembly, analysis and scenario development for this case study took approximately four man months. The required information was widely scattered over different agencies, so collection of the data was a time consuming process, partly due to the unfamiliarity of the author with the agencies. Now data sources and agencies have been identified, repetition of the data collection and analysis to obtain updated data should require considerably less time (± one man month). To conduct a similar study for another district would approximately take two months since a lot of common data sources have already been identified. Considering the present institutional set-up (i.e. centralised planning, weak local agencies) it cannot be expected that similar studies can be conducted for the whole country.
2. Although data are incomplete and sometimes lacking, assessment of the current energy situation, scenario development and forecasting for decentralised energy planning are still possible and feasible with respect to data availability. A start can be made with available data to identify data gaps, collect additional data, repeat analysis, identify data gaps, etc. Lacking data can be supplemented by data from other areas and by reasonable assumptions based on available data and some background information on the area and related issues;

Objective 2 (data):

3. Data had to be obtained from a wide variety of agencies at different administrative levels, mostly government agencies. Consequently the data were often difficult to integrate because they differed in definitions, scale, period and stratification. It was found that at present there is virtually no co-operation between agencies with respect to data and that agencies are often not aware of data collected and published by other agencies that may be useful for their own purposes. More co-ordination and co-operation is required to develop standards for data collection and presentation and to allow for the processing of raw survey data for specific purposes.
4. Data came mostly from government agencies, such as NSO, DEDP, DLD, RFD and the district office. Few data were identified from universities and private organisations. However, more data may be available but time was lacking to check this. At central level data were provided by several divisions or sections of five government agencies (CDD, DLD, DEDP, NSO, RFD). Four provincial offices provided data (RFD, PSO, PIO, OAC), while at district level the district office could provide data on several issues.
5. The National Statistical Office conducts surveys on a wide variety of topics on a regular basis and possesses a large amount of data. However, it was found that these data are not always useful because in several cases they are not consistent with other NSO surveys or with data from other sources regarding definitions and others. For example, boundaries of household income groups of subsequent energy consumption surveys do not correspond with each other, which complicates the historical analysis of consumption patterns, and these boundaries also do not correspond with data on the number of households per income

group per district as published by NSO. Stronger co-ordination between NSO surveys on the one hand and between NSO and other agencies dealing with specific topics on the other hand may enhance the usefulness of data for planning. NSO could play a central role in this, since its primary task is data collection and publication. Naturally, this would not only benefit the energy sector. This may apply to statistical offices in other countries as well.

6. The lack of data is often mentioned as a constraint to the implementation of energy planning in rural areas at national and sub-national level. A comprehensive data base is often considered as a prerequisite for energy planning. The case study has shown that a lot of data do exist and that the energy assessment at district level is feasible in the case of Thailand. Data base development occurred in several stages parallel to energy demand and supply analysis through the identification of missing or insufficient data. This showed that data base development is not a prerequisite to energy planning, but that it is part of the continuous process of energy analysis and assessment.
7. Data uncertainty can have a strong impact on the modelling results. Although for most data the uncertainty cannot be assessed analytically because a series of observations cannot be made or are unavailable, the uncertainty can be assessed by the estimation of the most probable range for each variable, and by the evaluation of error propagation. The impact of assumptions on driving parameters, such as growth rates, macro-drivers and elasticities can be evaluated by the use of sensitivity analysis. Before a new stage of data collection, analysis and scenario development, that should focus on those factors that cause the highest uncertainty, is conducted, the benefits of additional data should be evaluated compared to the cost of obtaining these data. If the costs are higher than the benefits, other methods should be identified to evaluate the need for and the type of interventions.
8. Time series data are often inconsistent with respect to definitions, coverage, scale, period and other factors which complicate their application to planning; trends are difficult to identify because changes may appear more due to different methods applied than any actual change that has taken place. Consistency of time series data may be more important for planning purposes than higher accuracy or a larger coverage.
9. In order to be useful for planning, data should distinguish different groups, areas or others to allow for analysis and forecasting. Especially for household energy this is important because households are small units and their behaviour shows a high variation. It is relevant to study the relationship between, for example, energy consumption and income (preferably gender-disaggregated), type of area (rural, sanitary, urban), household size, and occupancy. Forecasts can be based on (assumed) shifts in the change of population per group or area or the change of behaviour towards the behaviour of another group or area. Also a distinction per type of environment (e.g. agro-ecological zone) would provide data that are useful for planning.
10. The case study confirms that household energy consumption is site-specific and actually requires local surveys. The DEDP and NSO surveys for the Northern Region show large differences with the household survey in Phrao, especially in respect of fuelwood and charcoal consumption. In Phrao woodfuel use is higher and charcoal use lower than the average consumption for the Northern Region, probably because of the wood abundance in the district. Naturally, local surveys are more cost- and labour-intensive and time-consuming which prevents the coverage of all districts in a similar way as for Phrao. However, if data

from large-scale surveys distinguished different user groups, areas and others, there would be less need for local surveys (see point 9).

11. Although the ITC reports provided useful information, most of it was not essential for the case study. Only the household energy survey (Arriola, 1993) provided valuable information since household energy consumption is site-specific (see also point 10).
12. On the energy demand side enough data are available, but on the biomass supply side some data are lacking, especially on biomass resources (stock and yield). For forest areas, data of other areas and countries can be used since these are relatively homogeneous and comparable. Although for the non-forest wood resources in Phrao the same method was used, this is not realistic. More reliable methods are needed to assess these resources.

Objective 3 (minimal approach):

10. To limit the time and skill requirements a minimal approach to data collection and analysis can be followed. Of course this is related to the level of decentralisation at which planning is actually conducted, but considering the present institutional set-up in Thailand this is most feasible at central level. Feasible options to minimise data collection and analysis are the use of central data only, restriction to major sectors, the use of simple forecasting methods, and accessibility assessment without spatial evaluation.

Objective 4 (planning tools):

11. The Long-range Energy Alternative Planning model (LEAP) uses a flexible data structure and it includes a biomass module for the evaluation of the resources of wood, agriculture residues and dung, all of which make it applicable for planning at area-based level. It is appropriate for the method of iterative data base development as applied in the case study. It provides a comprehensive framework for the covering of the whole energy flow from biomass resources through conversion to end-use consumption. Forecasts for single factors can be made by using growth rates, macro-drivers and elasticities, or by explicitly specifying a value for each data year. In the last way LEAP can easily incorporate the results of other models that focus on a specific part of the energy flow or that apply another method, e.g. econometric demand models or simulation of power plants.
12. Before data could be entered into the model, the available data had to be analysed and converted into an appropriate format for LEAP. For this additional tools were required. Especially spreadsheets (such as Lotus 1-2-3, Quattro Pro, and Excel) can be useful and they were used extensively during the case study, for example to assemble data in tables, to convert energy consumption values using standard heating values for fuels, and to make population forecasts. They were also used for the formatting and presentation of results such as energy balances.
13. For the evaluation of the resources of wood and other biomass in the study area, LEAP's biomass module combines data on land use with data on tree stock and yield and crop productivity per land use type. Data on the area, stock and yield, and productivity have to be specified per land use type. Land use forecasting can be incorporated by specifying future conversions of parts of one land use type to another, e.g. agricultural land to settlement area. The accessibility of wood resources is incorporated by an access fraction for each land use type in which several constraining factors can be combined. This fraction determines the area, and thus the amount of woody biomass, that is accessible for each land use type. The

model can incorporate all of the above factors but it provides no tools or methods to obtain the required input data, so data analysis has to occur externally.

14. The Environmental Data Base (EDB) of LEAP contains data on emissions of materials to the atmosphere, water and soil for typical end-use and transformation devices, such as cookstoves, boilers and charcoal kilns. These data have been obtained from various literature sources reporting research on the emissions per unit of consumed fuel for the devices. The EDB can be used to evaluate the emissions for alternative scenarios. However, a major shortcoming is that it lacks an adequate description of the end-use and transformation devices that are included in the EDB. This complicates the linking of the devices in the scenarios with the devices of the EDB and limits the usefulness of the EDB since the results depend largely on the selection of the devices. An adequate description of the devices will enhance the usefulness of the EDB and the environmental impact assessment.
15. A Geographic Information System (GIS) can be a useful tool to analyse the available spatial data and to produce the data required for LEAP. Spatial land use data can be converted to attribute data, and land use changes can be evaluated by the development of (conceptual) models that describe spatial and non-spatial relationships of land use types. Furthermore, accessibility can be evaluated spatially, as was done in the case study. When land use information is not available or up-to-date, satellite images can be useful to obtain the required data. Because experience and equipment will mostly be lacking at energy departments, cooperation with other departments that do have the skills and facilities is required (e.g. forestry).

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APPENDIX A1: DATA UNCERTAINTY

Section 2.3 discussed the possible impacts of data uncertainty on results of energy assessment and modelling. This appendix discusses sources of uncertainty and methods for uncertainty assessment.

A.1 PROBABILITY THEORY AND ERROR ASSESSMENT

Probability theory can be considered as the language of uncertainty. It is required to examine uncertainty and risks in decision situations. It deals with the relative chance of the occurrence of events beyond the control of the scientist or decision-maker. This section discusses probability distributions and error propagation, based on discussions in Baird (1989) and Bevington (1969).

A.1.1 Measurement Errors and Probability Distributions

When a measurement is conducted for a physical phenomena, for which the outcome is uncertain, the outcome is a *random variable*. A random variable can be defined as a function with real values defined over all possible outcomes.

If a measurement is made of a quantity *x*, the observation will approximate the quantity, but it cannot be expected to be exactly equal to the quantity. If the measurement is repeated, also the second observation cannot be expected to be exactly equal to the true value of *x*, and it can be expected to deviate from the first one due to random errors. By making more and more measurements, a pattern will emerge, with some observations too large, others too small, but on the average they will be distributed around the true value, assuming systematic errors can be ignored or corrected. If an infinite number of measurements could be made, they would describe the way in which the observed data points are distributed. This is not possible in practice, but we can assume the existence of a hypothetical probability distribution, called the *parent distribution*, which determines the probability of getting any particular observation in one measurement. Similarly, the measurements can be considered as samples of an infinite number of possible measurements, called the *parent population*, which are distributed according to the parent distribution. Because we can only make a finite number of measurements, we cannot determine the true value of the quantity exactly, so we can try to describe the parent distribution as well as possible, to be able to estimate the uncertainty in the observations. Probability distributions can be visualised as shown in Figure A.1 for both discrete and continuous variables. The probability distribution for continuous variables is usually called *probability density function*. It should be normalised so that the total area under the curve is equal to one. Then, the probability that the observation will have a value smaller or equal to x_0 is equal to the area left of the line $x=x_0$, enclosed by the curve and the line $x=x_0$ (see Figure A.1), or in formula:

$$P(\bar{x} \le x_0) = \int_{-\infty}^{x_0} f(x)dx \qquad (A.1)$$

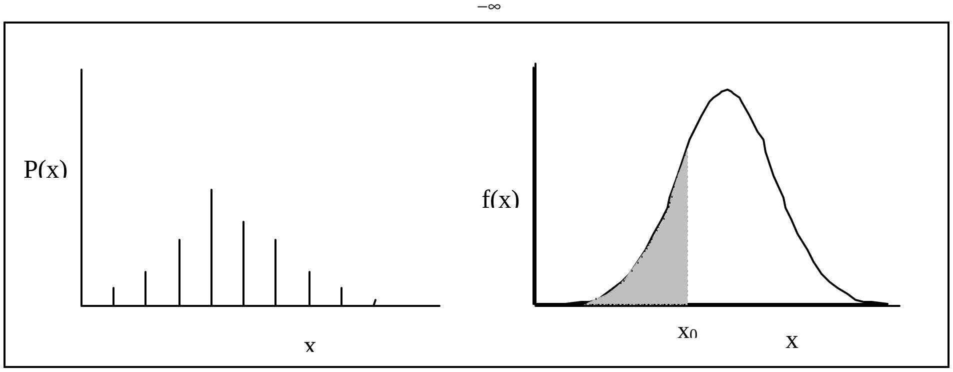

Figure A.1 *Probability distributions for a discrete and continuous variable*

A probability distribution can be described by a number of parameters. The *expected value E(X)* or *mean m* is equivalent to the average of the parent population, mathematically defined for discrete distributions as:

$$E(X) = x_1 \cdot P(x_1) + x_2 \cdot P(x_2) + \ \ldots.\ x_n \cdot P(x_n) = \sum_{i=1}^{n} x_i \cdot P(x_i) \qquad (A.2)$$

and for continuous distributions as:

$$E(X) = \int_{-\infty}^{\infty} xP(x)\,dx \qquad (A.3)$$

The *variance* s^2 and *standard deviation* s are measures of the dispersion of observations around the expected value. The variance is defined as the limit of the average of the squares of the deviations from the mean, and the standard deviation is the square root of the variance. In mathematical form for discrete distributions:

$$Var(X) = s^2 = \sum_{i=1}^{n} [x_i - E(X)] \cdot P(x_i) = E(X^2) - [E(X)]^2 \qquad (A.4)$$

and for continuous distributions as:

$$Var(X) = s^2 = \int_{-\infty}^{\infty} [x - E(X)]^2 P(x)\,dx = \int_{-\infty}^{\infty} x^2 P(x)\,dx - [E(X)]^2 \qquad (A.5)$$

When the probability distribution is symmetrical about the mean, then the true value of the measured quantity can be assumed equal to the mean, except for systematic errors. But if the probability distribution is not symmetrical about the mean, it can be considered as the best estimate that can be made of the true value under the circumstances. The variance and standard deviation characterise the uncertainty of the measurements. For a given number of observations the uncertainty in determining the mean is proportional to the standard deviation, so σ is an appropriate measure of the uncertainty due to fluctuations in the observations. Although the expected value does not have to be the true value, their difference should be less than the uncertainty given by the probability distribution, and so the standard deviation should be a measure of the discrepancy between μ and the true value.

When measuring two quantities *X* and *Y*, the covariance is a measure of the correlation of the variances of *X* and *Y*. It is defined as:

$$Cov(X,Y) = s_{uv}^2 = E\big[(X - E(X)) \cdot (Y - E(Y))\big] = E(XY) - E(X) \cdot E(Y) \qquad (A.6)$$

The determination of probability distributions by experiments is a complicated process and may not always be possible because it requires a large number of measurements. There also exist several useful theoretical distributions that are models of probability in the real world. They can be used instead of experimental distributions when assumptions underlying these distributions are approximately valid for the case at hand.

Gaussian or Normal Distribution

The Gaussian or normal distribution is the most important probability distribution for the statistical analysis of data. It is very useful because it seems to describe the distribution of random observations for most experiments, and it appears to describe well the distribution of estimations of the parameters of most probability distributions. It is accepted by convention and experimentation to be the most likely distribution for most experiments. The Gaussian distribution function is defined as:

$$f(X) = \frac{1}{s\sqrt{2p}} e^{-\frac{1}{2}\left(\frac{x-m}{s}\right)^2} \qquad (A.7)$$

It is a continuous function describing the probability that from a parent distribution with a mean *m* and a standard deviation *s* the value of a random observation would be *x*. Normal distributions are always bell-shaped and symmetrical about the mean. The total area under the curve for any normal distribution function is equal to one. The probability that the value of *X* is between *a* and *b* is equal to the area under the curve between *a* and *b*. In general, the normal distribution is used to describe the distribution of measurements. Then, the most probable value for the mean is the average of the observations.

A.1.2 Propagation of Errors

When determining a variable as a function of two or more variables, each with an uncertainty (which may or may not be described by the normal probability density function), these uncertainties will propagate to the derived variable. For a variable *x* that is a function of the variables *u* and *v*, the variance s_x^2 is a function of the variances s_u^2 and s_v^2 according to:

$$s_x^2 = s_u^2\left(\frac{\P x}{\P u}\right)^2 + s_v^2\left(\frac{\P x}{\P v}\right)^2 + 2s_{uv}^2\left(\frac{\P x}{\P u}\right)\left(\frac{\P x}{\P v}\right) \qquad (A.8)$$

When the fluctuations of *u* and *v* are uncorrelated the last term reduces to zero.

For specific functions of *u* and *v*, the formulas of s_x^2 are given below.

Addition:

$$x = au + bv$$
$$s_x^2 = a^2 s_u^2 + b^2 s_v^2 + 2ab s_{uv}^2 \qquad (A.9)$$

Multiplication:

$$x = auv$$
$$s_x^2 = a^2v^2 s_u^2 + a^2u^2 + 2a^2uv s_v^2 \qquad or: \qquad (A.10)$$
$$\frac{s_x^2}{x^2} = \frac{s_u^2}{u^2} + \frac{s_v^2}{v^2} + 2\frac{s_{uv}^2}{uv}$$

Division:

$$x = \frac{au}{v}$$
$$\frac{s_x^2}{x^2} = \frac{s_u^2}{u^2} + \frac{s_v^2}{v^2} - 2\frac{s_{uv}^2}{uv} \qquad (A.11)$$

Powers:

$$x = au^b$$
$$\frac{s_x}{x} = b\frac{s_u}{u} \qquad (A.12)$$

Exponentials:

$$x = ae^{bu}$$
$$\frac{s_x}{x} = b s_u \qquad (A.13)$$

Logarithms:

$$x = a \ln(bu)$$

$$s_x = a \frac{s_u}{u} \qquad (A.14)$$

For most of the functions the variance of the dependent variable *x* is determined partly by the covariance of *u* and *v*, which can either be positive or negative. As shown in Appendix A2, addition and multiplication are the most important operations for energy planning. For these a positive value of the covariance will increase the error estimate, whereas a negative covariance will decrease the error estimate. Often it will be difficult to estimate the covariance of two variables. An example of possible correlation between two variables that are relevant to energy planning is that of population and fuel consumption per capita. On the one hand, an increasing population may put pressure on the available resources, which causes a decrease of the per capita consumption. On the other hand, a population increase in rural areas that leads to a higher population density, makes the distribution of fuels to these areas more profitable, which causes an increase of per capita fuel consumption. Likewise, the increase in consumption for one fuel type, may lead to a consumption decrease for another fuel type because of fuel-switching.

A.2 SOCIAL DATA AND UNCERTAINTY

For energy planning, data on a wide variety of issues are required, including social phenomena. Data on these issues are obtained in different ways, often from secondary, existing sources, so they contain different types of errors. These are shortly discussed below.

A.2.1 Counting and Sampling

Data on social phenomena are often the result of counts of one sort or another, being either complete (e.g. population census, vote counts), or partial, which aim to represent a larger population or universe (Jacob, 1984). The best partial count is a random probability sample, in which each element of the whole population has an equal chance of being included. Variations on the random probability sample seek to stratify the sample according to known characteristics of the population, or seek to cluster the elements from which the data will be collected. However, often samples are not based on random selection, for example when only the most convenient locations are visited.

When data collection occurs through random samples a sampling error can be estimated for a chosen confidence interval according to the following formula:

$$u = \bar{x} \pm Z \frac{s^2}{\sqrt{n}} \qquad (A.15)$$

Where:

u is the measured variable
$\bar{x}$ is the mean of the samples
Z is the point under the normal curve of a standardized normal distribution corresponding to a selected confidence interval
s^2 is the sample variance
n is the number of cases in the sample

The second term of the equation is the estimate of the sampling error, without regarding measurement errors. Values for *Z* are 1.96 for a 95% confidence interval and 2.58 for a 99% confidence interval. Note that the larger the confidence interval, the larger the error term will be.

Data collected by full counting or non-random sampling will also contain errors, but it is not possible to give an estimate of an error range. For non-random sampling, the errors may not be symmetrically arranged around the mean and minorities may be over- or under-counted. In full counts of large populations it is inevitable that elements are missed. For these data it is recommended to avoid exaggerated precision by rounding off the given values.

A.2.2 Invalidity and Reliability

Differences in meaning between concepts and indicators may cause the invalidity of measures, especially when using published data. Research requires the conceptualisation from abstract concepts to concrete measures. An indicator is said to be valid when the fit between it and the underlying concept is close. Examples of ambiguously definable concepts are ‘literacy’, ‘family’, ‘unemployment’. The meaning of concepts may be different for different groups or areas and may also change over time. An example is the cost of living, which may be different for rural and urban areas, and which may change over time due to the disappearance and emergence of products. Therefore the use of secondary, published data requires the careful examination of applied concepts and their meaning.

Reliability refers to the ability to obtain consistent results in successive measurements of the same phenomenon. It can be affected by clerical errors (in counting, copying, transferring data), changes in collection procedures over time, corrections for errors afterwards (which may result in different values in different publications), and even data manipulation for ideological or organisational reasons. When data is the result of asking questions that are not completely clear or are confusing, the data will contain errors (Jacob, 1984).

No methods exist to estimate the uncertainty due to the above mentioned. Secondary data should always be carefully examined and, as in the case of non-random sampling and full counts, exaggerated precision should be avoided.

A.3 SENSITIVITY ANALYSIS

Methods for error assessment as discussed above and others which are common in social sciences (e.g. factor analysis, regression analysis, analysis of variance) require a number of observations. This may not always be possible due to the lack of time or budget, and data from existing sources give only one value for each quantity. In these cases sensitivity analysis can be applied to account for uncertainty in data analysis.

Basically, sensitivity analysis is the study of the responsiveness of conclusions or modelling results to changes or errors in parameter values or assumptions. The usual approach is to hold all aspects of the model constant and vary each parameter while observing the influence of the changes upon the optimal decision. If a particular parameter may be varied over the full range of possible values with no change in the conclusion, the decision is not sensitive to that parameter, and no resources should be expended to determine a more exact value for that parameter. In those circumstances in which the decision is sensitive to changes that are within a possible range, more precision may be required and further information must be obtained. In that case, the decision maker or data analyst must examine the benefits of additional information compared to the cost of obtaining it.

A limitation of sensitivity analysis is that the impact of changes of parameters values and assumptions is evaluated under the condition that all other factors remain constant. However, in reality variables rarely remain the same. Additionally, variables are assumed to be independent while in the real world variables often interact with each other, which may have a critical impact on conclusions and results (Baird, 1989).

Continuing the example of energy supply-demand balancing for fuelwood in Section 2.3, the use of sensitivity can be demonstrated as follows. The decision to intervene in the emerging situation will be based on forecasts of the supply-demand balance. When shortcomings of fuelwood are predicted, the plantation of trees to augment the wood supply can be considered, or in the case when there will be plenty of supply, the wood can be distributed to other areas. When for the results of the demand and supply analysis the errors cannot be estimated other than by subjective probabilities, the responsiveness of the supply-demand balance to changes in the input parameters can be measured to evaluate to reliability of the conclusions, like ‘enough supply’ or ‘emerging shortages’.

Figure A.2a shows again an example of an energy supply-demand balance, which shows that during the study period enough supplies are available, so no interventions are required. Now suppose that the variation of each demand parameter while holding others constant, shows that for a slight change of a particular parameter, the total demand can vary between the grey area shown in Figure A.2b. The demand may outgrow the forecasted supply, which requires intervention, or enough supplies may be available. More precise information about this parameter is required, before interventions can be chosen.

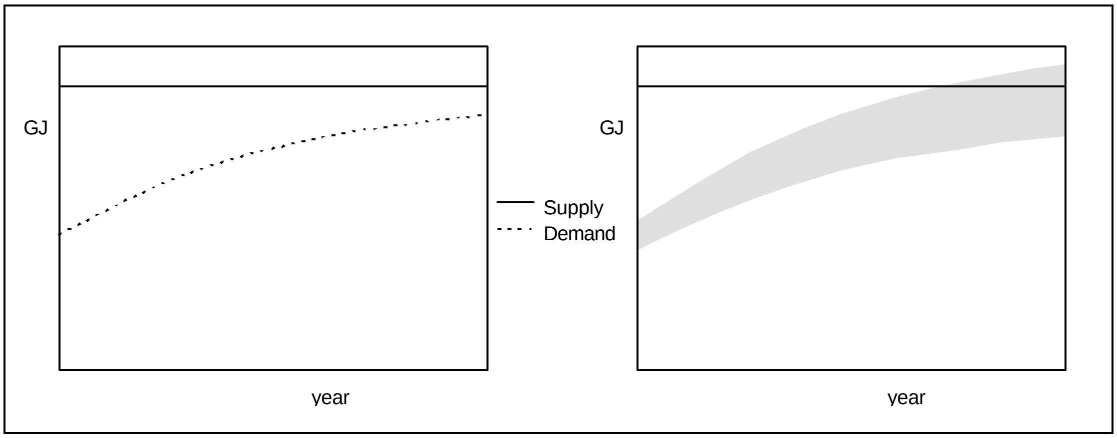

***Figure A.2a** Supply-Demand Balance*

***Figure A.2b** Response of Balance*

APPENDIX A2: SUPPLY-DEMAND BALANCING UNDER DATA UNCERTAINTY

In the uncertainty assessment two aspects can be distinguished. First, the tree structure consisting of sectors, sub-sectors, end-uses, devices and consumption, for each data year. The demand for one branch of this tree is calculated by multiplication of the five values of the levels of the branch. The total energy demand is calculated by summation of all branches. The uncertainty will be assessed by evaluation of the error propagation throughout these operations, as discussed in Appendix A1. The second aspect is the change of variables of the tree structure, determined by external projections, macro-drivers, growth rates and elasticities. The uncertainty in these factors will be evaluated by sensitivity analysis.

Error Propagation

The evaluation of error propagation requires the estimation of the variance for each variable. For most variables this is not possible analytically because it requires a number of observations for each variable and only one value is available. For the household energy survey the sample data are available, but the data was not obtained by random sampling, because sampling occurred in villages that were convenient to reach because of transport facilities shared with other researchers, and households in these villages were selected according to house characteristics, in order to reach households of different income groups. This means that certain minorities may be under- or over-counted, so the sample variance is not a sufficient estimate of the measurement error. Therefore, estimates will be made of the probable range for each variable, that will be used as the standard deviation in the formulas for error propagation.

For each branch *i* of the demand tree structure, the energy consumption for that branch is calculated by:

$$Branch\_Consumption_i = Sector_i \cdot Subsector_i \cdot Enduse_i \cdot Device_i \cdot Consumption_i$$

where $Consumption_i$ refers to the fuel consumption per $Device_i$ that is used to perform $Enduse_i$ by the share $Subsector_i$ of $Sector_i$.

For the used data, only the fuel consumption per unit of the sector is available, which implicitly includes the values for *sub-sector*, *end-use* and *device* (that represent: the share of the sector that forms the sub-sector, the share of the sub-sector that performs the end-use, and the share of end-use that uses the device, respectively) so the formula can be simplified to:

$$Branch\_Consumption_i = Sector_i \cdot Av\_Fuel\_Consumption_i$$

In the case of tobacco curing also the fuel share is included in the branch, for which an error has to be estimated.

The total energy consumption can be calculated by the summation of all branches. The total consumption of a certain fuel can be calculated by the summation of all branches for that fuel. The variance for branch consumption and total energy consumption can be calculated using formulas A.9 and A.10. For variables that are the result of summation and multiplication, the variance depends also on the covariance of the independent variables. For the calculation of the branches and their summation, this was considered very low and not included in the error assessment.

For all variables in the demand tree that contribute to woodfuel consumption, estimates of the relative deviations were made as follows: number of households, 3%; tobacco production, 10%; share of tobacco kiln types (wood or lignite), 50%; fuel consumption per kilo tobacco, 5%. For the average household fuel consumption different estimates were made for each fuel because the consumption was measured in different ways: fuelwood and charcoal, 10%; LPG and kerosene, 5%; electricity 2%. For the relative deviation of relevant transformation variables the following estimates were made: efficiency of charcoal kilns, 10%; share of types of kilns, 25%. For these estimates the relative deviation for the total wood requirements

in 1992 is 28.2 MJ, equivalent to 10%. Evaluation for the wood requirements in the year 2000 shows the same percentage.
For the potential woodfuel supply also a tree structure is used, for which the total sustainable supply for a certain land use type *i* is given by:

$$supply_i = area_i \cdot yield_i \cdot access\_fraction_i$$

The total supply can be calculated by the summation of all branches. Similar to demand, estimates for the relative deviations were made and the deviation for the total supply was calculated. For estimated relative deviations for area (1%), yield (10%) and access fraction (10%), the relative deviation for the total supply is 7%.

Figure A.3 shows the wood energy consumption and potential supply for the scenario period. The lines represent the values given in table 7.1 (see chapter 7), the grey areas surrounding the lines indicate the estimated standard deviation. This shows that during almost the whole scenario period, the potential supply is higher than the projected demand, but that at the end of the period it becomes uncertain whether the demand will outgrow the supply. More precise information is required for those variables, for which the uncertainty has the greatest impact on the results. These include the average fuelwood and charcoal consumption per household, because both the consumption and the estimate for the relative deviation are high. An estimate for the relative deviation of 5% instead of 10%, would result in a relative deviation of 8% for the total wood requirements. Also the high uncertainty for the share of charcoal kilns has a large impact. A reduction from 25% to 10% would decrease the relative deviation with 2%. On the supply side, the high uncertainties for the yield and the accessibility have the highest impact.

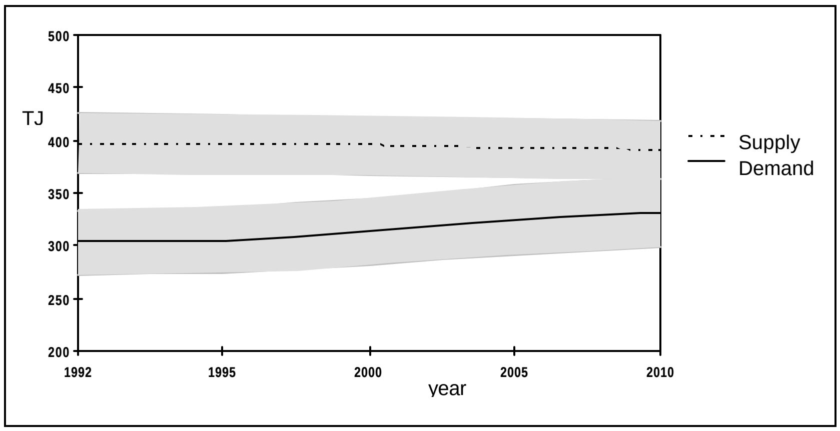

Figure A.3 *Uncertainty In Projected Wood Energy Consumption And Supply*

Sensitivity Analysis

The change of the tree structure for demand and supply from data year to data year is determined by external projections (e.g. population growth), assumptions on drivers and elasticities (e.g. for average fuel consumption per household) and growth rates (e.g. land use changes). The impact of these assumptions was evaluated by sensitivity analysis, because no error estimate can be given for these factors. Factors for which the response was evaluated are the number of households and the average household size, growth rate for the agriculture share of the Gross Provincial Product, elasticities for changes in income average household for each fuel, and land use changes as response to population growth. For all these factors a possible range of variation was identified and used to measure the response of the analysis results for each factor separately.

During scenario development the annual growth rate for the agriculture share of the Gross Provincial Product (GAP) was used as a measure for household income, which determined the change of household fuel consumption patterns. For the energy balance of table 7.1 it was assumed to be 3%, based on the past growth rate. It can be assumed that the agriculture sector will continue to grow, but it may be more or less than the adopted value. A higher growth rate would lead to lower increase of the total wood requirements, because more households would switch to conventional fuels. Likewise, the total wood requirements would increase faster with a lower growth rate for the GAP. For values of 2 and 4% respectively, the energy

balance was evaluated, leading to a difference of +3.5% and -3.5% respectively with the wood requirements in the year 2010 in the original scenario.
Because a higher population growth would lead to a stronger increase in the wood requirements, a new projection for the number of household and the average household size was made. This follows the same pattern of the first projection, i.e. a decreasing population growth, a higher population growth in the district centre than in the rural area, and a decrease of the average household size. For both area types, the number of households grows faster, and the average household size decreases more slowly, than in the original projection. According to the new projection, in the year 2010 the number of households will be 10% and 5% higher in the sanitary and the rural area respectively. This would cause an increase of 5% of the wood requirements in the year 2010.

The correlations between fuel consumption on the one hand, and income and household size on the other hand, as given by Arriola in her household energy survey in Phrao, were used as elasticities during scenario development. Since the survey samples were available, the possible range of deviation for these elasticities could be identified using the simulation approach, as described by Chatterjee and Hadi (1988). For each sample x_i, a random sample was drawn from the interval [$-\sigma$, $+\sigma$], where σ is the estimated standard deviation for the measurement of fuel consumption. These deviations were assumed to be 10%, 10%, 5%, 2% of the average consumption for fuelwood, charcoal, LPG and electricity respectively (see above), 25% for household income, and 2% for household size. This led to a set of new samples $x_i+\sigma$, for which the correlations were calculated and compared with their original values. Ample repetition of this process showed that the income elasticities vary between ± 0.03, and the household size elasticities between ± 0.02. These deviations were used for sensitivity analysis.

The deviations of the household size elasticities have hardly any impact on the results (less than 0.1%). Lower income elasticities lead to wood requirements in 2010 that are 1.5% higher than in the original scenario, for higher income elasticities this is -1.5%.

During woodfuel supply analysis, the population growth was used as a driver for land use changes, leading to increasing area for settlements and crops, and a slight decrease in forest areas. Parallel to the new household projection a new projection for the total population was developed, used for the sensitivity analysis, which led to a small reduction of the potential supply of 2%.

The response of the energy balance was strongest for changes in the growth of the number of households and the agriculture share of the Gross Provincial Product. More reliability for these factors would be required. Figure A.4 shows the range of woodfuel demand and supply for the range of the assumptions. Considering the uncertainty as estimated through error propagation, it becomes very difficult to reach a conclusion about ratio of wood demand and supply.

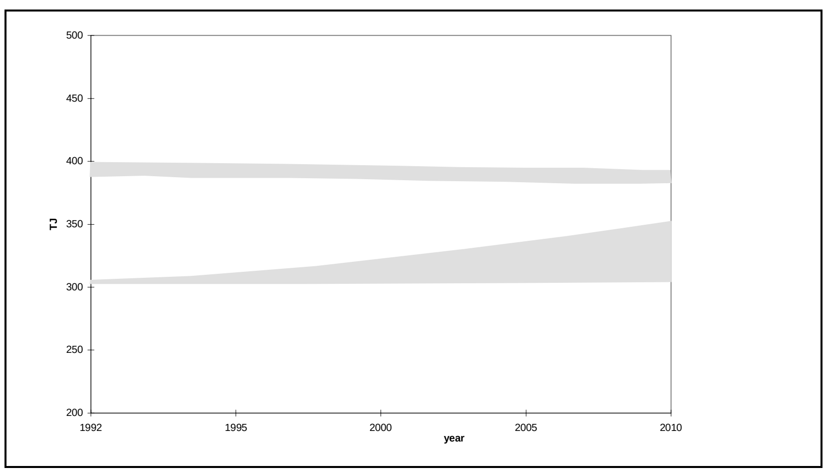

Figure A.4 *Response to Assumptions*

APPENDIX B: SCENARIO RESULTS

S1: Results of the Third Scenario of the First Stage (see section 5.2)

	1991	1995	2000	2005	2010
Residential	*(TJ)*	*(TJ)*	*(TJ)*	*(TJ)*	*(TJ)*
Electricity	32.7	34.0	38.0	41.9	45.8
Gasoline	0.1	0.1	0.1	0.2	0.2
Kerosene	2.2	2.2	2.5	2.7	2.9
Diesel	0.8	0.8	0.9	1.0	1.1
LPG	26.9	29.0	33.8	38.8	43.9
Fuelwood	102.0	99.1	101.1	101.4	99.9
Charcoal	163.8	164.8	176.5	186.8	195.5
Agriculture waste	17.3	17.8	19.6	21.3	22.9
Sub-total	*345.8*	*347.8*	*372.3*	*393.9*	*412.0*
Agriculture					
Gasoline	0.1	0.1	0.1	0.1	0.1
Diesel	8.2	8.1	8.0	7.9	7.9
Human labour	1.0	0.9	0.9	0.8	0.8
Animal labour	0.3	0.3	0.3	0.3	0.3
Sub-total	*9.6*	*9.4*	*9.3*	*9.1*	*9.0*
Total	**355.4**	**357.3**	**381.6**	**403.1**	**421.0**

S2: Results of the Third Scenario of the Second Stage (see section 5.3)

	1992	1995	2000	2005	2010
Residential	*(TJ)*	*(TJ)*	*(TJ)*	*(TJ)*	*(TJ)*
Electricity	31.5	34.3	39.3	44.4	49.4
Kerosene	0.6	0.5	0.4	0.2	0.0
LPG	27.2	29.5	35.5	42.2	49.7
Fuelwood	171.2	172.1	176.2	178.2	178.0
Charcoal	48.7	49.9	54.8	59.6	64.2
Sub-total	*279.3*	*286.4*	*306.2*	*324.6*	*341.4*
Industry					
Electricity	2.0	2.7	4.2	5.8	7.7
Gasoline	0.0	0.0	37.0	40.9	45.1
Diesel	7.3	6.8	5.8	4.6	3.0
LPG	0.0	0.0	0.3	0.3	0.4
Lignite	43.5	46.2	0.0	0.0	0.0
Fuelwood	9.9	10.5	0.0	0.0	0.0
Sub-total	*62.7*	*66.2*	*47.3*	*51.5*	*56.1*
Agriculture					
Gasoline	0.3	0.4	0.5	0.5	0.6
Diesel	12.4	13.3	14.8	16.5	18.2
Human labour	1.4	1.4	1.3	1.3	1.3
Animal labour	0.4	0.3	0.3	0.3	0.2
Sub-total	*14.4*	*15.3*	*16.9*	*18.6*	*20.3*
Total	**356.4**	**367.9**	**370.4**	**394.7**	**417.8**

S3: Results of the Second Scenario of the Third Stage (see section 5.4)

	1992	1995	2000	2005	2010
Rural Households	*(TJ)*	*(TJ)*	*(TJ)*	*(TJ)*	*(TJ)*
Electricity	23.3	25.2	28.4	31.6	34.7
Kerosene	0.5	0.5	0.3	0.2	0.0
LPG	20.8	22.3	26.4	30.9	35.8
Fuelwood	185.7	187.3	192.1	194.8	195.3
Charcoal	41.4	42.3	46.4	50.3	54.0
Sub-total	*271.7*	*277.6*	*293.6*	*307.7*	*319.8*
Sanitary Households					
Electricity	6.4	7.9	11.0	15.0	20.9
LPG	4.3	5.4	7.8	11.3	16.3
Charcoal	6.9	7.9	10.0	12.8	16.2
Sub-total	*17.6*	*21.2*	*28.8*	*39.1*	*53.3*
Industry					
Electricity	2.0	2.7	4.2	5.8	7.7
Gasoline	0.0	0.0	37.0	40.9	45.1
Diesel	7.3	6.8	5.8	4.6	3.0
LPG	0.0	0.0	0.3	0.3	0.4
Lignite	43.5	46.2	0.0	0.0	0.0
Fuelwood	9.9	10.5	0.0	0.0	0.0
Sub-total	*62.7*	*66.2*	*47.3*	*51.5*	*56.1*
Agriculture					
Gasoline	0.3	0.4	0.4	0.4	0.5
Diesel	12.4	12.8	13.5	14.2	14.9
Human labour	1.4	1.3	1.3	1.3	1.2
Animal labour	0.4	0.3	0.3	0.3	0.2
Sub-total	*14.4*	*14.8*	*15.5*	*16.1*	*16.8*
Total	**366.5**	**379.8**	**385.1**	**414.4**	**446.1**