Long term optimization of energy supply and demand in Vietnam with special reference to the potential of renewable energy

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List of Abbreviations

ABARE	Australian Bureau for Agricultural and Resource Economics
ADB	Asian Development Bank
AIT	Asian Institute of Technology
ASTAE	Asia Alternative Energy Programme
BAU	Business As Usual
BNL	Brookhaven National Laboratory
CDM	Clean Development Mechanism
CH_4	Methane
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CRI	Crop Residue Index
DO	Diesel Oil
ECMWF	European Centre for Medium-Range Weather Forecasts
EFF	Energy Efficiency
EU	European Union
EVN	Electricity of Vietnam
FO	Fuel Oil
GBV	Gross Bole Volume
GDP	Gross Domestic Products
GG	Gasoline Generator
GHGs	Greenhouse Gases
GIS	Geographical Information System
GR	Growth Rate
HUT	Hanoi University of Technology
IAEA	International Atomic Energy Agency
IEA	International Atomic Agency
IE	Institute of Energy
IEJE	Institute Economique et Juridique de l'Energie (Institute of Energy Policy and Economics, Grenoble, France)
IER	Institute for Energy Economics and the Rational Use of Energy
IIASA	International Institute for Applied System Analysis
IPCC	Intergovernmental Panel on Climate Change
KFA	Kernforschungsanlage Jülich (Jülich Research Centre, Germany)
LCC	Life Cycle Cost
LPG	Liquefied Petroleum Gas
MH	Micro Hydro

MOU	Memorandum Of Understanding
MUSS	MARKAL User Support System
NA	Not Available
NASA	National Aeronautics and Space Administration
NIHH	National Institute of Animal Husbandry
N_2O	Nitrous Oxide
NOAF	University of Agriculture and Forestry
NPV	Net Present Value
NREL	US National Renewable Energy Laboratory
NU	Not Used
ppp	Purchasing Power Parity
RD&D	Research, Development and Demonstration
RE	Renewable Energy
RES	Reference Energy System
R&D	Research and Development
SHS	Solar Home System
UNEP	United Nations Environment Programme
USD	United States Dollar
VGA	The Vietnam Gardeners Association
Vinalcoal	Vietnam National Coal Company
VND	Vietnam Dong
WB	World Bank
WHS	Wind Home System

Measures

cbm	Cubic meter
Gcal	Giga caloric
GJ	Giga joule
GW	Giga Watt
GWh	Giga Watt hour
kcal	Kilo caloric
kg	Kilogram
kgoe	Kilogram of oil equivalent
km^2	Square kilometer
ktoe	Thousand tons of oil equivalent
kWh	Kilo Watt hour
MJ	Mega Joule
MW	Mega Watt
MWh	Mega Watt hour
toe	Ton of oil equivalent
TWh	Tera Watt hour

Decimal prefixes

Kilo	k	10^3
Mega	M	10^6
Giga	G	10^9
Tera	T	10^{12}
Peta	P	10^{15}

Conversion factors

1 MJ = 10^6J = 239 kcal = 0.278 kWh
1 GJ = 10^9J = 278 kWh
1 PJ = 10^{15}J = 278 GWh = 0.0239 Mtoe

1 kWh = 3600 KJ
1 kcal = 4186 J
1 Gcal = 10^6 kcal = 4.18 GJ

1 kgoe = 0.0418 GJ = 10^4 kcal
1 toe = 41.8 GJ = 10^7 kcal
1 ktoe = 10^3 toe = 0.0418 PJ
1 Mtoe = 10^6 toe = 41.8 PJ

INTRODUCTION

The need for energy planning

Energy represents the basic background for the economic and social development of a country. A sufficient and sustainable energy supply is one of the decisive keys to economic growth. Therefore, special care should be taken in planning the energy infrastructure because just a single wrong decision would lead to serious consequences for long time periods. Energy planning offers an opportunity to keep the chance of making wrong decisions as low as possible and is thus an important development policy of a country.

The need to include renewable energies into national energy planning

Energy and environment - Economic development depends on energy. Traditionally, fossil fuels provide it in a cheap and concentrated form, and as a result they dominate the energy supply. At the same time however, they emit billion of tons of carbon dioxide (CO_2) and a range of other gases which have led to evidentially environmental degradation whose appearances have been classified by Ibrahim Dincer [Dincer00] [IPCC95]. Among these environmental risks, the most serious problem is the global climate change (greenhouse effect) because it leads to an increase in the surface temperature of the earth. Reports from IPCC show that during the last century, the Earth's surface temperature has increased by about 0.6^{o}C (figure 0.1). Much evidence exists, which suggests that the future will be negatively impacted if humans keep degrading the environment. It is therefore of vital importance to put these emissions under control.

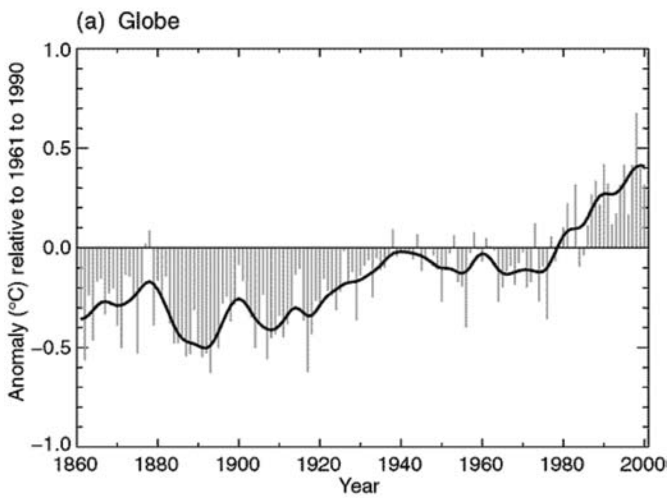

Figure 0.1: Annual anomalies of global average land-surface air temperature (°C) 1861 to 2000, relative to 1961 to 1990 values [IPCC01]

The climate change problem was first raised internationally in 1992 in the "Rio Earth Summit" agenda. By that time, collectively 167 nations expressed concerns over problems relating to the environmental degradation, the most important phenomena of which were acid rain, ozone depletion and the greenhouse effect. The Framework Convention on Climate Change (FCCC) has been signed as the first commitment of the world to keep the emissions under control. The commitment was concretized in the Kyoto Protocol (1997) by officially setting the limits for greenhouse gas emissions in developed countries, particularly at 5.2% below the 1990's level for the 2008-2012 time period [UNEPb]. Considering the per capita level, the greenhouse gas emissions from energy consumption in developing countries is much lower than that in developed countries. However, the rapid population growth and economic development in developing countries will significantly increase their share in the total energy use and green house gas emissions in the future. These environmental issues must be, therefore, expanded in the energy policies of all countries all over the world.

Energy and sustainable development - The long-term control of global climate change and holding it at safety levels requires a connection of policies for climate change to sustainable development strategies in developed and developing countries as well. Over the last few decades, a decline in precious fuel reserves has been observed world wide generally and in Vietnam particularly. Although some new reserves have been explored and few more are expected to be added to the existing reserves, it has been shown that except coal, fossil fuel reserves won't even last until the middle of this century (Fig 0.2) [BP03]. The sustainable development issue is therefore more than ever raised, stimulating the need to search for a sustainable development road.

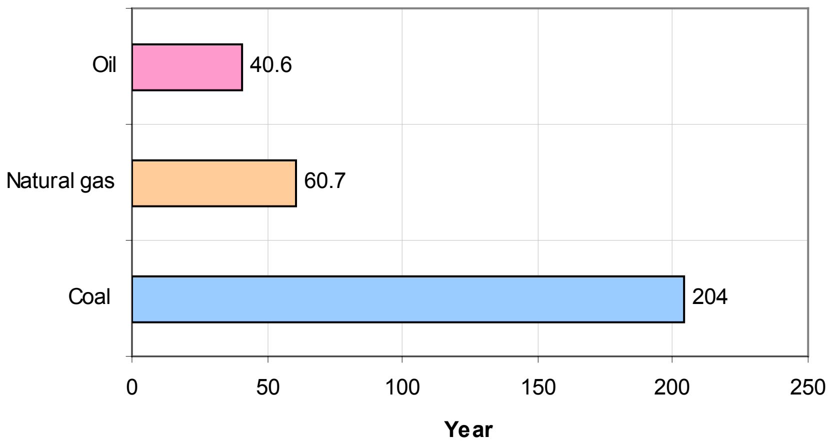

Figure 0.1: Reserves/Production ratio[1] of fossil fuels in the world [BP03]

Indeed, an alternative way for sustainable energy development exists without the risk of climate or ecology breakdown. This is the way to increase reliance on clean and renewable energies [Dincer00].

Renewable energies - Renewable energies would bring a number of benefits to the economy. First, they help increase the diversity of energy supplies, and thus lower the dependency on fossil fuels and improve the security of energy supplies. Second, they help make use of indigenous resources to provide a cost-effective energy supply (characterized by mobility, modularity and low operating costs; renewable energies are very flexible in case of upgrade and competitive technologies as decentralized systems) while reducing local and global greenhouse gas emissions. Finally, from the social point of view, renewable energies can create more domestic employment since their constructions are generally of modest scales [APEC99b].

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[1] If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that level.

Such benefits have created a strong motivation for pursuing renewable energies in both developed and developing countries. For example, the European Union (EU) has set out a strategy to double its share of renewable energies in gross domestic energy consumption in the EU by 2010 (from the present 6% to 12%) [EC97] and in 2000, renewable energy electricity contributed 14.9% of its gross electricity consumption [IEA02]. China and India also assessed critically the possible contribution of renewable energies in their energy supply mix and issued incentives to obtain that objective [China01] [India00].

The results of this effort are that renewable energies have quickly been developed and expanded. World-wide installed capacities of wind and solar PV grow at 30% and 24% per year, respectively, compared to the 1.4% annual growth of conventional energies in the period 1992-2002 [BP03]. This effort leads also to a significant reduction in the investment cost. For example, the costs of solar PV technologies were reduced by more than 80% during 1976-1992 [WiTe93], wind turbines by 52% during 1982-1997 [Neij99]). This makes investment in renewable energy technologies more attractive.

Vietnam energy scene

Energy demand in Vietnam has increased greatly year by year, beginning in 1986 when the country started a reform program for the economy. Between 1990 and 2000, an average increase rate of 11.2% per year was recorded, significantly higher than the growth rate of the economy (7.6%) in the same period. Among the energy compartments, electricity increased by 14%, petroleum products by 12% and coal by 9% per year. Also associated gas, which was used to be flared, has been transported to onshore for power generation [IE]. Nevertheless, Vietnam is still among countries with the lowest per capita consumption level of conventional energies (144 kgoe) in the world [WB98]. With 75% of the population living in the rural areas and 30% of them have not yet been provided with electricity, Vietnam will have an energy strain kept driven by electrification, urbanization and population growth. Furthermore, economic growth, industrialization, and globalization of trade as results of the economic development also directly affect the energy demand of the country. This expected accelerated growth of energy demand calls for the search for energy sources that would provide an increment to the energy supply in the short and long term and in a secure and sustainable manner.

From the geographical point of view, Vietnam has rich renewable energy resources. The inclusion of renewable energy into the national energy planning would be, therefore, the right direction, not only for a sustainable development of the country but also as the responsibility of Vietnam toward global common task for environmental protection.

Research objectives and approach

The objective of this research study is to *optimize the long term energy supply and demand in Vietnam with special reference to the potential of renewable energy*. In pursuing this broad objective, a multi-period linear programming–MARKAL is chosen to be adaptable to the Vietnamese specific energy conditions.

In connection with the above mentioned objective, the following activities will be undertaken

- Assessing the potential of renewable energy resources in Vietnam,
- Identifying proper renewable technologies for Vietnam,
- Making a long-term forecast of the energy demand for Vietnam,
- Establishment of the database on energy technologies including conventional technologies and renewable technologies,
- Establishment of the RES for Vietnam,
- Cost-benefit analysis of Vietnam energy sector through developing multiple futuristic scenarios,
- Assessment of green house gas emissions for above generated scenarios,
- Assessment of the decentralized technologies for isolated areas.

The following methodological issues will be addressed:

- Establishment of methodology for assessing the potential of renewable energy resources in Vietnam,
- Establishment of methodology for making a long term energy demand forecast for Vietnam,
- Establishment of methodology to model renewable energy technologies in MARKAL,
- Establishment of methodology to assess the decentralized renewable energy technologies for isolated areas.

Structure of the study

The present study is organized into seven parts. The first chapter gives an overview of the entire economy in Vietnam, from both the economic and energy points of view, and discusses energy problems in which the country is facing. In chapter 2, a review of existing tools related to energy planning is given. A summary on the application of these tools in various countries is also presented along with coverage on relevant work done in Vietnam so far. A full description of MARKAL – the model which has been selected for this investigation is also given in this chapter. Chapter 3 focuses on the assessment of the technical potential of various renewable energy resources including wind, solar, biomass, biogas, hydropower and geothermal along with discussion of suitable technologies. Chapter 4 devotes to the development of the model MARKAL–Vietnam. For this, the specifications of various parameters which enable the construction and investigation of the energy system in Vietnam are evaluated (from energy resources through transmission, conversion and demand technologies to energy demand or from the discount factor to the emission factors). Chapter 5 discusses different scenarios to represent varying assumptions on the basic parameters of the study such as a change in the energy service demand forecast, and development of energy technologies. In the last chapters, results of the MARKAL model adapted to Vietnam are evaluated and different scenarios are compared.

Apart from this, the accompanied supported annexes provide various data and parameters used in the study in full scale. Annex 1 describes the methodology and results of the future long-term energy demand forecast. Annex 2 is an investigation of the decentralized technologies for isolated areas. Annex 3 & 4 show the calorific values and emission factors adopted for the present study. And finally, annex 5 provides the detailed results of the BAU–Base scenario.

Chapter I

SOCIO-ECONOMIC AND ENERGY SITUATION IN VIETNAM

1.1 General overview

Vietnam lies in the center of South East Asia and covers a total area of about 331,111 km^2. The country has borders with China in the north, Cambodia and Laos in the west and the South China Sea in the east and south. It has a total border line of 7770 km, of which 3260 km are bordered by water. The widest cross distance is 600 km (in the north) and the narrowest cross distance is only 50 km (in the Center) (Figure 1.1) [VN02].

Land use in Vietnam has changed significantly over the last few decades. Prior to 1970, more than 35% of the country's territory was covered with forest, about 21% was used for agricultural land and 39% was waste land. In 1993 forest area decreased to 30% while agricultural land increased to 22.2%.

Vietnam has a greatly changeable climate due to influences of Central Asia and the Yellow Sea (The Pacific Ocean) in the north. There are large differences in temperature between summer and winter as well as sudden temperature changes. Generally, the winter season (from November to April) has an average temperature of around 16^0C with frequent light drizzle from February onwards. The summer season (from May to October) is very hot and humid with frequent rains and typhoons. In the south, the monsoons from the Pacific and Indian oceans cause the tropical climate with temperatures between 25 and 30^0C and a regular rainy season. In the north there are three seasons. May to October is hot and rainy, November to February is relatively dry and cool, and February to April is dry and warm. The central part of Vietnam has a mixed climate of the north and south; the area is thus cooler than in the south, and the dry and rainy seasons are less pronounced.

Population in Vietnam has grown at a high rate. In 1930 there were only 17.85 million peoples, in 1995 it became nearly 72.32 million, thus the population has multiplied 4 times within 65 years. Of the population in 1995, 79% lived in rural areas.

1.2 Socio-economic situation

Before 1986, the economy in Vietnam operated under central planning mechanisms. Since then, especially from 1989, Vietnam has undertaken a full reform program called Doimoi, aiming at (i) introducing the market economy to increase flexibility and efficiency, (ii) developing and diversifying international economic relations and (iii) reshuffling the state administration. After more than 10 years of the implementation, Vietnam has achieved several prominent results (Table 1.1).

High growth rates of the economy - Before 1986, the economy in Vietnam remained almost constant. After the reform program had been applied it was restored and developed stable with high growth rates year by year. The highest growth rates were achieved in 1995-1996 (9.5%). Although the growth rate of GDP fell significantly in 1998 (to 5.8%) as a consequence of the regional financial crisis, Vietnam was still among the countries with the highest growth rate in the region.

Figure 1.1: General map of Vietnam

Table 1.1: Some economic parameters of the economy in Vietnam between 1986-1998

Parameter	Data source	'86	'91	'92	'93	'94	'95	'96	'97	'98
GDP growth rate (%)	[Thuong99]	0.3	6.0	8.6	8.1	8.8	9.5	9.4	8.2	5.8
Accumulation/GDP (%)	[Thuong99]	0	10.1	13.8	14.8	16.9	17.0	16.7	20.1	17.0
Inflation rate (%)	[Thuong99]	774.7	67.6	17.5	5.2	8.8	12.7	4.5	3.7	9.2
Paddy output (mill tons)	[GOS01]	16.0	19.6	21.6	22.8	23.5	24.9	26.3	27.5	29.1

Internal accumulation - Before 1986, national income could satisfy only 80% of the national expenditure, 20% was normally compensated by foreign aid or long-term loans. After 1986, especially from the 1991-1995 period, Vietnam started having internal accumulation.

Curbing super inflation - From an economy with three-digit inflation rates before 1988, since 1989 the inflation reduced to two-digit rates. The currency value (VND) now is relatively stable and allows favorable conditions for economic development.

Attraction of more foreign investments -As of February 1997, Vietnam has attracted 1696 projects with a total registered investment capital of 28.2 bill USD within 9 years of the implementation of foreign investment law. Implemented projects are present in 50 provinces with an investment capital of 8 bill USD, creating more than 170,000 jobs [Thuong99].

Advances in economic transition - Before the reform implementation, the economy in Vietnam was based mainly on agriculture. The industrialization and open door policy enabled development of non-agriculture and service activities, that in turn, has an impact on economic transition. Thus, before 1986 the proportions of industry-agriculture-service sectors in GDP were 28.9%-38.1%-33%, respectively, in 1997 these proportions changed to 32.1%-25.8%-42.2%, respectively.

Penetration of science and technology into the economy - The investment capital for science and technology researches increased from 0.1% of the GDP in 1986-1990 to 0.4% of the GDP in 1995. Application of advanced technologies in all fields of the economy was encouraged. Training scientists, especially in important sectors, have been given with special attentions.

High growth rate in the industry - Total gross industrial value in 1995 was 3.36 bill USD, 1.8 folds higher than that in 1984. In the period 1990-1995, the industry sector reached a yearly growth rate of 10%.

Overcoming food shortages - Since 1988, food has become a commodity in Vietnam and rice production has not only met domestic demand but also been exported. Vietnam is now the second rice exporter in the world (3.8 mill tons of rice were exported in 1998). Paddy output in 1998 was 29.1 mill tons, equivalent to about 385 kg per capita on average.

Trade development - Total service retail turnover reached 9.52 bill USD in 1995, 1.5 folds higher than that in 1990. As of 1995, Vietnam has established trade relations with 120 countries, achieving the export turnover of 5.3 bill USD (in 1976 it was only 222.7 mill USD)

Improved living conditions - As of early 1996, 55% of all households in Vietnam were supplied with electricity. In 1998, this figure grew to more than 63%. Percentage of rich households increased from 8% in 1986 to 15% in 1995, whereas the percentage of poor households decreased from 50% in 1986 to 25% in 1995. Per capita income increased from 114 USD in 1990 to about 285 USD in 1995 (equivalent to 1511 USD according to the purchasing power parity (ppp)).

1.3 Energy situation

1.3.1 Primary energy production

Coal - Coal production increased from 4.6 million tons in 1990 to 11.6 million tons in 2000, attaining an annual growth rate of 10.8% (Table 1.2). The production capacity of all underground and open-pit mines is estimated to be 12 million tons of raw coal per year, equivalent to 11 million tons of clean coal.

Table 1.2: Energy production in Vietnam during 1990 - 1999

Fuel	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00
Coal output (PJ)	107.8	117.2	117.2	138.3	133.6	196.9	229.7	267.2	250.8	225.0	271.9
Crude oil (PJ)	115.1	168.8	234.4	268.5	302.6	323.9	375.1	464.6	532.8	647.8	694.7
Gas production (PJ)	0.1	1.0	0.7	0.9	1.0	6.8	10.8	20.1	37.8	52.5	58.7
Gas for electricity (PJ)	-	-	-	-	-	6.8	10.4	19.8	33.4	38.1	45.4
Hydro (PJ)	19.4	22.7	26.0	28.6	33.3	38.1	43.2	42.0	39.9	50.2	52.4
Biomass (PJ)	518.7	530.8	541.7	567.9	584.6	595.9	591.7	N.A	N.A	N.A	N.A

Source: [IE]

Crude oil - Crude oil production has grown at high rates during the last years, from 2.7 million tons in 1990 to 7.6 and 16.3 million tons in 1995 and 2000, respectively. This is equivalent to a growth rate of some 20% in the 1990-2000 period (Table 1.2). So far, most of the exploited crude oil has been exported since there is not yet an oil refinery plant in Vietnam. Local demand for petroleum products is thus covered by import. To enhance security for the energy sector, Vietnam is currently constructing the first oil refinery plant with a capacity of 140,000 barrels per day.

Gas - Associated gas has been exploited for use since late 1994 when the pipeline system from the White-Tiger oilfield to Ba-Ria power station was finished. Gas production has increased steadily as a result of the increased oil production (Table 1.2). At the present, the gas output reaches 4-4.5 mill cubic meter/day, equivalent to 1.5-2.0 bill cubic meter/year, able to satisfy demand of Ba-Ria, Phu-My power plants and Dinh-Co LPG plant.

Hydropower - Hydropower plays an important role in Vietnam. It always occupies more than 50% of output of the total electric generation system. In 1994, hydropower supplied 75% of the electricity demand. The annual growth rate of hydropower application was 10% in the 1990 - 2000 period.

Biomass - In the total final energy production, biomass plays an overwhelming proportion because it dominates the energy mix consumed in rural areas. This share however has been decreasing in the last years as a result of increasing urbanization and improved living conditions (Figure 1.2b).

1.3.2 Energy import and export activities

Energy import - export balance has changed significantly since 1990 due to the strong growth in crude oil and coal export. Such development has changed Vietnam from an energy import country to an energy export country (Table 1.3) [IE]. However, 100% demand for petroleum products are still covered through imports. Of the petroleum products imported in 1995, 42% was diesel, 29% - gasoline, 20% - fuel oil and 5% - kerosene, and they were mainly consumed in transportation and industry sectors.

Table 1.3: Development of energy import-export balance in Vietnam between 1990-2000

Energy activities (mill tons)	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00
Import of Petro. products	2.9	2.6	3.1	4.0	4.5	5.0	5.9	6.0	6.9	7.4	8.7
Export of Crude oil	2.6	3.9	5.4	6.2	6.9	7.7	8.7	9.6	12.1	14.9	15.4
Export of Coal	0.8	1.2	1.6	1.4	2.1	2.8	3.6	3.5	3.2	3.3	3.3

1.3.3 Primary consumption

Total primary energy consumption increased from 812 PJ in 1990 to 1141 PJ in 1996, achieving an annual growth rate of 5.8%. If biomass was excluded, this rate rose to 11%. Among energy sources, biomass took the biggest proportion, whereas petroleum products the second largest (Figure 1.2.a). As a noticeable trend, biomass is gradually lagging behind petroleum products, coal and gas (Figure 1.2.b).

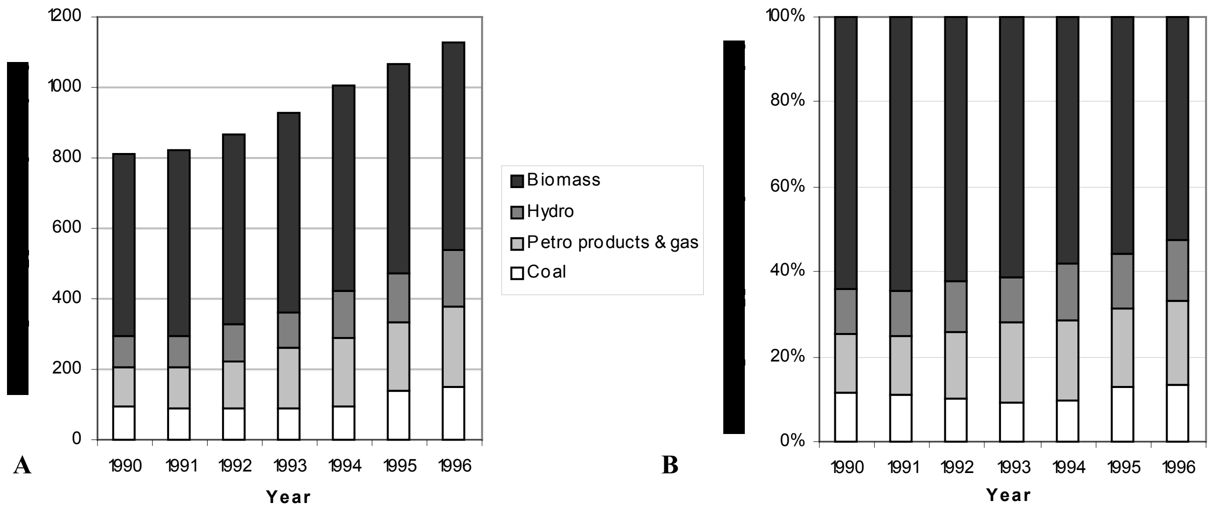

Figure 1.2: Development of primary energy consumption in Vietnam between 1990-1996 (a) in PJ, (b) in proportion.

1.3.4 Final energy consumption

The total final energy consumption in Vietnam increased from 695 PJ in 1990 to around 962 PJ in 1996, implying an annual growth rate of 5.6%. This is lower than the rate of the primary energy consumption, suggesting an increasing loss in the conversion, transmission and distribution of energy. In fact, loss in the total primary energy consumption increased from 14% in 1990 to 16% in 1996. Regarding fuel composition, contribution of biomass decreased from 75% in 1990 to 61% in 1996. In contrast, the share of petroleum products increased from 14% in 1990 to 22% in 1996. A similar trend happened to coal and electricity, whose shares increased from 8% and 3% to 12% and 5%, respectively [IE]. In general, the trend is that commercial energy is replacing non-commercial energy (Figure 1.3).

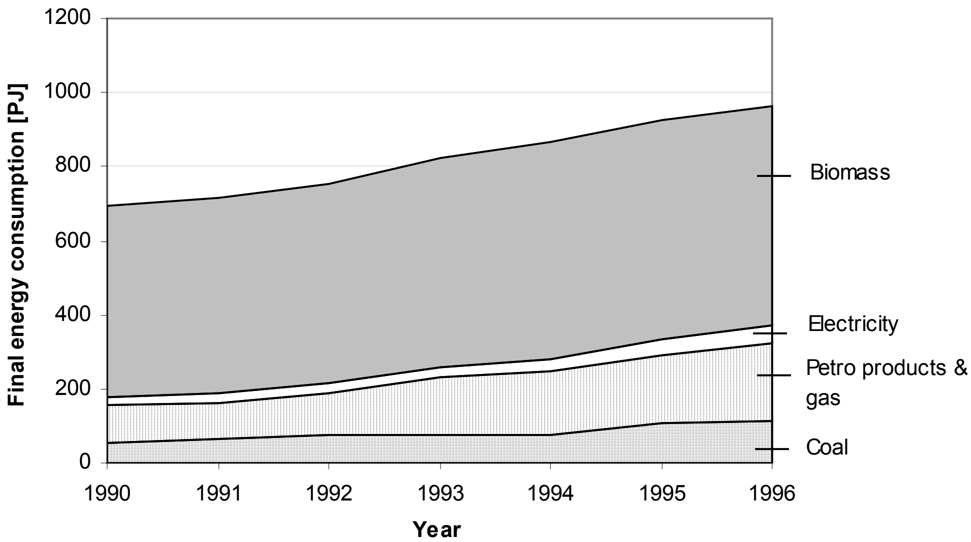

Figure 1.3: Final energy consumption in Vietnam between 1990-1996

Coal - Of all local energy end-uses, the industry sector has been the biggest coal consumer with a relatively stable consumption at about 3 mill tons per year since 1991. Coal use for electricity generation dropped to 0.5 million tons in 1993 but since then has risen, reaching 1.4 million tons in 1996. Coal consumption for transportation (mainly railways) has fallen due to the replacement of coal by diesel in train locomotives.

Petroleum products - Major uses of petroleum products were the transportation and industry sectors. From 1990-1995, the consumption grew at 10%, about 1.35 times of the growth rate of GDP (Table 1.4). Among petroleum products, gasoline, diesel and fuel oil consumption grew at 12%, 7% and 14% per year, respectively. Consumption of LPG increased remarkably from 3.4 KTOE in 1990 to 51.5 KTOE in 1995, mainly for urban use in cooking [WB98].

Table 1.4: Petroleum products consumption in Vietnam (KTOE)

Petroleum Products	1990	1995	Average growth
LPG	3.4	51.5	72%
Gasoline	717	1243	12%
Aviation Fuel	109	236.3	17%
Kerosene	224	243.4	2%
Diesel	1211	1713	7%
Fuel oil	413	792	14%
Total	**2677.4**	**4279.2**	**10%**

Gas - For many years, most of the associated gas in the oil industry was flared off near the wellheads. Since 1995 it has been used for electric generation and the volume supplied for this purpose has increased significantly, from 182 millions cbm in 1995 to 900 millions cbm in 1998.

Electricity - During 1990-1999 electric consumption grew by 13.7% per year, far higher than the GDP growth rate in the same period. The highest growth rate of electric consumption has been recorded in the residential sector (19.4%), followed by that in the industrial sector (11.5%). The growth of electric demand in the agriculture sector has had a negative value (Figure 1.4). However, this did not reflect the real trend of electricity consumption in this sector because before 1995 it had been assessed together with electricity consumption in the rural residential sector. Total net electric output in 1999 was 19550 GWh, indicating a per capita consumption level of 255 kWh. In 1999, Vietnam had an installed power capacity of 5665 MW. Hydropower plants made the biggest contribution, accounting for 50%. Thermal and diesel turbines contributed 21%, gas turbines 29% [IE]. Shares of renewable energy technologies (solar, wind) were insignificant and used in distributed forms.

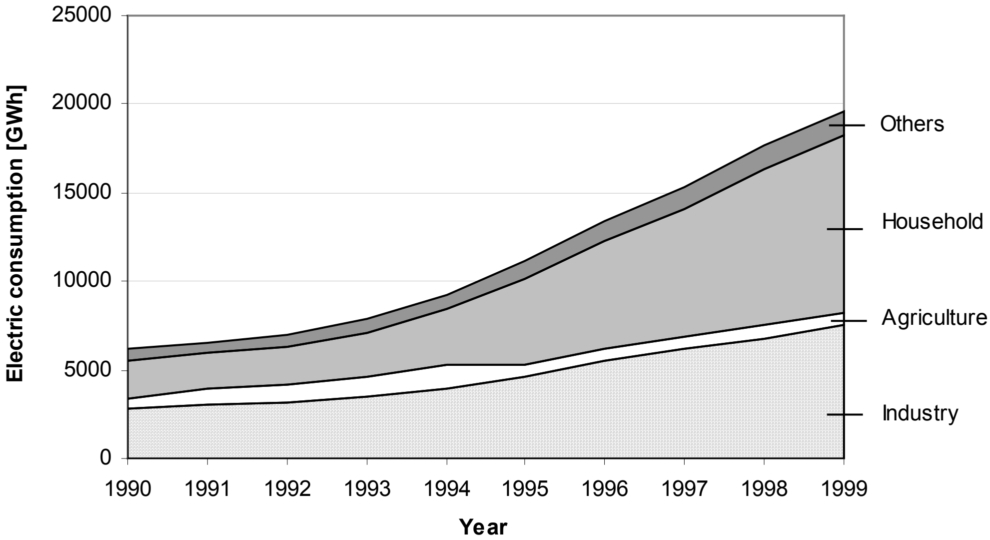

Figure 1.4: Electric consumption in Vietnam between 1990-1999

Biomass - Biomass occupied 90% of the energy consumption in the rural domestic sector. A significant amount (approximately 400,000-500,000 tons per year) has also been used in the industrial and agricultural processing as well as in the construction material industry [FAO92]. According to a report of the Hanoi University of Technology [HUT99] and own estimation, the consumption in 1995 was 14470 KTOE.

1.3.5. Greenhouse gas emissions

The first inventory of greenhouse gases (GHG) for the energy sector in Vietnam was carried out in 1993. It covered only emissions from the combustion (CO_2 and non-CO_2 from fuel burning processes) and fugitive activities (exploitation of primary resources such as coal, crude oil and gas). The total emission of CO_2 in 1993 was 19.850 million tons, implying a per capita level of CO_2 emission of 285 kg (Table 1.5).

Table 1.5: GHGs emissions by fuels in the energy sector in 1993 in Vietnam

Fuel type	CO_2	CH_4	N_2O	NO_x	CO
Fossil	**19850.9**	**1.92**	**7.80**	**52.22**	**126.50**
Coal	7351.9	0.78	4.59	18.35	15.16
FO	2384.9	0.05	1.31	0.42	0.49
DO	6285.9	0.14	0.54	21.36	6.96
Gasoline	2732.1	0.95	0.99	10.82	103.75
Kerosene	571.8	0.01	0.38	1.27	0.14
Other oil products	506.9				
Gas	17.4				
Biomass		**162.38**	**1.12**	**38.59**	**1420.84**
Total (Thousand Tons)	**19850.9**	**164.30**	**8.92**	**90.81**	**1547.34**

1.4. Challenges to the energy sector in Vietnam and proposal

Despite considerable growth in energy consumption, Vietnam still remains one of the countries with the lowest level of conventional energy consumption in the world (about 144 kgoe per capita in 1995) [WB98]. In the coming periods (2000-2030), energy demand in Vietnam will keep growing significantly mainly due to the following reasons:

- **Population growth** is forecasted at 1.0% per year.
- **Urbanization** is expected to increase at 3.0% per year.
- **Electrification** expands for about 5.9 million rural households not presently electrified.
- **Industrialization -** The industry sector is expected to increase at a rate of 7.8% per year.
- **Economic growth -** The economy is expected to grow at an average rate of 6.9% per year.

With such a development, Vietnam is facing a number of questions regarding the availability of energy resources as well as environmental concerns.

Renewable energy (RE) offers several benefits to an economy. It helps increase the diversity of energy supplies, and thus lowers the dependency on fossil fuels and improves the security of energy supplies for the economy. It helps make use of indigenous resources to provide cost-effective energy supplies (especially as decentralized technologies) for the economy and avoid higher costs of imported energy. It contributes to the reduction of global and local atmospheric emissions. It can also increase domestic employment of local labor since the construction of renewable energy facilities are generally of modest scales and modular in nature for which local labor can be used.

Geographically, Vietnam is well endowed with renewable energy resources; hence the promotion of RE is considered as a strategic move for benefits of economy strengthening, energy security enhancement and local environment protection.

Being an important infrastructure for the economy, energy needs to go ahead the economy. An integrated energy planning study, which considers adequately the role of renewable energies, is, therefore, necessary to be carried out. This is also the main goal of the present study. In the following section we will review existing models and studies so far to facilitate the selection of methodology to achieve the specified goal.

Chapter II

LITERATURE REVIEW

2.1. Review of energy planning models

Energy planning is an important task for national governments and international agencies as well because it aids in making decisions on development strategies nationally and internationally. The history of the energy planning discipline started in the 1960s [Schlen98] when the first studies which focused on energy supply were carried out. At that time, their methodologies focused separately on aspects of the problems such as cost, environmental damage or energy supply security. Usually, only one energy carrier or only one economic sector was considered. The oil crisis in the 1970s caused countries to give special attention to critical assessment of fuel reserves, rational use and conservation of resources and long-term energy planning. Energy models based on single energy carriers were no longer sufficient. A series of new energy models were developed, the most typical models of which are energy planning models such as MESSAGE, EFOM, and MARKAL and energy demand models such as MEDEE and MAED. Energy models become even more important considering the increasing environmental degradation due to the increase in energy consumption. According to the Intergovernmental Panel on Climate Change (IPCC), aggregated energy related activities together contributed 80% of the total greenhouse effect [IPCC95]. This created the needs for new energy planning tools which can take the environmental problems into consideration. Therefore, besides new tools specific for environmental studies pertaining to assessment, projection and mitigation, existing energy planning tools were expanded to cover the environmental aspect of energy activities such as EFOM-ENV.

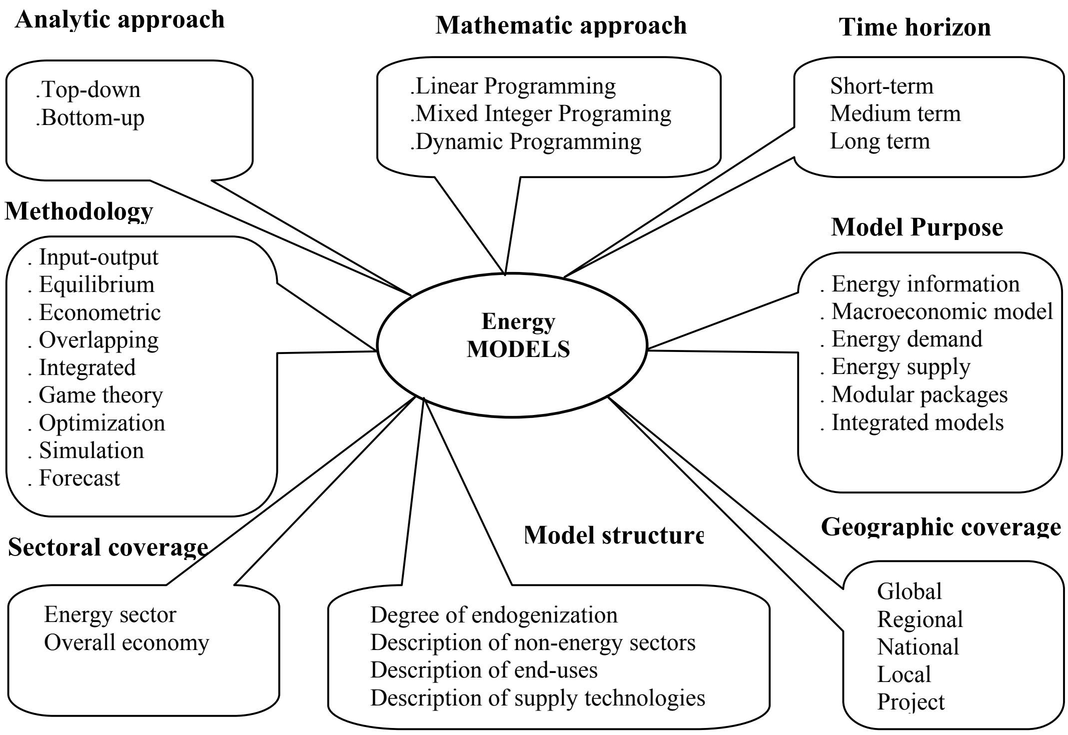

Figure 2.1: Criteria to classify energy planning models

Energy planning models differ from each other in the model purpose, the model structure (internal and external assumption), analytical approach (top-down or bottom-up), study methodology, mathematical approach, geographic coverage, sectoral coverage, the time horizon, and data requirement (Figure 2.1) [Schlen98], [Beeck99b], [MIT97], [Kem97]. The model purpose is the most commonly used parameter to characterize energy models. Based on this parameter, following categories of energy planning models are recognized: Energy information systems, Macro economic models, Energy demand models, Energy supply models, Modular package and Integrated models.

2.1.1. Energy information systems

Energy information systems are typically databases for management of statistic and technical data. They include a module to enable data to be presented in graphical and table formats. In addition, some databases offer opportunities to analyze and compare technologies. Examples of these databases are CO2DB, DECPAC, IKARUS.

CO2DB is a database software system for collecting data on technologies related to the CO_2 problem. The system predefines the information to be entered into the data bank, structures it according to sector and type, and supports the evaluation of chains of energy conversion and utilization technologies. The database has been specifically designed to provide a uniform framework for the assessment of the ultimate reduction potential of greenhouse gases resulting from the introduction of new technologies over different time frames in different regions. Currently, CO2DB contains approximately 1800 technologies [CO2] [Strube99].

DECPAC database contains technical, economic and environmental aspects of different energy sources for electricity generation. The model provides several levels of analysis (power plant, fuel chain, and electric power system) to support and facilitate comparative assessment studies. At the system level, DEPAC integrates electric system expansion planning with the analysis of primary energy supply chains, and computes the resulting environmental emissions [DECPAC].

IKARUS database contains all relevant technological, economic and emission specific data of available technologies in Germany. It comprises the primary energy and conversion as well as the final energy sectors (households, small consumers, industry and transport). A special part of the database is devoted to the cross-sectional technologies like electrical drives or lighting technology. These are sector-independent technology descriptions as well as an important part of the technical systems contained in the data base [IKARUS].

2.1.2. Marco economic models

Macroeconomic models are concerned with questions on how the price and the availability of energy influence the economy in terms of GDP, employment and inflation rate and vice versa. Two examples under this category are MACRO and MIS models.

Marco economic information system (MIS) was developed by the University of Oldenburg as a module in the IKARUS[2] project. The system provides framework data for the economic development and the evaluation of the optimization results with respect to overall economic

[2] IKARUS: Instrument für Klima-Reduktionsstrategien (Instruments for Greenhouse Gas Reduction Strategies)

consistency. It is based on a dynamic input/output approach. The overall economy in Germany is aggregated into 30 sectors, 9 of which are energy sectors, corresponding to the functional structure. The MIS system consists of an input/output generator, a growth model and several sub-models, namely electricity, transport and dwelling [Pfaff95].

MACRO was developed by IIASA. It is a two-sector (production and consumption), aggregated view of long term economic growth. Its objective function is the total discounted utility of a single representative producer-consumer. Energy demand in two categories (electricity and non-electric energy) is determined within the model, consistent with the development of energy prices and the energy intensity of GDP. Energy supply is represented by two quadratic cost functions relative to two demand categories, and is determined to minimize costs. MACRO's outputs include internally consistent projections of world and regional realized GDP (i.e., taking into account the feedback that changing energy, and other costs have on economic growth) including the disaggregation of total production into macroeconomic investment, overall consumption, and energy costs [Gold01].

2.1.3. Energy demand models

Energy demand models are built to forecast the energy demand of either the entire economy or of a certain sector. Among the energy demand models, the technical-economic ones are widespread, but econometric models are used as well. Important demand tools are MEDEE, and MAED.

Modèle d'Evaluation de la Demande En Energie (MEDEE) was developed by IEJE[3] in Grenoble, France and is a technical-economic "bottom-up" model for long-term energy demand forecast. MEDEE follows the end-use method. By breaking up the energy demands into homogeneous sub groups and identifying the direct and indirect "determinants" of these demands i.e. social, economic, or technical determinants, the model is able to evaluate the future energy demand based on the evolution of these determinants [Chate82] [Lapi83].

Model for the Analysis of Energy Demand (MAED) is a module of ENPEP[4] package which is also a technical-economic bottom up model for energy demand forecast. In fact, MAED is a simplified version of MEDEE simplified by IAEA to overcome the shortage of input data as known in developing countries. MAED consists of (i) an energy demand module that calculates the final energy demand for the desired years which are broken down into consumer sectors and energy forms, (ii) an Hourly Electric Power Demand that converts the total annual demand for electricity for each sector into the hourly power demand, and (iii) a module that calculates the Electric Load Duration Curve [MAED].

2.1.4. Modular packages

These tools may consist of several different kinds of models such as a macro-economic component, an energy supply and demand balance, an energy demand alone, etc., which are integrated into a package. The user does not need to run all the models but may select only a subset depending upon the nature of the analysis to be carried out [AssTool]. Some of the well-known tools are ENPEP, LEAP, ETB, and MESAP.

[3] IEJE: Institute Economique et Juridque de l'Energie (Institute of Energy Policy and Economics)
[4] See next page: 16

ENergy and Power Evaluation Program (ENPEP) was developed at Argonne National Laboratory with support from the U.S. Department of Energy, the International Atomic Energy Agency, and the Hungarian Electric Board. ENPEP is an integrated planning package used for evaluating energy needs and corresponding resource requirements and environmental impacts of a country. ENPEP begins with a macroeconomic analysis; develops an energy demand forecast based on this analysis, carries out an integrated supply/demand analysis for the entire energy system, evaluates the electric system components of the energy system in detail, and determines the impacts of alternative configurations. Also, it explicitly considers the impacts the power system has on the rest of the energy system and on the economy as a whole. The program has been applied in numerous developing countries with a scope of applications including an electric expansion plan and a greenhouse gas mitigation option [ENPEP].

The Long Range Energy Alternative Planning (LEAP) is a scenario-based energy-environment modeling tool. Its scenarios are based on comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, price and so on. Range of application includes energy policy analysis, environmental policy analysis, biomass and land use assessment, pre investment project analysis, integrated energy planning, and full fuel cycle analysis [LEAP2000].

Modular Energy System Analysis and Planning Software (MESAP) is a tool for integrated energy and environmental planning. It was developed at the Institute for Energy Economics and the Rational Use of Energy (IER), University of Stuttgart. It offers tools for investment calculation, energy and environmental accounting, demand analysis, integrated resource planning, demand-side management, electricity operation and expansion planning as well as life cycle and fuel chain analysis. The MESAP system consists of three layers of modules: the database tools, the models and the external information systems. Backbone to the database is the database management system called MESAP DBMS. The planning tools include: PlaNet for demand analysis and supply simulation, INCA for investment calculation and financial analysis, TIMES for energy system optimization (LP) and PROFAKO for electricity and district heat operation and expansion planning. At the external information system level, MESAP includes ENIS (the ENergy Information System), a link to geographical information systems, and a link to the IKARUS technology database [Schlen00].

Energy Toolbox (ETB) is a comprehensive set of integrated planning tools for carrying out an energy assessment in a region or a country. Energy Toolbox comprises a number of different analysis systems arranged in a hierarchical fashion in 3 levels. Level A is devoted to the creation of a Reference Energy System (RES). Level B contains 2 modules. The energy supply planning system module automatically turns the RES into a LP problem and solves it to find the least cost set of energy flow and investments. The Module Disaggregated Demand Analysis System (DDAS) allows the projection of energy demand disaggregated in any fashion to the user's requirement. Level C consists of tailor-made models for specific studies [ETB].

2.1.5. Integrated models

These tools consist of an integrated set of equations that are simultaneously solved. These models usually cover energy-economy-environmental interactions. Included in this category are IMAGE 2.0, AIM, ASF and RAINS.

The IMAGE 2.0 model is a multi-disciplinary, intergraded model designed to simulate the dynamics of the global society-biosphere-climate system. The objectives of the model are to investigate linkages and feedbacks in the system, and to evaluate consequences of climate policies. The model consists of three fully linked sub-systems: Energy-Industry, Terrestrial-Environment, and Atmosphere-Ocean. The Energy-Industry sub-model computes the emissions of greenhouse gases in 13 world regions as a function of energy consumption and industrial production [IMAGE2]. End-use energy consumption is computed from various economic/demographic driving forces. The Terrestrial-Environment sub-model simulates the changes in global land cover on a grid-scale based on climatic and economic factors, and the flux of CO_2 and other greenhouse gases from the biosphere to the atmosphere. The Atmosphere-Ocean sub-model computes the build-up of greenhouse gases in the atmosphere and the resulting zonal-average temperature and precipitation patterns. The fully linked model has been tested against data from 1970 to 1990, and after calibration the following observed trends can be reproduced: (i) Regional energy consumption and energy-related emissions, (ii) Terrestrial flux of CO_2 and emissions of greenhouse gases, (iii) Concentrations of greenhouse gases in the atmosphere, and (iv) Transformation of land cover.

The Asian-Pacific Integrated Model (AIM) is a computer simulation model developed by the National Institute for Environmental Studies in collaboration with Professor Matsuoka, Kyoto University and several research institutes in the Asian-Pacific region. The AIM assesses policy options for stabilizing the global climate, particularly in the Asian-Pacific region, with the objectives of reducing greenhouse gas emissions and avoiding the impacts of climate change. The AIM comprises three main models: the GHG emission model (AIM/emission), the global climate change model (AIM/climate) and the climate change impact model (AIM/impact). The AIM/emission model estimates greenhouse gas emissions and assesses policy options to reduce them. The AIM/climate model forecasts concentrations of greenhouse gases in the atmosphere and estimates the increase of global mean temperature. The AIM/impact model estimates climate change impacts on the natural environment and socio-economy of the Asian-Pacific region [AIM].

The Atmospheric Stabilization Framework model (ASF) is an engineering-economic integration of various regional models to provide emission estimates for 9 regions of the world. The current version of ASF includes energy, agriculture, deforestation, GHG emission and atmospheric models. The ASF energy model estimates the energy consumption for four end-use sectors (residential, commercial, industrial, and transportation sectors). The agricultural ASF model provides a production estimate of major agricultural products that are driven by population and GDP growth. This model is linked with the ASF deforestation model, which estimates the area of land deforested annually as a function of population growth and demand for agricultural products. The ASF GHG emission model uses outputs of the energy, agriculture, and deforestation models to estimate the GHG emission in each ASF region [ASF].

The Regional Air Pollution INformation and Simulation model (RAINS) has been developed by IIASA[5] as a tool for the integrated assessment of alternative strategies to reduce acid deposition in Europe and Asia. The RAINS model uses data, stored in dBase format, regarding energy scenarios, emission control technologies and abatement costs, atmospheric

[5] International Institute for Applied System Analysis

transport and critical loads. RAINS allows the user to examine the costs and effectiveness of the different emission control strategies under various energy-use scenarios [RAINS].

2.1.6. Energy supply models

Energy supply models are often concerned with the finding of the least cost options of the energy supply system meeting a given demand and subject to a number of constraints. These models generally use a simulation or optimization method, where the latter is usually based on linear and non-linear programming. Some of the energy supply models are extended to include parts of the energy demand analysis. Others provide additional features to calculate the impacts of the planned energy system including emissions, economic and social aspects. Representative models under this category are: MARKAL, EFOM, MESSAGE, POLES, WASP.

Energy Flow Optimization Model (EFOM) is an energy supply linear optimization model originally developed in 1970 at IEJE in Grenoble, France using GAMS[6]. The model aims to elaborate the strategies making west Europe more independent on oil imports and to determine technologies to reach the goal. EFOM is driven by exogenous energy demand assumptions and assumed resources, environmental, and policy constraints. The model contains an energy-environmental database describing the energy system being studied. Technologies are explicitly represented by parameters for economic, social, and environmental conditions and linkages among energy systems. The linear programming optimizes the energy system according to an objective function defined by the model user. To account for environmental problems, EFOM was extended into EFOM-ENV in 1985 by the Institute of Industrial Production, University of Karlsruhe [Rosta02].

Prospect Outlook on Long-term Energy Systems model (POLES) is a simulation model providing long-term energy supply and demand scenarios on the basis of hierarchical systems of interconnected sub-models at international and regional levels. On the basis of energy consumption scenarios, future GHG emissions can be analyzed in order to identify strategic areas of action and to define appropriate technological change as well as R&D strategies. Furthermore, the impacts of the emission reduction strategies on the international energy markets can be assessed. A detailed description of the oil, coal and gas market at a world level allows a significant increase in the size and complexity of the model.

The Model for Energy Supply Systems Analysis and their General Environmental Impact (MESSAGE) developed by the International Institute for Applied Systems Analysis (IIASA) is a dynamic linear programming model, calculating cost-minimal supply structures under the constraints of resource availability, the menu of given technologies, and the demand for useful energy. The model estimates detailed energy systems structures, including energy demand, supply and emissions patterns that are consistent with the evolution of primary and final energy consumption specified by a defined scenario. The model is typically used in long-term scientific investigations, but also in analyses for specific planning issues. MESSAGE exists in many versions, including one that has endogenous non-linear learning curves and one that accounts for uncertainties. All versions can be classified as bottom-up technology-oriented models, requiring the provision of energy-related demands as input [MESSAGE] [Carpros].

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[6] a high level language for the compact representation and the solutions of large and complex problem (see www.gams.com)

The Wien automatic System Planning (WASP*)* is the most frequently used model for the analysis of electric capacity expansion. The model was originally developed in the USA by the Tennessee valley authority and Oak Ridge National Laboratory for the International Atomic Agency (IEA). The primary objective of WASP is to determine the generating system expansion plan that adequately meets demand for electric power at a minimum cost while respecting constraint input by the user. WASP uses probabilistic simulation to estimate generating system production cost and dynamic programming to determine the optimal expansion pathway [WASP].

2.2. The MARKAL Model

2.2.1. Structure of MARKAL

a. General features

MARKAL is a large scale model used for long term analysis of energy systems for a province, state, country or region. The model was developed by a consortium of members of the International Energy Agency (IEA) in the early 1980's based on the General Algebraic Modeling System (GAMS) - a computer language specifically designed to facilitate the development of algebraic models. The Brookhaven National Laboratory (BNL), New York, USA and Kernforschungsanlage Jülich (KFA), Jülich, Germany are the host for the program [Fishb83]. The model's acronym stands for MARKet ALlocation, indicating the intention of its developers to build an instrument for the analysis of the market potentials of energy technology and fuels. Many modifications were later brought to MARKAL and cumulated in the present variants of the model. Major events were the introduction of the *MARKAL User Support System* (MUSS), MARKAL-MACRO and recently the Windows based ANSWER.

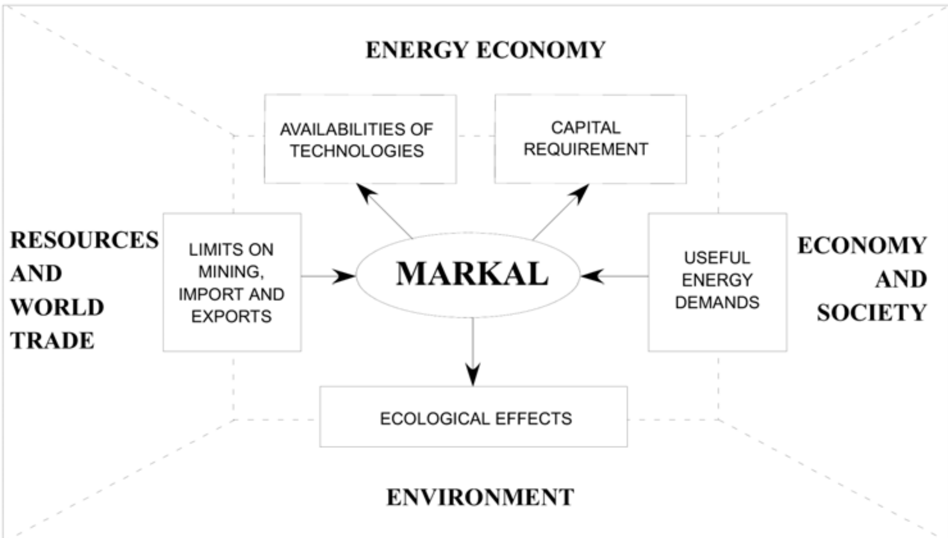

Figure 2.2: Interfaces of the model

The backbone to MARKAL is the *Reference Energy System* (RES) which is typically a flowchart showing all possible routes from each source of primary energy through various transformation steps to each end-use demand sector. RES has the great advantage of giving a graphic idea of the nature of the energy system. Another important characteristic of the MARKAL is that it is driven by a set of demand for energy services, i.e., feasible solutions are obtained only if all specified end-use demands for energy are satisfied for every time period. End-use demands are specified exogenously by the users. Once a reference energy system has been specified, and its component technologies have been fully described, MARKAL generates a set of equations and inequations which hold the system together. In addition, MARKAL possesses a clearly defined objective, for which usually the long-term discounted cost of the energy system is chosen. The objective is optimized by running the model, which means that configuration of the RES is dynamically adjusted by the models in such a way that all equations are satisfied and the long-term system cost is minimized. With this optimizing feature, MARKAL ensures that a partial economic equilibrium of the energy system at each time period is computed, i.e. a set of quantities and prices of all energy forms and materials, such that supply equals demand at each time period [Loulou97]. The energy system as visualized by MARKAL is shown in figure 2.2.

b. Reference energy system (RES)

An energy system may be thought of as a network of four kinds of elements: the energy resources, the technologies, the flows of energy forms, and the set of demand segment. Each energy supply technology defines a linear relation between its input and its output. Similarly, end-use technologies define linear relations between the energy input and the respective end-use demand. There is a fixed and variable cost associated with each technology. The first one is the cost of capacity creation and the second one is that of capacity utilization. As these costs are also linearly related to the capacity and flow respectively, the problem can be formulated as a linear program to determine the minimum cost flow to meet the given end-use demand. The energy flows and end-use demands for a particular period are independent of the other periods. Nevertheless, there are two factors that link the technologies across periods. First, technology capacities created in one period may extend into other periods. Second, cumulative phenomena like resource depletion and CO_2 emission in any time period are determined by the sum of technology activities in all previous periods.

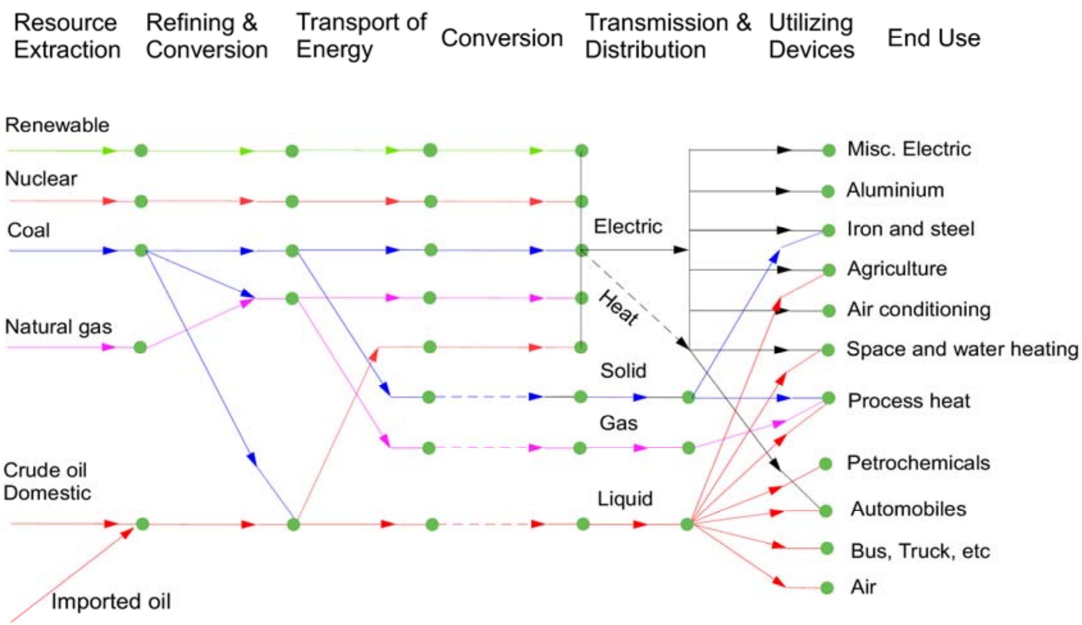

Figure 2.3: A simplified reference energy system (adapted from [SeeGold01])

The main advantage of the RES concept is that it provides a graphical support for thinking about a techno-economic model such as MARKAL, and thus is a convenient short-cut for the detailed mathematical equations which constitute the model. End-use technologies and end-use demands are required. It thus offers the opportunity of fuel substitution for a more efficient energy system. MARKAL is a good choice for the evaluation of new technologies, for example, renewable energy.

c. The mathematical structure

The MARKAL model consists of a set of equations and inequations (the *constraints)*, and one *objective function* (usually taken as the total discounted cost of the energy system). Constraints and objective functions are mathematically expressed in terms of two types of quantities, namely the decision variables and the parameter. The decision variables are unknown quantities which the model has to determine, whereas the parameters are known quantities which are specified by the users. The variables and parameters are selected in order to enable the model to state precisely all important constraints of the system. In the MARKAL model, there are five sets of variables as given below:

INV(k,t): The investment in technology k, at period t

CAP(k,t): The capacity of technology k, at period t

ACT(k,t): The activity of technology k, at period t

IMP(i,t): The amount of energy import, of form i, at period t

EXP(i,t): The amount of energy export, of form i, at period t

Below are the constraints of MARKAL summarized in simplified forms from the detailed mathematical formulations given in the MARKAL user's manual (variables are in upper case italics, and parameters are in lower case italics) [Loulou97].

Flow conservation. For each energy flow, the consumption must not exceed the availability through the inequality according to:

$$\sum_k out_{k,f} * ACT(k,t) + \sum_s IMP(f,t) - \sum_k inp_{k,f} * ACT(k,t) - \sum_d EXP(f,t) \geq 0 \quad (2.1)$$

where k represents energy technology in the model; f represents any form of energy; $out_{k,f}$ *is* amount of energy form f produced by one unit of activity of technology k; $inp_{k,f}$ *is* amount of energy form f consumed by one unit of activity of technology k.

Electricity peak reserve constraints. Installed capacity of electricity producing technologies must meet the peak season demand multiplied by a reserve factor. Each power plant's capacity may participate in the fulfillment of this constraint to some degree, from 0 to 100%, depending upon the fraction of time the plant is up and running at peak hours. Similarly, the peak season demand is established by summing up all demands which are classified as non-interruptible.

Demand satisfaction. Demand for each energy service d must be met at each period through the condition:

$$\sum_k CAP(k,t) \geq dem_{d,t} \tag{2.2}$$

where $dem_{d,t}$ is the demand for energy service *d* at period *t*, and the summation is done over all technologies *k* which produce energy service *d*. Demand in the above expression is the gross demand that includes losses in the transmission, distribution and utilization, incorporated through different parameters in the model.

Capacity transfer. In each technology *k*, total capacity at any period results from the initial capacity plus previous investments which are still operative:

$$CAP(k,t) \leq resid_{k,t} + \sum_p INV(k,p) \tag{2.3}$$

where $resid_{k,t}$ is the residual capacity of technology *k* at period t, *p* must be in the range such that *t-p* does not exceed the life of technology *k*.

Capacity utilization. In each technology *k,* its activity must not exceed its installed capacity at any time period t:

$$ACT(k,t) - util_k * CAP(k,t) \leq 0 \tag{2.4}$$

where $util_k$ is the annual utilization factor of technology *k*. The electricity generation technologies may have single annual utilization factors or seasonal factors at the sum of which should be less than the unity.

Source capacity. Use of any energy carrier/form of energy *f* through technology *k*, must not exceed the annual availability of its capacity at any time period *t*:

$$\sum_k inp_{k,f} *ACT(k,t) \leq \sum_i srcap_{f,t,i} \tag{2.5}$$

where $srcap_{f,t,i}$ is the annual availability of energy form f from source *i* at period *t.*

Growth constraint. Capacity of each technology can not grow by more than a certain percentage per period:

$$CAP(k,t+1) - (1 + growth_k) * CAP(k,t) \leq 0 \tag{2.6}$$

where $growth_k$ is the maximum allowable growth factor (less than 1) for technology *k.*

Emission constraint. These constraints specify the upper limit on the emission of certain pollutants by the system as a whole. The limits may be imposed in one or two ways: separately at each period, or cumulatively over the whole horizon. To make these constraints active, emission coefficients must have to be defined for all polluting technologies.

Other constraints. The user may include many other constraints built explicitly by the modeler. Belonging to such constraints are inequalities showing that the market share of a certain technology or group of technologies can not exceed a certain fraction. All such special constraint are easily programmed in MARKAL by means of special data tables called ADRATIO tables.

Objective function. This is the main expression that is optimized by the MARKAL model. Usually it is taken to be the long term total discounted system cost (TDSC) which is the combination of five types of cash flows:

$$TDSC = Technology\ cost + Import\ cost - Export\ revenue - Salvage\ value + Emission\ fees \quad (2.7)$$

where

Technology cost is the discounted sum of all technological investments and O & M costs. It is expressed in terms of three types of technology variable: INV, CAP, and ACT.

Import cost is the discounted cost of imports of energy forms. It involves the IMP variables.

Export revenue is the discounted sum of export revenue. It involves the EXP variables.

Salvage value is accounted for the residual monetary value of all investments remaining at the end of the planning horizon, and discounted to the beginning of the first period. This is an important refinement which avoids to a large extent the distortions that would otherwise plague the model's decision towards the end of the horizon. Without this corrective term, the model would tend to avoid new investments toward the later periods, since such investments would be productive over short duration only.

Emission fees (or pollutant taxes) are paid if the model user specifies a cost per ton of pollutant emission, within the ENV table. It may involve any MARKAL variable (technology variables, imports, exports). The specification of emission fees is an alternative to using emission constraints.

The set of variables and constraints constituting the model of the energy system is defined in the form of a coefficient matrix as shown in figure 2.4.

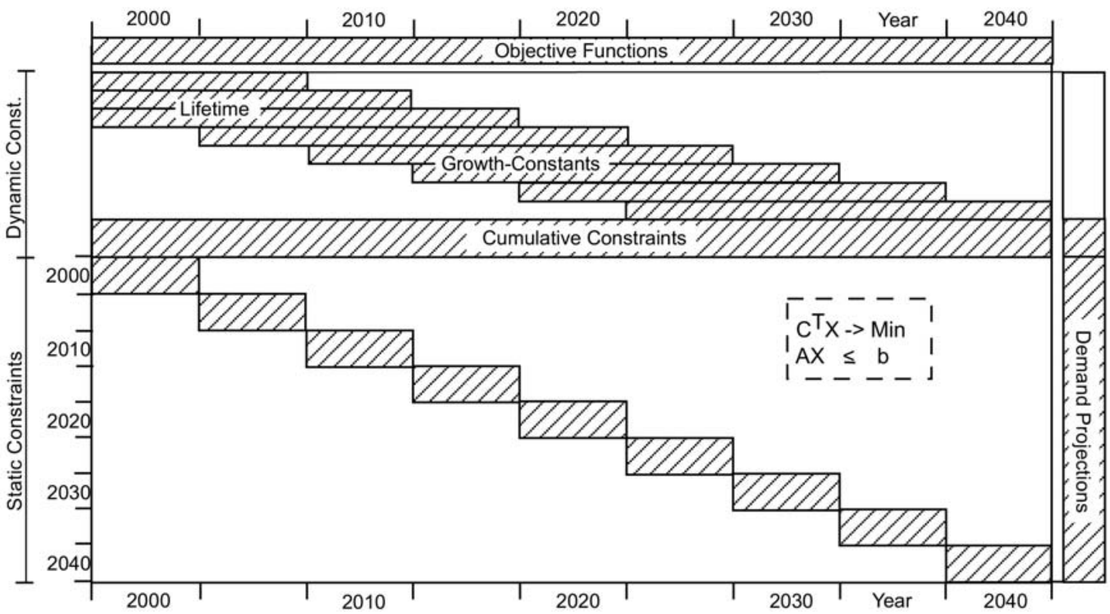

Figure 2.4: Structure of the multi-period matrix

The X-axis shows the time horizon of the study with a specific time period, whereas the Y-axis shows two types of constraints, the static one which is 'time independent' (in the lower part) and the dynamic one which is 'time dependent' (in the upper part). Bars traveling horizontally in the upper part represent dynamic constraints relevant to different time durations. They may cross boundaries of single time periods, start from any point of time and end at any time within the time span of the study. The lowermost bar in this part represents cumulative constraints (such as upper limits on cumulative consumption of coal), which are relevant over an entire period of study and are to be satisfied in each time period. Small boxes in the lower part represent static constraints confined to a certain time period of the study (such as bounds on capacity in a certain time period) which may have different values for each time period and each value in turn relevant to the certain time period only. The length of these boxes, therefore, does not exceed the length of the single time periods. The entire figure represents the main matrix and each box individually represents a sub-matrix with non-zero coefficients. Complexity of the matrix depends on the types of energy carriers, conversion technologies, emissions and their linkages in the reference energy system [Fishb83] [Mathur01].

2.2.2. Input and output of MARKAL

a. Input

To operate, MARKAL requires extensive data inputs which can be classified as the following components:

The global component comprises data parameters that describe some aspect of the global energy system such as the discount rate.

The energy carrier component encompasses all energy forms in the energy system.

The end-use demand component comprises demands for end-use energy services in the economy.

The demand technology component refers to technologies that consume energy carriers to meet end-use energy demands.

The conversion technology component indicates all load-dependant plants that generate electricity or district heat or both.

The process technology component indicates all load-independent processes that convert one energy carrier to another, excluding electricity and/or heat.

The resource technology component refers to the means by which energy enters or leaves the energy system, other than end-use consumptions.

The constraint component comprises user-defined constraints that are additional to the standard constraints of the MARKAL model.

The emission component encompasses environmental impacts of the energy system.

Each group of data input in turn requires a set of defined information as represented in table 2.1 [ABARE02].

Table 2.1: Standard data needed for each group of data input of MARKAL

Group	Basic information needed
Technologies	- Investment cost - Fixed and variable operating costs - Fuel costs - Technical characteristic, such as conversion efficiency, energy efficiency of demand devices, and capacity and availability factors - Productive life of technologies
Energy carriers	- Resource costs such as export, import and extraction costs - Annual or cumulative limits on availability - Period of resource availability
End-use Demand	Specified in terms of : - Energy requirement or - Useful energy demand (e.g. demand for cooking) or - Service needed (e.g. amount of goods to be transported)
Other constraints	Additional constraints using ADRATIO
Emissions	Emission factors according to source of a fuel (e.g. CO_2 emission from coal import) or The technology used (for example CO_2 emission from road transport technologies)

On the other hand, the user has to choose proper units for costs, energy flows, final demands, activity levels, and capacities. The standard units normally used are presented in table 2.2.

Table 2.2: Standard units for MARKAL

Items	Description	Abbreviation
Cost	e.g., constant 1995 US dollar	e.g., 1995$USm
Energy carriers	Petajoules	PJ
End-use Demand (except transport)	Petajoules	PJ
Passenger Transport End-use demand	billion-passenger-kilometres	bn-pass-km
Freight Transport End-use demand	billion-tonne-kilometres	bn-t-km
Emissions	million tonnes contained carbon	mt C
Technology activity (except transport)	Petajoules	PJ
Passenger Transport Demand activity	billion-passenger-kilometres	bn-pass-km
Freight Transport End-use activity	billion-tonne-kilometres	bn-t-km
Conversion Technology capacity	Gigawatts	GW
Process Technology capacity	petajoules/annum	PJa
Demand Technology capacity	petajoules/annum	PJa
Passenger Transport Demand Technology capacity	billion-passenger-kilometres/annum	bn-pass-km/a
Freight Transport Demand Technology capacity	billion-tonne-kilometres/annum	bn-t-km/a

b. MARKAL output

A typical MARKAL solution consists of the following results [Loulou97] [ABARE02]:

(i) A set of investments in all technologies selected by the model at each time period. This set indicates the level of new investments expressed in terms of plant capacity of each technology in each period.

(ii) A set of operating levels of all technologies at each period. MARKAL suggests the optimum utilization level of each technology in each period. This is expressed in terms of percentage utilization of installed power generation capacity.

(iii) Quantities of each fuel produced, imported, and/or exported at each time period. Based on the information on plant capacity and utilization factors, MARKAL gives the total quantity of each energy carrier/fuel required or consumed in the energy system in each period.

(iv) Emissions of pollutants at each period. If sufficient information about different emissions is provided in terms of emission coefficients for each technology, this table will provide values of total emission due to the utilization of different technologies.

(v) Implicit prices of all energy forms (their shadow prices).

(vi) Implicit prices of all energy services (their shadow prices).

(vii) Overall system's discounted total cost. It is the minimum value of operation of the reference energy system under the defined energy demand level for each period of the study. It is the value of the objective function of the model.

2.2.3. Interface of MARKAL

a. MARKAL User Support System (MUSS)

MUSS was developed in the late 1980s when MARKAL was ported to personal computers. It is a relational database management system designed specifically to facilitate the use of the MARKAL model. MUSS oversees all aspects of working with MARKAL. It manages all the input data required by MARKAL, organizes data sets into scenarios to foster sensitivity analysis, integrates seamlessly with the modeling system, and manages the results from model runs. Despite this, the utility offered by MUSS are still limited. It is desirable to derive a more user friendly interface.

b. ANSWER

The window interface of MARKAL called ANSWER was introduced in 1998 by the Australian Bureau for Agricultural and Resource Economics (ABARE). With this window based system, MARKAL is more readily accessible and usable to the energy policy and system analyst. ANSWER provides a number of enhancements over MUSS for the analysis and presentation of input assumptions and results [APEC99b]. These enhancements include:

- Data editing capabilities via 'direct cell editing', similar to a spreadsheet.
- Utilities for scenario management or model data, and for case management of model runs and results.
- Screening/filtering options.
- Inputs or results may be simultaneously examined side-by-side.
- Powerful graphics and report writing capabilities via a link to EXCEL and paste capabilities into WORD for Windows.

2.2.4. Renewable energies in MARKAL

MARKAL does not handle assessments of renewable energy differently from non-renewable energy. The plausible solutions for renewable energy technologies thus depend on the constraints added by users to control the availability and utilization of each renewable energy technology included in the model. The model however provides several parameters that could be applied to specify the existence of renewable energy technologies [APEC99b] [DDNN96] [Fishb83], for example:

❖ Table PEAK, which was originally designed to specify a fraction of the total capacity of a technology available to the supply peak demand for electricity or heat, could be used to specify the availability of renewable energy technologies to supply total demand. An example is that by using this tool it could be specified that a wind generator has an availability of only 20% of its total capacity to supply peak electric demand for electricity.

❖ The parameter "Seasonal Capacity Utilization Factor", which is the average use of installed capacity expressed as a fraction of time in use, can be used to capture seasonal availability of renewable resources. For example, solar energy technologies (such as solar photovoltaic) can be included in the model by separating capacity utilization into utilization on a winter day, summer and intermediate day, or in greater detail of day and night for each season.

❖ The parameter "Annual Availability Factor", which is used to specify total annual availability of a process or conversion technologies, can be used to determine the annual availability of biomass technologies.

❖ The parameter "BOUND" which is designed to put a constraint (lower, fixed, or upper bounds) on capacity, annual production of technology, or investment in new capacity for conventional technologies, can be applied the same to renewable technologies. Examples of this application could be, for example, to specify the maximum capacity of wind, hydro, or geothermal resources used in central electric generation.

❖ The cost parameters, including O&M costs (variable and fixed), investment cost, and delivery cost can be used to compare competitiveness among technologies.

❖ The parameter "LIFE" can be used to show the number of periods of a technology's productive life.

❖ New parameters that are added in the new versions of MARKAL, for example parameter SRAF (Z) for simulation of the seasonal reservoir availability of hydro.

❖ User-defined constraints can be built to represent renewable energy policies. For example, the case where there is a policy that 10% of all electricity generations must come from "green" technologies or the electricity generation from solar plus wind must be less than 20% of the system generation output.

❖ MARKAL distinguishes between decentralized technologies and centralized technologies. For the latter, both transmission cost (from point of generation to point of distribution) and distribution cost (from point of distribution to point of end user) are included. The former are charged a distribution but not a transmission. In addition, there are no transmission losses associated with electricity from decentralized technologies.

Renewable energy technologies in MARKAL could be specified as demand technologies, conversion technologies, or process technologies. Some examples are given in table 2.3.

Table 2.3: Some examples of renewable energy technologies

Categories	Technology examples
Conversion technologies	Solar PV, wind turbine, geothermal power plant, hydro power plant, biomass gasification
Demand technologies	Solar water heater, biomass boilers, wood stoves
Process technologies	Biogas digester, municipal waste landfill gas

2.3. Review of similar studies

CHINA has conducted an assessment study on future energy-technology strategies for China at the Tsinghua University in co-operation with the Princeton University. The study aimed to explore prospects for China to continue social and economic developments while ensuring national energy-supply security and promoting environmental sustainability over the next 50 years. MARKAL model was used to build a model of China's energy system representing all sectors of the economy, including both energy conversion and end-use technologies. Different scenarios for the evolution of the energy system from 1995 to 2050 were explored, enabling insights to different energy development plans [China01].

NIGERIA has been using MARKAL to examine the future prospects of renewable energies in Nigeria for the period 1990-2030. The study found that the contribution of renewable energy sources could increase to 47%, 45% and 38% from 18% in 1990 corresponding to three scenarios: high, medium and low respectively. The study also pointed out barriers to the development and recommended policy to overcome these barriers [Akin01].

ESTONIA performed the project "Possible energy sector trends in Estonia" in the context of global climate change and the target for greenhouse gas emission mitigation. MARKAL and MARKAL-MACRO were used to design development scenarios for the energy system and to analyze various greenhouse gas mitigation options. Renewable energies are specially treated as an option for greenhouse gas emission mitigation [Tallin99].

INDONESIA carried out the project "environmental impacts of energy strategies for Indonesia", as a part of a scientific cooperation between Indonesia and Germany. The goal of the project was to develop proposals for environmentally compatible energy supply strategies for the next 30 years, based on air quality forecasts and risk assessments for ecosystems and human health. Optimization of the future energy supply was done with the help of MARKAL. Various renewable energy technologies were described [APEC99].

LATVIA had a study focusing on enhancing the utilization of renewable energy sources in the country to meet the energy demand. The available modern technologies and the possibility to introduce them into practice had been analyzed using the MARKAL model. The study concluded that by 2020 energy from renewable sources would contribute to about 25-30% of the total energy supply [Schip99].

INDIA strongly pushes researches and applications of renewable energies. Costs and taxes targeted toward the penetration of renewable energy technologies in the energy supply system of India have been proposed [Kanu96]. A new energy model was developed which determines the possible contribution of renewable energies based on the available sources and the renewable energy end-use requirement. It has been revealed that the renewable energy requirement is expected to be around $8.12*10^{15}$kJ during 2020-2021 while the commercial energy requirement is expected to be around $23.73*10^{15}$kJ [India00].

Asia-Pacific Economic Cooperation (APEC) has initiated the project entitled "Including new and renewable energy technologies in economy level energy models" in an effort to reduce the GHG emission. The study aims to increase the utilization of new renewable energy technologies in selected economies by refining their economy level energy models to better characterize the potential of new and renewable energy technologies [APEC99b].

EUROPE (EU) has been the host for many renewable energy studies. The most recent study was an attempt to predict the likely impacts from major investments in renewable energy technology (RET) on the growth of the economy and the levels of employment in the EU during 1995 and 2020. The study tried to link the bottom-up technology based effects with the macro economic effects to reach the objective. The bottom-up model determines the penetration level of renewable energy technologies in the future energy mix while the macro model assesses the impact of this mix to the employment and economic development [ECOTEC].

2.4. Review of related studies conducted for Vietnam

A number of energy studies have been conducted in Vietnam at both national and local levels.

- The Institute of Energy has carried out a project called "Master plan for power development stage V" for the period 2000-2020. In this project the WASP III model was used to examine the least-cost expansion plan for a number of demand and fuel price scenarios. In addition, a separate spreadsheet model was used to allocate investment between regions because WASP can only treat the country as a single system. The study proposed the construction of the largest hydropower plant in Indochina with a capacity of 2400 MW in the time period 2013-2016. A nuclear power plant has also been proposed to be in operation by 2018, however there are still many controversial discussions. Concerning renewable energy technologies, only hydro and geothermal power plants were considered [IE00a].

- The Hydro Meteorological Service of Vietnam with technical supports from the RIS∅ National Laboratory conducted the project "The economics of GHG limitation". The goal of the study was to examine the GHG emission level and analyze the mitigation options for Vietnam. The EFOM-ENV model was used to optimize the primary energy requirements and the related investments in energy production and consumption under different abatement scenarios. As renewable energy related scenarios, development of wind power plants and increase of biomass stove efficiency were considered in the study [HSV99].

- The Hanoi University of Technology was host of the study 09-09 focusing on rural energy up to 2020. The study used the LEAP as the analytic tool. The contribution of renewable energy sources, mainly as decentralized systems, was analyzed. The study pointed out barriers to the development of renewable energies. Lack of suitable studies, for example on renewable energy resources and tentative policies, are perceived as main obstacles [HUT99].

- The Institute of Energy made a similar study on rural energy. The study focused on identifying isolated non-electrified communes that could be supplied by renewable energy technologies. Rough renewable energy resource assessment has been made as a base for the study [IE00b].

- The COWI[7] classified communes into 6 categories and for each category a different electrification strategy was applied. The viability of renewable energies as decentralized technologies was examined using the local planning models HYBRID and HOMER [EVN99].

- The Asian Institute of Technology (AIT) in collaboration with the Hanoi University of Technology (HUT) carried out a study of the long term energy demand forecast of Vietnam. The MEDEE-S model was used to make the energy forecast. Three energy demand scenarios corresponding to three macro economic scenarios were examined [Lefe94].

- A study on the necessity of nuclear energy in Vietnam was carried out by the Institute of Energy in collaboration with other relevant agencies. After estimating the energy demand up to 2020 and considering possibility of the available resource supply, the study pointed out the necessity of nuclear energy. The module DDAS of the Energy toolbox modular package was used to make the energy demand forecast and the WASP model was used to determine the optimal supply pathway [IE99].

2.5. Adopted methodology

Based on the issues discussed in chapter 1 and the review of literature above, it is clear that a study on energy demand and supply which considers equally all available resources especially renewable energy sources is needed. With the salient features as described above, in this research, the MARKAL model with ANSWER interface is chosen to be adapted to the Vietnam energy economy system. For this purpose, the following sections will focus on the specifications of various parameters for the establishment of the MARKAL Vietnam.

[7] a danish company acted as a main foreign partner in this project

Chapter III

RENEWABLE RESOURCE ASSESSMENT

Renewable energies encompass a broad range of energy resources. Vietnam is known to have a good potential for renewable energies but so far no systematic study has been done to quantify this potential. Based on data from different studies, this section attempts to estimate the technical potential of renewable energies in Vietnam from a point of view of different promising available technologies. The obtained results will help specify the input for the optimization of the program MARKAL as well as for future related studies.

3.1 Selection of renewable energy forms and related exploited technologies

Whereas conventional energy sources are fixed in stock, renewable energy sources are not limited, but usually are not in ready-to-use forms. To convert renewable energies into usable forms, energy-converting systems are needed. The potential of renewable energies is, therefore, dependent on the technical ability of this conversion. There are several technologies that can be used to harvest renewable energies but not all of them appear promising. Based on the specific situations, the availability of renewable energy resources, technology level and financial conditions in Vietnam, the present study focuses on renewable energy resources for which commercial technologies are in hand (Table 3.1).

Table 3.1: Selected renewable energy technologies

Resource	**Technology**	**Output**		
		Electricity	Heat	Fuel
Wind	Grid connected wind turbine	√		
	Stand alone wind turbine	√		
Solar	Building integrated solar PV	√		
	Solar home system	√		
	Solar collector		√	
Biomass	Direct combustion	√	√	
	Gasification	√		
Biogas	Anaerobic digestion			√
Geothermal	Binary cycle	√		
Hydro	Large hydro	√		
	Small-hydro	√		

3.2 Introduction to selected renewable energies and the related technologies

3.2.1 Wind energy

The energy from continuously blowing wind can be captured by using wind turbines that convert kinetic energy from wind into an usable form (mechanical energy) and then into electric power. Electricity generated by wind turbines can feed to the central network (as in the case of large grid connected wind turbines) or locally consumed (as in the case of stand alone wind turbines).

Large grid connected wind turbines have capacities ranging from 600 kW to 2 MW. They are often placed in wind parks with a total capacity of 10 to 100 MW. Suitable sites for wind parks should satisfy several geographical and technical conditions such as high annual wind speed, low turbulence and easy access to the power distribution. Wind turbines of this range are the most demanded in the market, increasing at 29% per year between 1992 and 2002. In 2002, the world total installed capacity reached 32 GW [BP03]. Technologies for these kinds of turbines are becoming mature and their costs have been dropping significantly (52% between 1982 and 1997 [Neij99]).

Stand alone wind turbines have capacities less than 25 kW, among those, turbines of 25 - 150 W are most commercially successful. Equipped with a battery, these turbines can ensure a continuous electric supply to rural families. With no requirement for fuel and little maintenance, wind home systems can be good energy technologies for isolated areas.

In the case of Vietnam, both categories are selected. The specific types with technical and economic parameters are explained in detail in section 3.3.2 and annex II respectively.

3.2.2 Solar energy

The energy from sunlight falling on the earth is of a huge potential that can be exploited and usually used for two main purposes: producing heat and generating electricity. Among several available technologies, solar water collectors (producing heat) and solar photovoltaics (PVs, generating electricity) are most promising. Solar water collectors are known as simple, cheap technologies, whereas PV technologies are more sophisticated. Still, unit costs of PVs have sunk at several orders of magnitude while the efficiency is continuously being improved [May02] [WiTe93] [Green04] [EnerTech]. PVs become more and more popular owing their high modularity, no requirement for additional resources (like water, fuel, etc.), no moving parts and low maintenance requirement.

In this study, these two applications are investigated on the basis of representative technologies. The flat plate solar water collectors are chosen for the heat production systems. For the PV systems, two technologies, the building integrated grid-connecting PVs and the distributed solar home PVs, which are distinguished by their relative location of installation to the general electrical grid are selected.

Flat plat solar water collector - This is an insulated, weatherproofed box containing a dark absorber plate under one or more transparent or translucent covers. Water or conducting fluid passes through pipe systems located below the absorber plate. Thus, the sunlight's heat is transferred to water or conducting fluid in the pipes via the absorber plate [RET01a]. The system is known for simple technology and easy operation. It produces no noise and has quite competitive costs, especially when there is favorable sunlight.

Building integrated grid connected PV - Principally, this consists of a PV module converting sunlight into electricity and an inverter connecting PV power with the grid. The systems are usually integrated directly into structural elements of buildings (roof, facade), therefore they would have the following advantages [RET01b]:

+ Reduce both energy and capacity in the utility distribution network
+ Avoid or delay upgrades to the transmission and distribution network where the average daily output of the PV systems corresponds with the utility's peak demand

period (afternoon peak demand during summer as a result of loads from air conditioning).

+ Cost competitive since the cost for the replaced building material is counted.

Building integrated solar PVs are preferred as far as PV installations are concerned. In Germany, the 100,000 roof program was proposed to the government in 1999 and so far 55,000 roofs have been approved. In Japan 70,000 roofs have been installed with PVs. The government of Japan is aiming to install a capacity of 4.6 GW of PVs by 2010 [Green04].

Solar home systems (SHS) - The systems consist of a 10 to 50 Watt peak (Wp[8]) PV module, a rechargeable lead-acid battery, and sometimes a charge controller. With appropriate sunlight regime, the systems have proven themselves to be competitive for remote areas. SHS are thus pursued in many developing countries [KuLew03] [PainUsh04]. In Vietnam, as of 1999, about 1,000 SHSs were installed [EVN99].

3.2.3 Biomass

This category covers all energy materials derived from plant origin, including wood wastes and agricultural residues. Usually biomass is used for two purposes, to produce heat, and to generate electricity. Two widespread technologies are direct combustion and gasification.

Direct combustion - This is one of the main processes used to convert biomass into useful energy. In developing countries, heat and/or steam produced during this process are used to provide heat for domestic cooking, space heating, industrial processes or can be used to generate electricity (activities are listed in the order of most common use). Electricity generating technology based on this process is the Rankine cycle which currently costs about 2000 USD/kW and offers an efficiency of some 20% [DOE97].

Gasification for power production - This technology involves devolatilization and conversion of biomass at atmosphere of steam or air to produce a medium or low calorific gas. The gained “biogas” is then used as fuel in combined cycle power generation plants, i.e. working systems of a gas turbine topping cycle and a steam turbine bottoming cycle. Being produced in a combined cycle technology, electricity from this technology has higher efficiency and is more competitive than that from a steam turbine. The current unit investment cost of the biomass gasification/gas turbine technology is estimated at 1,800-2,000 USD/kW [DOE97].

3.2.4 Biogas

Biogas is a mixture of CH_4 (~ 65%) and CO_2 (~ 35%) produced from animal dung, human excrement and other biomass wastes in specialized biodigestors. This gas is combustible and thus can replace other fuels like wood, agricultural residues, ‘dung-cakes’ and kerosene for use in simple gas stoves and lamps. In addition, the slurry material produced from biodigestors can be used as fertilizer in fields. Biodigestors, therefore, play a significant role in rural areas, especially in integrated farming systems [GTZ-ISAT]. In Vietnam, application of biogas energy has been investigated by several research institutions and different types of biodigestors have been introduced to the market. By the end of 2000, about 15,000 biodigestors with a capacity of 0.13 PJ/year have been installed in the country [IE00b].

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[8] capacity measured at standard laboratory condition: solar irradiance 1000W/m^2, temperature 25^{0}C, air mass 1.5.

3.2.5 Hydro energy

Kinetic energy from flowing or falling water is exploited in hydropower plants to generate electricity. Hydro plants are divided into two categories, mainly to account for their ability to match electric loads. Large hydro plants (capacity > 10 MW) usually with reservoir can not only produce electrical energy continuously but also are able to adjust their output accordingly to electricity loads. Small hydropower plants (capacity < 10 MW) are less flexible to the load fluctuation due to their dependence on the water resource. In Vietnam these are further grouped into smaller ranges to represent their differences in cost and operation characteristic (see section 3.3.6).

Currently, hydropower technologies are mature and widely available. Almost 19% of the electrical energy in the world comes from hydroelectric facilities operating in over 80 countries [HydroW]. Hydropower is the most widely accepted technology for electricity generation in Vietnam. In 1998, the total installed capacity of the existing hydropower plants reached 2,826 MW, representing 50.5% of the total installed capacity.

3.2.6 Geothermal energy

This energy form originates from radioactive decay in the depths of the earth and comes out as hot water, steam, or hot dry rocks. The heat energy from geothermal systems can be trapped for producing electricity in three major technologies: dry steam, flash steam, and binary conversion. Binary cycle systems appear suitable for the conditions in Vietnam [Hoang] because they allow power to be generated from liquid at a lower temperature.

In 2000, geothermal resources have been identified in over 80 countries, 58 of which have quantified records. The world-wide use of geothermal energy amounts to 49 TWh electricity per year (7974 MW) [Frid01], representing 1.6% of total renewable energy production. In the future, advances in drilling and extracting methods, together with improvement in conversion technologies can help expand the current share of geothermal energy in the market.

3.3 Assessment of renewable energy resources in Vietnam

The use of energies requires a good understanding of the resources. In the case of renewable energies, parameters characterizing their resources differ greatly. These are wind speed (for wind energy), solar irradiation (for solar energy), area, cultivation and productivity of forests (for biomass), animal type, number and specific gas yield (for biogas), flow rate and hydraulic head (for hydropower), temperature and volume (for geothermal energy). They in turn vary differently in the course of the day or year, depending on the climate and the environment, for example wind and solar change with seasons, days and places; water resource changes with seasons etc. In addition, the respective exploitation technologies are subjected to different constraints (regulation on sites and operating characteristics). For each form of renewable energy, a respective proper methodology for determination of its potential should be required.

3.3.1 Definition of potentials

Renewable potentials are classified into different categories. The most common ones are theoretical potential, available potential, technical potential and economic potential (Figure 3.1) [Voiv98].

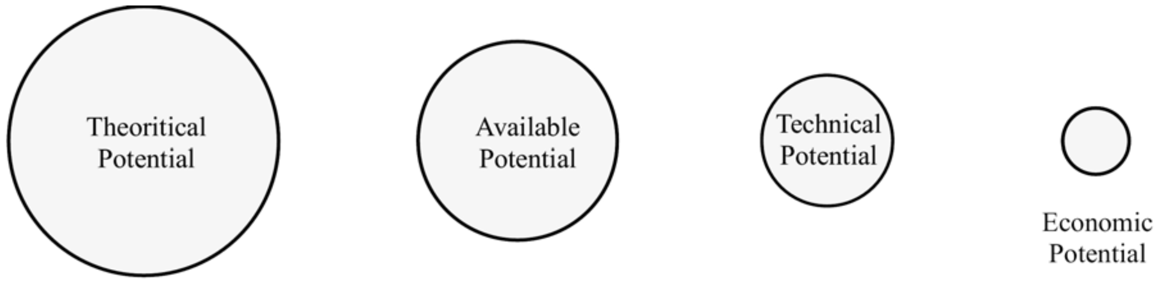


Figure 3.1: Classification of potential

The theoretical potential refers to the total amount of energy available for extraction in a defined region without consideration of availability or technological restrictions. For several energy forms such as solar, wind, wave, the theoretical potential is therefore very huge.

The available potential is defined as the part of the theoretical potential that can be harvested easily without causing impacts on the environment.

The technical potential refers to the amount of energy that can be harvested using existing technologies and thus depends on the time point of assessment.

The economical potential refers to the amount of potential that is economically viable by currently given technologies. Infrastructure or technical constraints (i.e. roads, grid network) and economic aspects (i.e. energy production costs, expected profits) decide the limits for the economical potential. Economic potential therefore depends upon the costs of alternative/competing energy sources.

3.3.2 Wind resource assessment

3.3.2.1. Assessment of the technical potential for grid connected wind turbines

The evaluation of wind potential is conducted by a sequence of steps which represent restrictions on the exploitation of the potential. To begin, the theoretical potential is estimated. This is possible by using a reference wind turbine and available wind speed data. The technical potential is then assessed by introducing restrictions grouped as social constraints and technical constraints.

Social constraints help eliminate areas not suitable for the exploration of wind energy such as:

- High altitude areas, due to access difficulties
- Political areas (high populated cities), for safety reasons and minimize visual impact
- Water areas, due to arising costs
- Protected areas (forests, national parks), due to legal constraints
- Living areas, due to noise and visual impact

Technical constraints define “basic” conditions for the operation of wind turbines such as the arrangement of wind turbines, the minimum level of wind resource.

To satisfy all the above conditions it is ideal to use a Geographical Information System (GIS) for the assessment. GIS has been used widely to assess wind resource on a national scale [Voiv98] [Aret02] [BaPar00] and even on a global scale [ECMWF]. For the Vietnam case, wind resource assessment will be made on the basis of the following data (Table 3.2).

Table 3.2: Sources of GIS data for wind resource assessment

Data type	Data source	Data format
Average wind speed at 65 m	[TW01]	Spatial Indrisi grid
Water areas	[DCW]	.e00 format
Administration boundaries	[DCW]	.e00 format
Population	[GOS00]	Table
Land cover	[DIVA]	Grid file
Elevation	[DIVA]	Grid file

The approach is shown in figure 3.2. First themes of land cover, elevation, water areas are displayed and unsuitable areas such as cities, high altitude areas, and protected areas are removed accordingly. The resulted map is then combined with a wind speed grid theme to create a new map which inherits attributes of both themes. Each feature in the new map then holds not only wind speed value but also attributes of the other themes. Based on a reference wind turbine and a standard wind farm arrangement, the technical potential of wind energy can then be estimated.

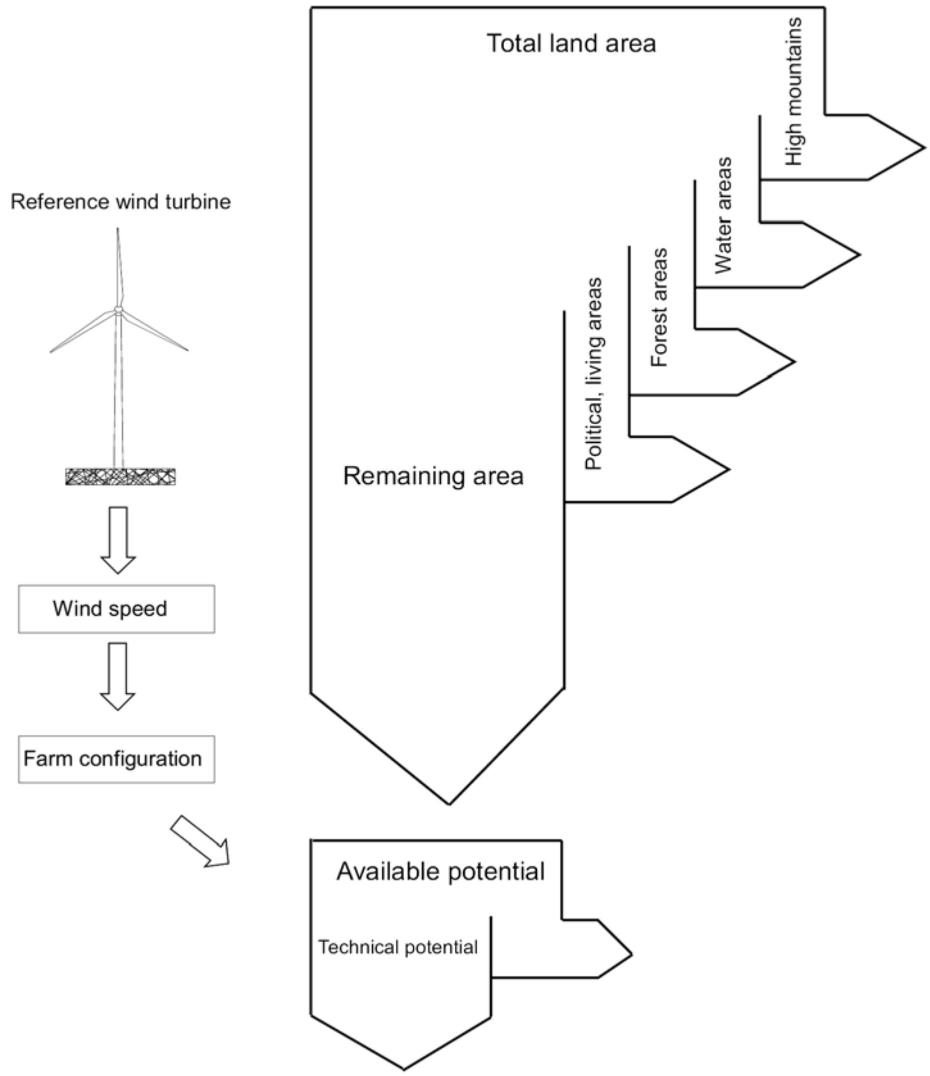


Figure 3.2: Methodology for technical potential investigation

Selection of a reference wind turbine - To determine the technical potential of wind energy it is necessary to have a reference wind turbine so that a theoretical power output corresponding to each wind speed value can be calculated. This reference wind turbine should suit the local conditions, including the local possibility of manufacturing accessories. For example, tower of heavy weight but low value content should not be imported to reduce transportation cost. Furthermore, road conditions, the availability of suitable mobile cranes or trucks are the other important factors that should be paid attention to as well [SYN01].

If all the above requirements are considered, a wind turbine of 600 kW from Enercon (E-40) is the best suitable type. As can be observed from its power curve (fig. 3.3), E-40 starts operation at a cut-in wind speed of 3 m/s and reaches its rated capacity at 13 m/s. Beyond 13 m/s rated power output is kept constant as a result of the pitch control. Cut-out wind speeds are those higher than 25 m/s. Other specifications of the turbine E-40 are provided in table 3.3 [BWE00].

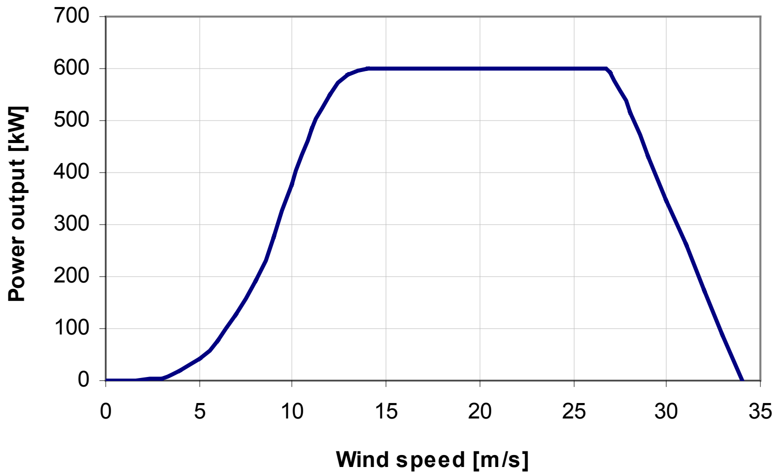


Figure 3.3: Power curve of E-40 – 600 kW wind turbine

Table 3.3: Detailed specifications of E-40

Indicator	Value
Rotor diameter	44 m
Swept area	1521 m^2
Rated power	600 kW
Power regulation	Pitch
Starting wind speed	3 m/s
Rated wind speed	12 m/s
Cut out wind speed	28-34 m/s
Endurance wind speed	60 m/s
Generator	Synchronous
Number of blades	3 of Epoxyharz
Tower height	65 m

Energy output calculation - With the reference wind turbine, this section introduces a method to estimate the energy production from a given average wind speed.

It is well known that wind speed varies continuously with time and is very sensitive to topography. Power from wind, in turn, varies with the cube of the wind speed. For the determination of energy output it is, therefore, of importance to know in addition to average wind speed the wind speed distribution. So far, the Weibull function is most widely used to represent the distribution of wind [CavaHo93]. This function expresses the possibility *f(v)* to have a wind speed *v* during a year according to

$$f(v) = \left(\frac{k}{A}\right) * \left(\frac{v}{A}\right) * \exp\left(\frac{-v}{A}\right)^{k} \tag{3.1}$$

where k is the shape factor which typically ranges from 1 to 3. For a given average wind speed *v* (≥ 0), the higher the shape factor is, the narrower the distribution of wind speed around the average value (Figure 3.4). Because wind power varies with the cube of wind speed, a lower shape factor normally leads to higher energy production at a given average wind speed. A gives the scale of the curve, it is >0 and often estimated as

$$A = \frac{v_m}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{3.2}$$

where v_m is the average wind speed; Γ is the gamma function.

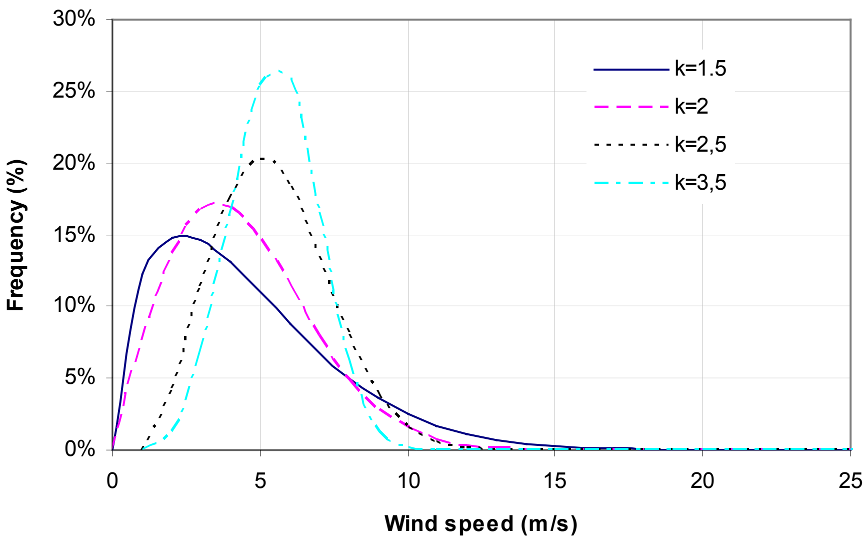


Figure 3.4: Wind speed frequency distributions based on the Weibull curve for a mean wind speed of 5 m/s and various *k* values.

When k = 2 it is called the Reyleigh function. Fortunately, it has been concluded from experience that k = 2 represents well enough the real wind speed distribution. It is then possible to derive the wind speed distribution if only yearly average wind speed is known. The scale parameter is then calculated by

$$A = \frac{2}{\sqrt{\pi}} v_m \tag{3.3}$$

where v_m is the average wind speed.

The distribution function then becomes

$$f(v) = \frac{\pi v}{2(V_m)^2} * \exp\left(\frac{-\pi}{4}\right)\left(\frac{v}{V_m}\right)^2 \tag{3.4}$$

With the distribution function and the power curve, the yearly energy production can be calculated by integrating the power output at every bin width:

$$YEY(v_m) = \sum_{v=1}^{v=25} f(v) * P(v) * 8760 \tag{3.5}$$

where v_m is the average wind speed; *P(v)* is the turbine power at wind speed *v*; *f(v)* is the Weibull probability density function for wind speed *v*, calculated for average wind speed v_m.

By applying this method, energy output for each location has been calculated and presented in figure 3.5 in the form of hours with full power.

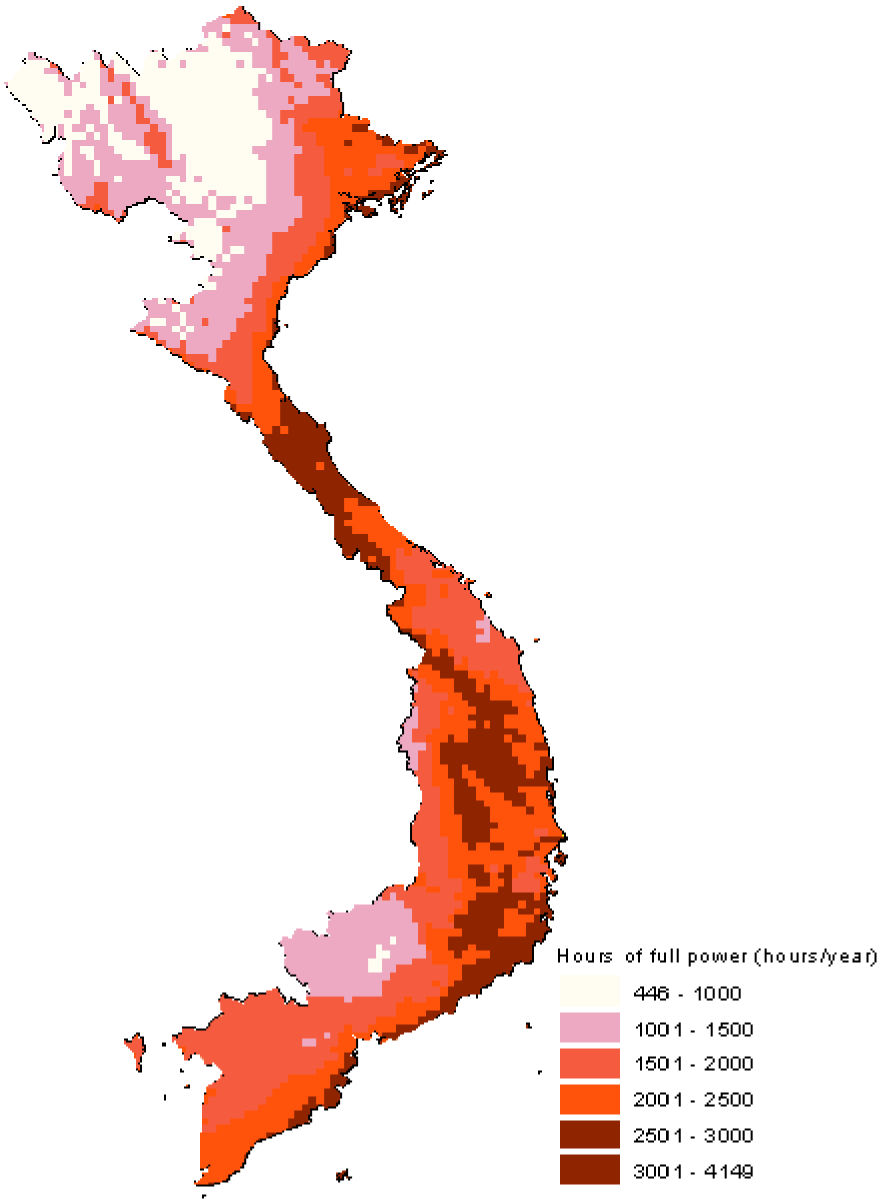


Figure 3.5: Theoretical potential of wind energy in Vietnam

Determining areas unsuitable for wind development - The theoretical wind potential given above however, has some limitations in the exploitation. The most significant of which as already indicated are land use, geographical topography and political reasons. Several categories of unsuitable areas for development of wind energy in Vietnam and their territory sizes are listed in table 3.4.

Table 3.4: Unsuitable areas for wind development

Criteria	Examples	Disadvantages	Area (km^2)
Very high altitude areas	Mountain areas	High cost of transportation and erection	63578.6
Water areas	Swamp areas, lakes, river etc.		2829.5
Protected areas	Natural, artificial, protective forests, national parks, conservation areas.		87994.4
Political areas	Administrative areas, big cities with high populations.		3681.5

In addition, other disadvantages of wind energy are noise and shadow flicker disturbance to the surrounding areas. To avoid these, living areas should be first identified. However, such information in Vietnam is not readily available; hence, in the present study, the population density is used instead. In particular, population density was classified into different categories and the possible proportion of land use for development of wind energy was determined accordingly (Figure 4.6) [Aret02]. Because of this restriction, the suitable area for wind development will reduce from 136 thousand km^2 to 42 thousand km^2 (Table 3.5).

Table 3.5: Suitable areas for wind development

Criteria	Area (km^2)
Suitable areas	42,370

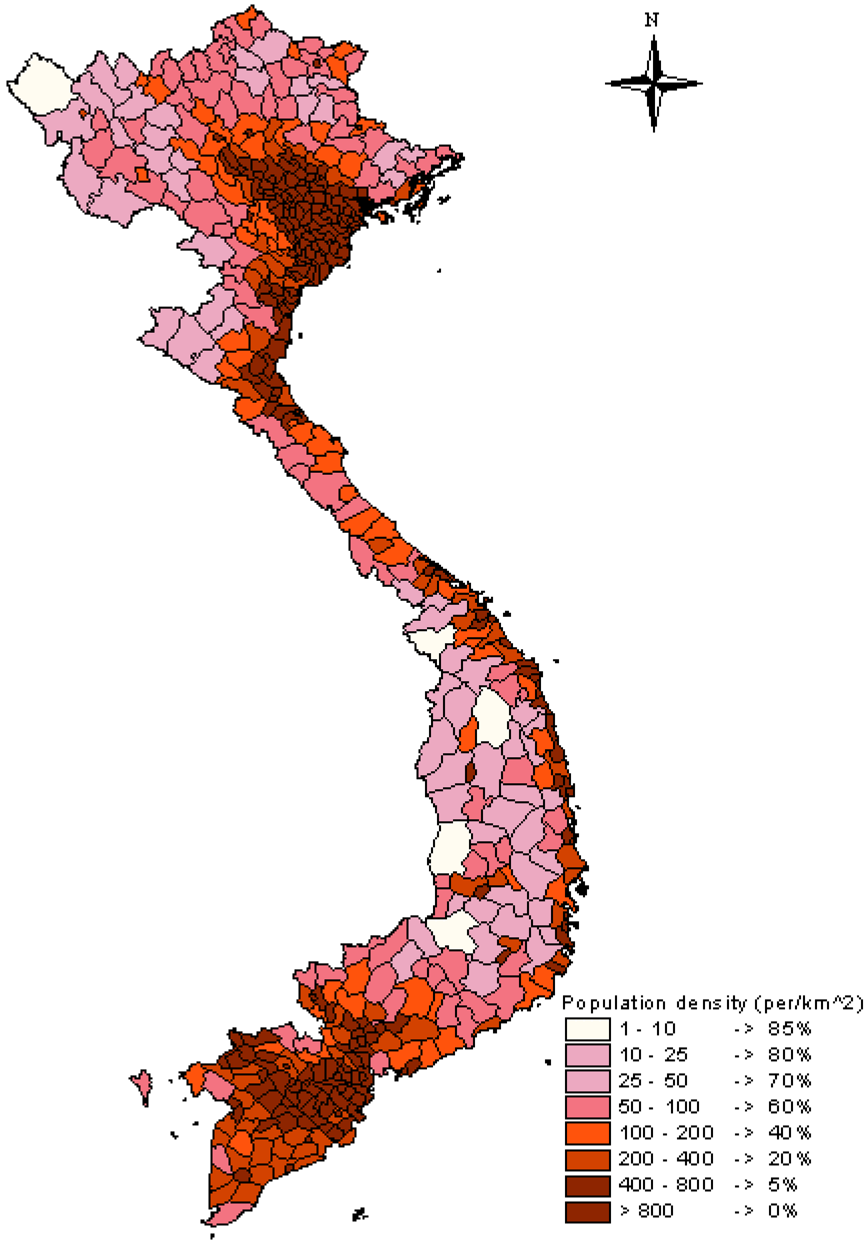


Figure 3.6: Population density and the possible proportion of land use for wind development in Vietnam in 1995

Land requirement - Once the potential of land use for wind energy has been determined, the next question is how many wind turbines could be erected. It has been noted that an operating wind turbine reduces wind speed for some distance downstream of the rotor. If turbines are located too closely, they will interfere with each other, and consequently output of those locating downwind will be reduced. The actual output from clustered turbines in comparison to the theoretical output without consideration of turbine-turbine interference is expressed as array efficiency which depends on spacing between turbines and the nature of wind regime [Nguyen01].

Extensive theoretical and wind-tunnel studies indicate that under typical conditions, interference increases quite rapidly when turbines are at distances less than 10 rotor diameters (10D). For an infinite number of wind turbines with 10D spacing, the limiting array efficiency is about 60% [GruMe93]. But for a finite number of turbines, the average loss is much lower, and a closer distribution is practical. Rule of thumb puts the distance at 5 to 9 rotor diameters in the main wind direction and at 3-5 rotor diameters in the direction perpendicular to that [DWIA].

Table 3.6: Typical array efficiencies for different sizes and spacing of square arrays

Array size	Turbine spacing					
	4D	**5D**	**6D**	**7D**	**8D**	**9D**
2 X 2	81	87	91	93	95	96
4 X 4	65	76	82	87	90	92
6 X 6	57	70	78	83	87	90
8 X 8	52	66	75	81	85	88
10 X 10	49	63	73	79	84	87

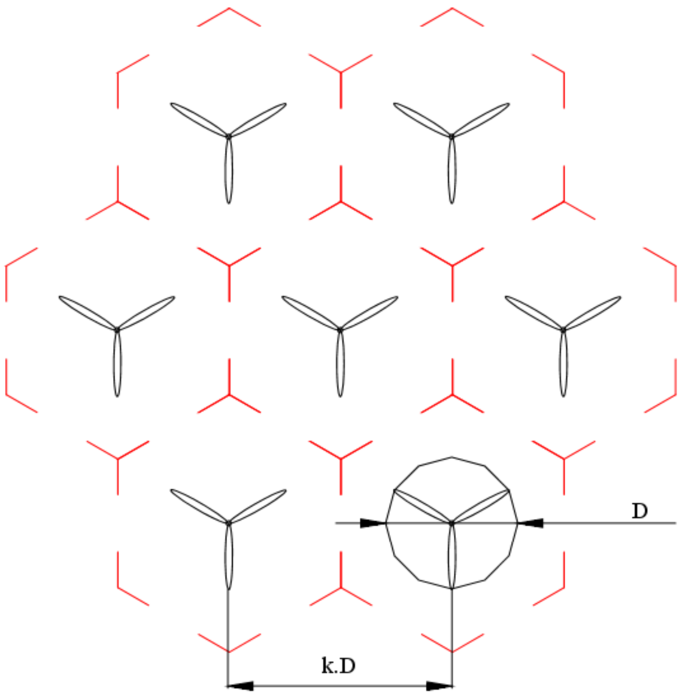


Figure 3.7: Assumed arrangement of wind turbines in the wind farm

For simplicity, the present study takes 10D as the standard distance between two wind turbines. Thus, the area requirement for each wind turbine will be 0.152 km^2 and as the result, wind turbine density will be 3950 kW/km^2.

Results – Assuming that 1000 hours of full power is the feasible threshold for the exploitation of wind energy, then the areas that satisfy this condition in Vietnam would be enough for the installation of 160.73 GW of wind power, meaning 267,000 wind turbines of E-40 series. These wind turbines can theoretically generate 328 TWh of electricity annually.

3.3.2.2. Estimation of the potential of small wind turbines

Small wind turbines appear competitive only in areas far from the grid due to their relative high initial investment cost. The estimation of the potential of stand alone wind turbines is, therefore, practically the search for non-electrified households which situate in good wind regions.

For this purpose, wind resource at 10 m height (common height for small wind turbines) need to be identified. Here the estimation is based on the already known wind speed of 30 m and 65 m [TW01] according to

$$\frac{u(z_1)}{u(z_2)} = \frac{\ln(z_1/z_0)}{\ln(z_2/z_0)} \tag{3.6}$$

where $u(z_1)$ is wind speed at height z_1; $u(z_2)$ is wind speed at height z_2; z_0 is roughness length.

The value z_0 is first calculated by using the known wind speeds of 30 m and 65 m high. The obtained z_0 values are then applied back to formula (3.6) to calculate the wind resource at 10m (Fig 3.8).

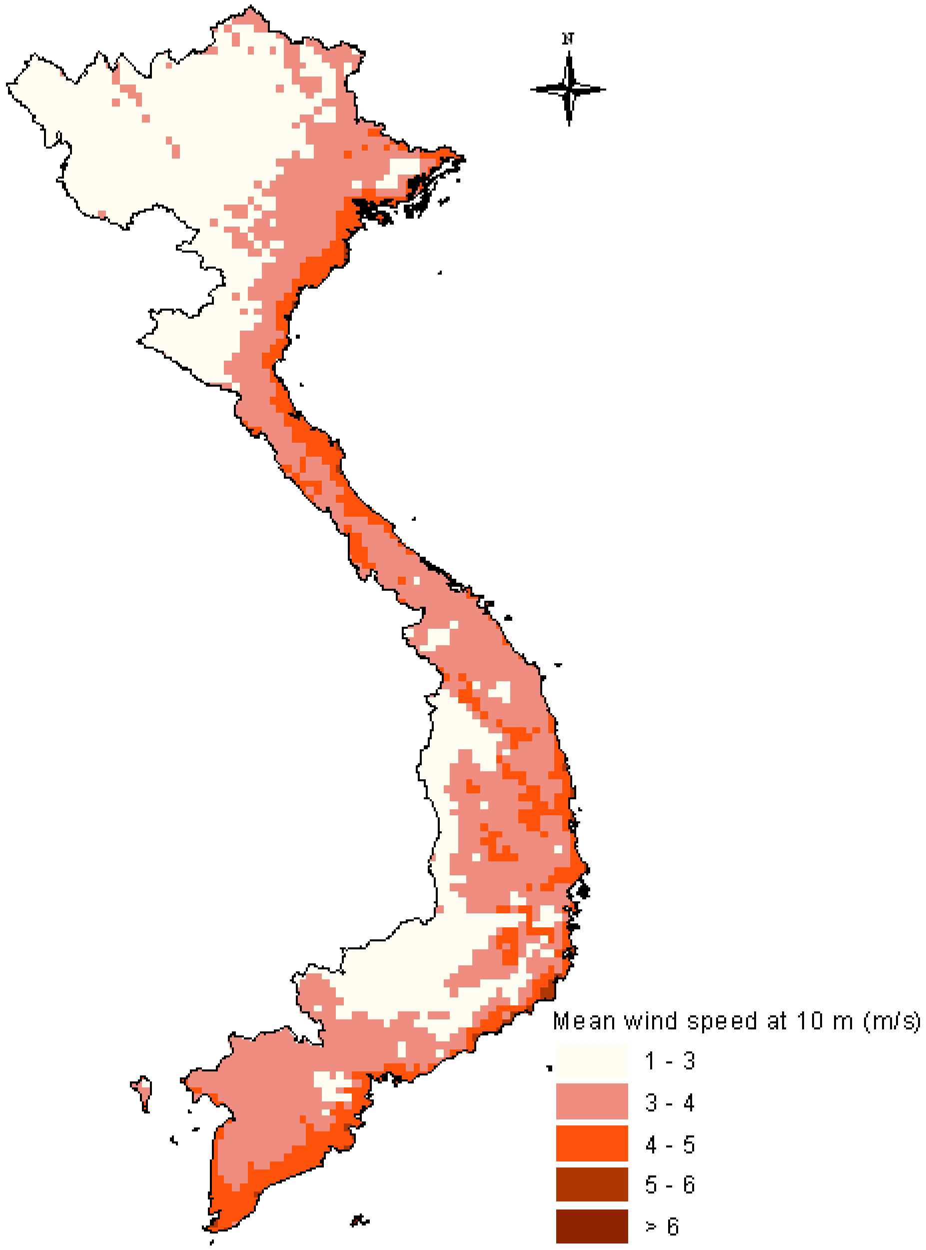


Figure 3.8: Wind resource at 10 m above ground level in Vietnam

Matching good wind resources with non-electrified households is, however, not simple because: (i) good wind resource areas might be included in the electrification plan and (ii) these areas might sometimes be better served by other available renewable resources such as hydro and solar. In this context, an overview on the economics of available decentralized technologies for different regions in Vietnam and comparative analysis of suitable technologies for a defined region are given in annex II.

Nevertheless, a rough estimation of potential has to be carried out. In this case, it is based on the portion of non-electrified households that are able to pay for the wind home systems (WHS). Of course, these households must be located in good wind regions.

According to a report by EVN [EVN99], in 1998 Vietnam had about 6 million of non-electrified households. Assuming that 50% of households in rural areas without electricity today would be electrified within ten years, and only 10% of the remaining households could afford and would be willing to pay for a WHS; a potential market of about 300,000 units would be realistic. Assuming a household would be equipped with a 150 W wind turbine which is the common and locally manufactured size in Vietnam (see also annex II for detailed technical and economic parameters of this kind of turbine), the respective capacity would amount to 45 MW.

3.3.2.3. Estimation of the economic potential of large grid-connected wind turbines

Methodology - Considering the overall objective of the study, an estimation of the economic potential of wind energy seems to be unnecessary since similar analyses are performed by the MARKAL program. However, for future studies on wind energy, such estimation is still needed. This is calculated based on not only price information of all stages leading to erection of wind turbines, but also on the lifetime of wind turbines, their maintenance and operation cost, as well as purchasing price offered by the local government. The costs and benefits of a wind turbine throughout its lifetime are then analyzed and assessed through the Net Present Value (NPV) as in the formula

$$NPV = TB_{pw} - TC_{pw} \tag{3.7}$$

where *pw* is a subscript that indicates the present worth of each factor; *TB* is the total benefit brought about by the wind farm during its service lifetime; *TC* is the total cost arisen during the construction and operation of the wind farm.

Wind farms that have $NPV \geq 0$ are considered economically viable and therefore classified as economic potential.

The formula for converting an amount of money (F) in a given future year (n) at a given discount rate (i) to present value is given by:

$$P_{pw} = \sum_{t=1}^{n} \frac{F_t}{(1+i)^t} \tag{3.8}$$

Cost components - Except some wind turbines of small capacities, Vietnam presently has no wind farm in operation. In this study, a wind farm of 6 MW is therefore proposed as a standard wind farm. Costs associated to this wind farm are presented in table 3.7 [ASTAE01]. For validation, the total cost is then compared with actual values from other developing countries such as India and China [Aret02] [Tang01].

Table 3.7: Cost items for a standard 6 MW wind farm

Cost components	Value
Installed capacity	6 MW
Specific capital cost	900 USD/kW
O & M cost	23.7 USD/kW
Lifetime	20 year

Benefit components - Similar to the cost component section, this section assumes the buying price. This is made with reference to the other developing countries where commercial wind farms have been introduced (Table 3.8) [Aret02] [Tang01].

Table 3.8: Benefits items and other parameters for a typical wind farm

Benefit components	Value
Buying price of electricity	0.045 USD/kWh
Wind farm efficiency	94 %
Wind farm availability	98 %
Discount rate	10 %

Table 3.9 presents the results of economic analysis of wind energy in Vietnam. The economic boundary in the study means the net present value of zero at the indicated interest rate and the purchasing price of 0.045 USD/kWh. More than this, the project implies a higher level of benefit. Different interest rates are used to deal with uncertainty.

Table 3.9: Economic potential of wind energy in Vietnam

Interest rate	Economic boundary (h/yr)	Useable area (km^2)	Installed capacity (GW)	Energy production (TWh/yr)	Average hours of full power (h/yr)	Total investment cost (Mill. USD)
8 %	2765	2665	10.517	30.70	2921	9465.3
9 %	2973	816	3.220	10.09	3132	2898.0
10 %	3188	199	0.788	2.67	3389	709.2
11 %	3408	77	0.310	1.08	3539	279.0
12 %	3634	0	0	0	0	0

3.3.2.4. Prospect for wind energy

Along with the increasing exploitation of wind energy, the cost of wind turbines has fallen significantly; by 52% between 1982 and 1997 [Neij99]. The Danish Energy Agency predicts that a further cost reduction of 50% can be achieved by 2020 [AkerSö02]. Therefore, with the environmental penalty and the increasing fuel cost applied to conventional technologies, wind turbines are becoming more and more attractive.

3.3.3 Solar resource assessme

3.3.3.1. Methodology

Estimation of the technical potential of solar energy in Vietnam is done by using solar data from NASA and vector maps provided by the GIS program (Table 3.10). First of all, theoretical potential of solar energy is estimated, based purely on the available data on solar irradiation and land area. This potential is then converted into technical potential by introducing the following limitations:

- Social constraints dealing mainly with the identification of suitable locations for application of solar installation (exclusive restriction).

- Technical constraints dealing with the characterization of exploitation technologies and the organizational conditions that have to be satisfied in the implementation of renewable energy projects.

Table 3.10: Data sources for solar potential evaluation

Data type	Data source	Data format
Monthly average daily solar irradiation	[NASA]	Text format
Administration boundaries	[DCW]	.e00 format
Land cover	[DIVA]	Grid file

3.3.3.2. Calculation of the technical potential

Theoretical potential - The annual average daily global irradiation on the horizontal surface (Figure 3.9) and the data on land area indicate that theoretically, Vietnam receives approximately $5.2x10^{14}$ kWh of solar energy every year, i.e. more than 2,000 times higher than the current energy consumption in the country. However, in the course of exploitation, some limitations such as land use, geographical area and climate are encountered. In addition, several technologies of solar energy which are constrained by different factors exist. To have exact information, it is, therefore, necessary to examine the potential of solar energy from the viewpoint of a specific application.

Selection of solar energy technologies - Different solar energy technologies are available in the world market. As introduced in section 3.2.2, the three technologies that seem to be the most suitable for Vietnam, namely building integrated PV, solar home system and solar water collector are focused on.

Identification of suitable locations for solar energy conversion systems - Unlike other energy technologies, solar energy technologies cause neither noise, nor pollution; hence they are often installed near consumers to reduce construction costs. Thus, identification of suitable locations for application of solar energy is practically the search for suitable rooftops.

Identifying potential market for integrated solar PV and solar collectors - Suitable locations for grid-connecting PV and solar collectors are rooftops of domestic residences and commercial buildings. Because of the lack of data on roof areas and types of buildings in Vietnam, the percentage of roof areas suitable for the application of solar energy is simply estimated to be 0.5% for towns and 1% for cities [Soren01]. Assuming that solar PVs and solar water collectors are distributed equally, the potential market for these systems would be calculated. The obtained results are presented in table 3.11. Capacity of integrated PV is then derived by dividing the total areas by the areas corresponding to 1 kW_p of PV. Thus, the technical potential of integrated solar PV has been found to be about 1,799 MW. In the case of solar collectors, potential in terms of energy rather than capacity is estimated. Assuming that the overall efficiency is 50% [Naha02], the total potential is estimated at 42.2 PJ per year.

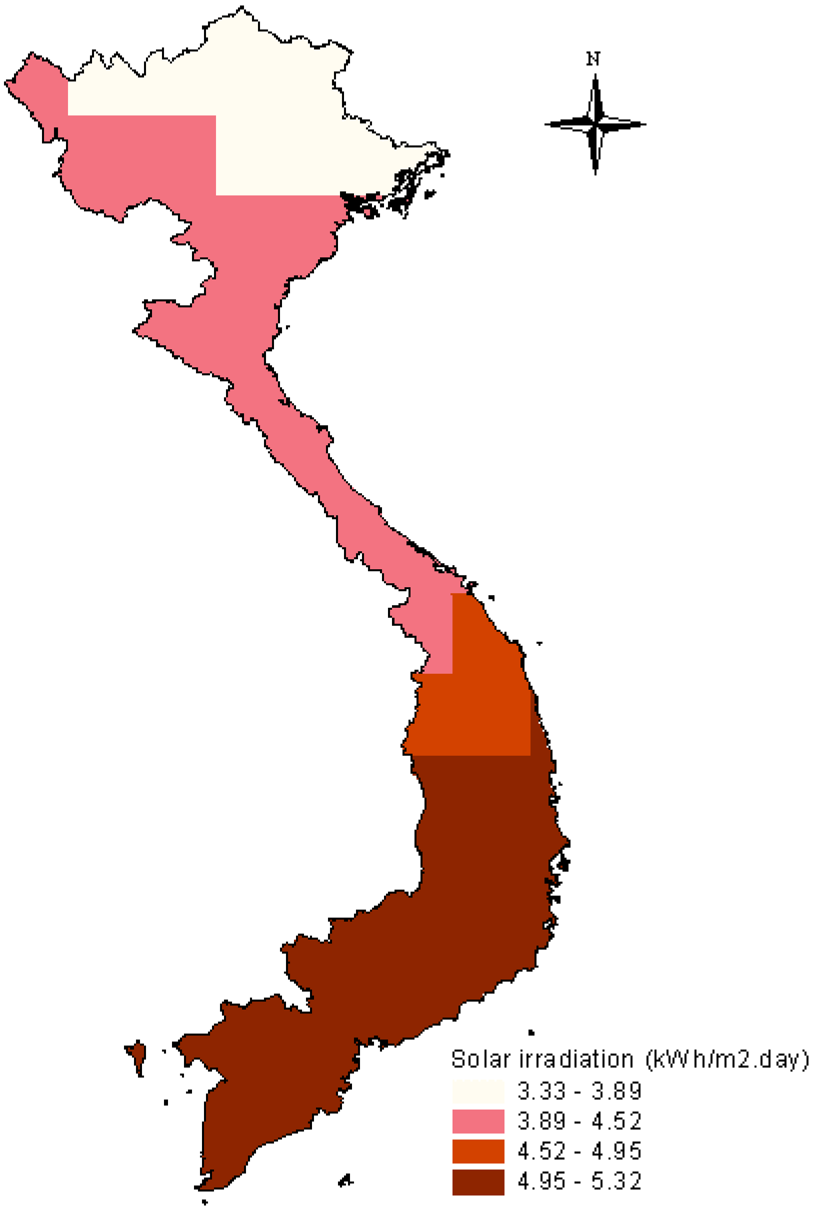


Figure 3.9: Annual average daily global irradiation on a horizontal surface.

Table 3.11: Technical potential for integrated solar PV and solar water collectors in Vietnam

Market	**Area [Km²]**	**Suitable area for PV [Km²]**	**Suitable area for collector [Km²]**
Cities and towns	1869	9.32	9.32
Provincial municipal areas	1812	4.53	4.53
Sum	**3681**	**13.85**	**13.85**

Identifying potential market for decentralised PV applications - Whereas potential market for distributed PVs and solar water collectors is densely populated in towns and cities, the potential market for solar home systems (SHS) are families without access to the national network, especially those living in remote and mountainous areas. Assuming the number of households similar to that of the wind home system (section 3.3.2.2), the potential market for SHS in Vietnam would be about 300,000 Units. These numbers translated into capacity will be equivalent to 20 MW.

3.3.3.3. Economics of integrated solar photovoltaics

Although PV electricity is not yet competitive to conventional grid power because of high investment costs, an overview of its production cost is necessary. Here only grid connected solar PV is considered, solar home systems will be dealt with in details later (see annex II). Production costs of the PV electricity depend on associated costs and operation life of the systems. The essential data and system characteristics used for calculations of life cycle costs are given below (Table 3.12).

Table 3.12: Technical and economic parameters of integrated PV

Parameters	Unit	Values
Installed capacity	KW	1
Cost of solar cell	USD/Wp	5
Lifetime of solar cells	Years	20
Cost of inverter	USD/kWp	1000
Inverter lifetime	Years	10
Balance of the system	USD/kWp	1200
O & M costs	% of initial cost	0.7
Efficiency of PV	Percent	13
Efficiency of inverter	Percent	95
Other losses	Percent	3
Discounted rate	Percent	10
Evaluation period	Years	20

Other benefits such as avoiding upgrades of transmission and distribution are ignored. As a rule, the module must be facing south and tilted at the latitude angle. The life cycle cost of PV electricity for all locations in Vietnam is displayed in figure 3.10.

3.3.3.4. Prospects for solar photovoltaics

There are several factors that can make PV energy more competitive in the future:

Cost of PV - The cost of PV is decreasing; between 1976 and 1992 inflation-adjusted prices of PV dropped by 18% with every doubling cumulative production [WiTe93]. Prospects for PV are obvious by extrapolating an historical PV experience curve. If all current segments of the PV market grow by 20% annually and prices decline by 20% for every doubling of cumulative PV sales, module costs would fall from a wholesale price of $3.65 per Wp (like in 1998), to about $1.20 per Wp by 2018.

Efficiency - The current efficiency is far below the theoretical efficiency and typically 80% of that is measured under standard laboratory test conditions [EnerTech]. This indicates a sufficient room for improvement of efficiency. Multinational firms such as British Petroleum and Shell have invested millions of dollars in PV development and research programs. The new generation of PV, which is more competitive, is expected to appear soon [Green04].

Increasing prices of conventional energy - At the same time, conventional energies experience an opposite trend as PV does, i.e. prices of produced electricity increase due to the growing penalty for the environment and the dwindling resources.

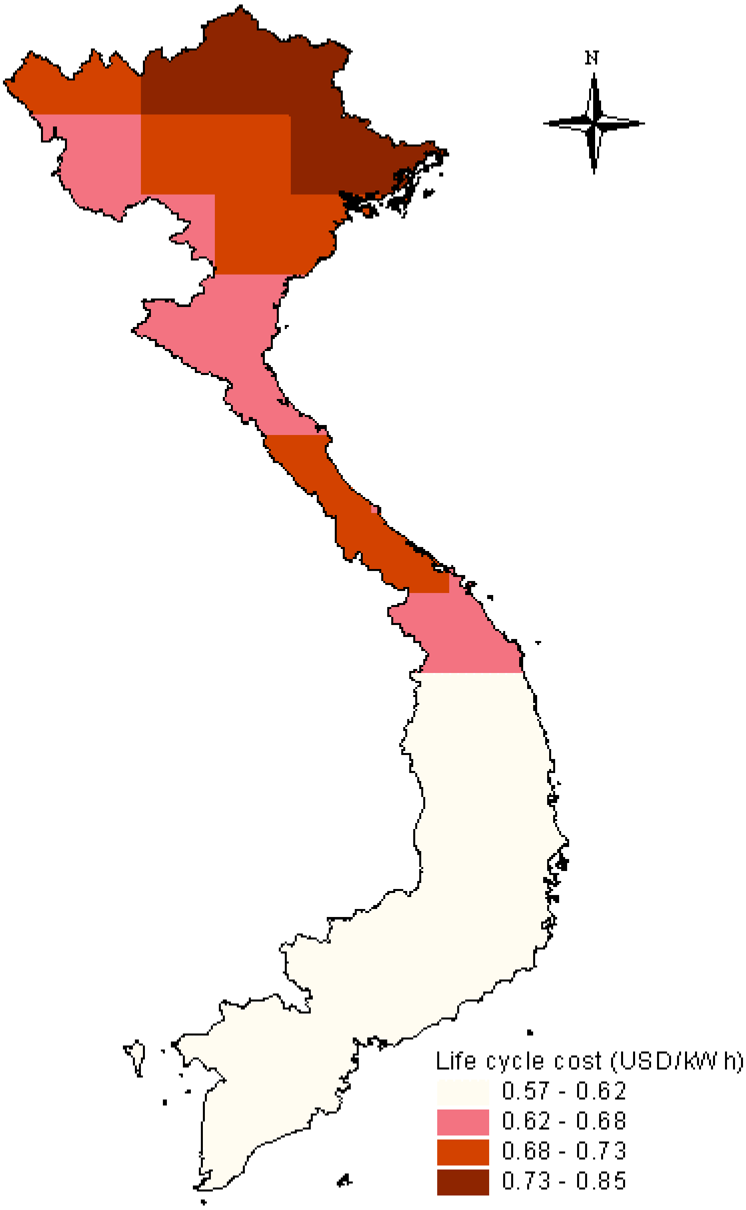


Figure 3.10: Cost of electricity from integrated solar PV

3.3.4 Biomass resource assessment

3.3.4.1. Methodology

Biomass mainly comes from fuel woods and agriculture residues, the availability of which is linked with forestry resources and crop production, and therefore depends largely on land-use patterns within a region. Estimation of biomass resource is based just on the areas covered by a defined plant, its volume per area, its growth and its residue index (reduced by the amount that could be used in other non-energy uses).

Concerning fuel wood source, data on forest areas is available from the Ministry of Forestry. Furthermore, data on volume of trees per unit area, volume increment and fuel wood index for different tree types is collected from different sources. On the other hand, data on agricultural residues, including yields of different crops and their respective cultivation areas is available from statistics in which total crop production can be determined. Crop residues can be estimated by using the Crop Residue Index (CRI) which expresses the ratio of the residue to the total crop produced for a particular plant species. Reduction factors are applied to account the amounts of crop residues consumed for non-energy and energy uses [VeRa97].

3.3.4.2. Fuel wood resource assessment

The main sources of fuel wood are natural and plantation forests, scattered trees, perennial trees, bare land forests and residues of forest industry.

Natural forest in Vietnam occupies about 19 million ha (of 33 million ha of land territory). However, only 9.3 million ha is essentially covered with forests, the other, about 9.6 million ha, is actually deforested [HSV99]. Of total forested areas, production and protection forests contribute 7.28 million ha. Their classifications according to forest plantation types are presented in table 3.13.

Table 3.13: Forest land by production and protection class in 1989 *

Forest type	Production (mill ha)	Protection (mill ha)	Sum (mill ha)
Evergreen/Semi-Deciduous/Deciduous	4.245	1.466	5.711
Bamboo types			
a) Bamboo	0.775	0.235	1.010
b) Bamboo wood	0.255	0.059	0.314
Conifer types	0.089	0.029	0.118
Tidal forest/ Mangrove	0.123	0.008	0.131
Total forest	**5.487**	**1.797**	**7.284**
Total non-forest/degraded	***5.873***	***3.253***	***9.126***
Total forest land	**11.360**	**5.050**	**16.410**

*: *Table excludes special use forest, special multipurpose forest, etc.*

According to the commercial timber volume, the natural forests have been classified into three quality categories: rich forests have more than 150 m^3/ha gross bole volume (GBV), medium forests – 80 to 150 m^3/ha and poor forests – under 80 m^3/ha. As a rule, young forest has no commercial wood. The rich and the medium forest together have a total of 1.688 million ha (about 40% of the production forest) with the balance in poor and young forest (Table 3.14).

Table 3.14: Evergreen/Semi-Deciduous/Deciduous forest areas by productivity class

Productivity classes	Production forests		Protection forests		Sum	
	mill. ha	%	mill. ha	%	mill. ha	%
Rich	0.365	8.6	0.113	11.1	0.478	9.1
Medium	1.323	31.2	0.3	29.5	1.623	30.8
Poor	1.59	37.5	0.391	38.4	1.981	37.6
Young	0.966	22.8	0.214	21.0	1.18	22.4
Sum	**4.244**	**100.0**	**1.018**	**100.0**	**5.262**	**100.0**

It has been indicated that with sustained yield management and proper control over harvesting practices to minimize damages, an increment rate up to 2 m^3 of gross bole volume per hectare per year would be achieved for the dipterocarp forests in South-East Asia [Armi90]. Assuming that in Vietnam, the increment rate 2 m^3/ha/year also applies to the rich/medium production, mangrove and coniferous forests, 1 m^3/ha/year for young forests, 0.5 m^3/ha/year for poor and bamboo/wood forests, the total gross increment would be 5.7 millions m^3/year.

Furthermore, accepting that the portion of fuel wood makes up 50% of the gross increment, plus about 30% for top/branches, a total of 2.58 million tons of fuel wood per year could be potentially available on a sustainable basis (Table 3.15).

Table 3.15: Sustainable fuel wood (FW) from production forests

Forest type	Productivity (m^3/ha/year)	Area (mill. ha)	Annual sustainable production		
			mill. m^3 GBV	mill. tons GBV	mill. tons FW
Hardwood					
Rich/Medium	2.0	1.69	3.38	2.36	1.54
Young	1.0	0.97	0.97	0.68	0.44
Poor	0.5	1.59	0.80	0.56	0.36
Other					
Coniferous	2.0	0.09	0.17	0.12	0.08
Mangrove	2.0	0.12	0.25	0.17	0.11
Bamboo		0.78			
Bamboo/Wood	0.5	0.25	0.13	0.09	0.06
Total		**5.49**	**5.68**	**3.98**	**2.58**

In addition to the above source, a significant but unknown amount of fuel wood in the type of fallen trees, dry branches, leaves, etc from protection and special purpose forest are collected by the local people everyday. Experts estimate this to be 0.5 ton/ha per year. Including this portion, natural forest could then supply about 4.15 mill tons fuel wood per year.

Plantations present another important source of fuel wood. In 1995, there were 1.007 mill ha of plantation forests in Vietnam [HUT99]. The main settlers in the plantations are fast growing plant species such as eucalyptus, acacia pines and casuarinas. Plantation forests usually have short rotations (8-15 years). They serve as a timber source for building rural houses, wood for other domestic uses or fuel wood, and provide pulpwood for paper industry. It is assumed that a total yield of 10m^3 wood/ha/year would be realistic for the plantation forests [HUT99]. Taking 50% of that as fuel wood with a density of 0.7 ton/m^3, plantation forests would potentially provide about 3.52 million tons/year.

Bare forest lands represent areas formerly carried high forests of various productivity classes but now are covered generally by low woody vegetation, ranging from herbaceous plants to shrubs or scattered trees in various stages of degradation [FAO92]. In Vietnam there are more than 9 million ha of such forest areas that have been resulted from in-moving crop cultivation, fuel wood gathering, uncontrolled logging as well as fire damages. Much effort has been made by the Ministry of Forestry as well as the provincial governments to reforest these areas. With protection from people and proper management mechanism, these bare forest lands can supply about 0.5 ton of fuel wood/ha/year, or a total yield of 4.5 million tons per year.

Scattered trees mean individual trees that are planted mainly in home gardens, in crop lands, along farm boundaries, roadsides, canal banks and other similar areas. These are planted for different uses such as providing shade, soil protection, production of timber, fuel wood and fodder. In 1995, 300 billion trees were planted, covering 3 million ha of land at a density of 1,000 trees/ha [HUT99]. Assuming that annual yield of wood of the scattered trees would be the same as that in plantation forests (10 m^3/ha/year), but with a lower portion of fuel wood (2 tons /ha /year), about 6.0 million tons of fuel wood per year would be expected.

Perennial crops serve as sources of biomass i.e. rubber, coconut, tea and coffee. In 1986, Vietnam had about 202,000 ha of rubber forests which produced approximately 50,000 tons of dry rubber. In 1989, out of the reported 216,000 ha, only some 67,000 ha were productive, the remaining required replanting. During the recent past, replanting has been carried out at a rate of about 5,000 ha per year [HUT99]. Biomass yields, at a very conservative estimate of 100 m^3/ha of stem and branch wood, and could amount to some 0.5 million m^3 or 0.35 million tons per year, over a period of 10-20 years. However, only about 50% of that could be used as fuel because rubber wood is also suitable for furniture and acceptable paper pulp raw materials either for local use or export as wood chips. Thus, the available amount of fuel wood from this source would be 0.175 million tons per year. This amount is expected to increase in the next future as existing forests reach the end of their productive lives in about 25-30 years while replanting still continues. In addition, a considerable amount (about 0.5 ton/ha/year) of dead branches and damaged trees is often collected by local peoples for use as fuel. In 1995, approximate 0.139 million tons of fuel woods were supplied by the rubber forests.

Coconut palms make an important component in home gardens, especially in Southern Vietnam. They serve as a significant source of biomass energy (as fronds, husks and shells) and a potential source of trunk wood. In average, a palm produces 13 fronds per year, weighing about 1 kg; with about 160 palms per ha, a sustainable supply of about 2 tons of frond /ha per year is realistic. In addition to this, coconut husks and shells are often used as fuel in households. From a yield of about 5,500 nuts/ha/year with 1.5 kg/nut, where husks and shells make up 37% and 14%, respectively, an amount of 4.21 tons of wet biomass/ha/year would be generated. After drying and putting it aside for alternative uses (for example as ropes), the amount of fuel available would be 1.7 tons/ha/year. In 1995, Vietnam had 173,000 ha of coconut palms, providing about 0.64 million tons of fuel biomass.

Other perennial crops such as tea and coffee also supply biomass as fuel. In 1995, there were 66,000 ha tea and 186,600 ha coffee in Vietnam [HUT99]. Pruning of bushes estimated to produce 0.5 ton of biomass/ha/year, resulting to a total amount of about 0.17 million tons of biomass per year.

Residues from forest industry contribute an important source of fuel wood. In 1995, sawmills produced about 770,000 m^3 of sawn timber. Two main types of sawmills are present in Vietnam: (i) those that use mechanical sawing systems (over 300 plants) and (ii) small workshops with manual sawing methods (unidentified number). The production of sawn timber indicated above belonged just to sawmills of the first type; there is no record on production of the latter. Taking a recovery rate of 40% for sawn wood, there would be 60% residues (10% as sawdust and 50% as wood waste) available as fuel, yielding a total amount of 1.16 millions m^3 of residues per year. There are also many informal sawmill activities that might add up to 50% to this figure. Collectively, with a density of 700 kg/m^3, sawmill activities can supply on a sustainable basis about 1.21 million tons of residue per year to be used as fuel.

Wood wastes are also derived from replacement of old and defective woody materials in buildings, fences and other structures, especially from rural houses. On the average, a house in rural and mountainous areas needs 5 m^3 of wood and has an average lifetime of 25 years; consequently, a replacement rate of 4% is expected. Supposing that 50% of wood from these replacements is used as fuel, the amount of fuel wood would be roughly 0.8 million tons per year [HUT99].

The total sustainable fuel wood supply was estimated to be about 21.3 million tons in 1995 and details are summarized in table 3.16.

Table 3.16: Fuel wood supply potential in 1995 in Vietnam

Fuel wood source	Annual supply (mill tons)
Natural forest	4.15
Plantation	3.52
Bare lands	4.50
Scattered trees	6.00
Forest industries	1.21
Perennial crop trees	1.12
Other wood waste	0.80
Total	**21.30**

Considering the plan of 5 million ha plantation forests for the period 1997 - 2010 and the initiatives on scattered trees as well as potential from the rubber industry [HUT99], it would be assumed that fuel wood potential will increase at a rate of 0.5% per year (Table 3.17).

Table 3.17: Fuel wood supply potential between 1995-2030 in Vietnam

Biomass sources	1995	2000	2005	2010	2015	2020	2025	2030
Fuel wood potential (mill. Tons)	21.30	21.84	22.59	23.39	24.23	25.13	26.08	27.09

3.3.4.3. Agricultural residue resource assessment

Rice, sugar cane and maize are the main agricultural residue resources. Analyses on the crop residue index (CRI) issued by the Institute of Forestry [HUT99] showed that for rice plants, dry weight of straw accounts for 50% of the rice plant dry weight while hush represents 20% of the paddy weight; for sugar cane, bagasse with a calorific value of 1,850 kcal/kg represents 1/3 of its weight. For maize plants, it is estimated that production of a ton of maize is coupled with 2 tons of residues (as stalks and cobs) which can be used as fuel. In 1995, the yields of rice, sugar canes and maize were 24.964, 10.711 and 1.177 million tons, respectively. The potential delivery of residues was estimated at 37.1 million tons. However, not all residues are available for use as fuel because there are some competing uses. Sugar cane tops, rice and other straws are widely used as feed or litter for animals; straws are used together with dung and other farm waste to make fertilizer. Supposing that 50% of residues from rice, maize and sugar can be used as fuel, the amount of biomass provided from each species in 1995 was estimated at 17.47 million tons, 1.177 million tons and 3.57 million tons, respectively. Other cultivation plants such as peanut, soybean, tobacco, rush, cassava, etc. also produce a significant amount of residues that were estimated to be 1.2 million tons in 1995. Thus, the total agriculture residue in 1995 was 23.42 million tons.

The amount of agriculture residue would increase in the next future due to increases of food production. Also, the sugar industry that is under process of development is expected to produce more waste. Considering the limitation on arable land, it is assumed that the agricultural residue supply would increase at a rate of 2% in the period of 2000 - 2005 and 1.2% in 2005 - 2010, then would be kept at the level in the year 2010.

The total biomass potential in Vietnam is provided in table 3.18. Biomass from fuel wood and agricultural residues is converted to PJ by using the standard calorific energy content, i.e. 1 kg wood equivalent to 15 MJ, whereas 1 kg agricultural residue 12.5 MJ.

Table 3.18: Total biomass supply potential between 1995 - 2030 in Vietnam

Biomass sources	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Fuel wood potential (PJ)	319.56	327.63	338.88	350.81	363.48	376.92	391.20	406.35
Agricultural residue (PJ)	292.77	363.43	400.00	419.99	419.99	419.99	419.99	419.99
Total (PJ)	**612.33**	**691.06**	**738.88**	**770.80**	**783.47**	**796.91**	**811.19**	**826.34**

3.3.4.4. Review of current biomass energy technologies in Vietnam

Although biomass consumption has a long history in Vietnam, applied technologies are still inefficient and causing pollution. Commonly, biomass is consumed by direct combustion like direct burning in stoves or boilers to serve for cooking, producing building material such as bricks, tiles, limestone and processing food and food stuff such as tea, pasta and soybeans.

Biomass energy technologies in the domestic sector - Significant portions of biomass are consumed for domestic cooking in Vietnam, like in many developing countries in the region. Traditional stoves so far dominate in the rural market because they can accept any kind of fuel and this is a preferred feature considering the wide variety of agriculture residues in rural areas. Efficiency of these stoves is however very low, varying from 6% to 16% because the flames are not concentrated and the distance between cooking devices and the flames is often long (to support the use of various fuel types). Improved stoves with chimneys show higher efficiencies, about 25%. However, due to the relative high capital cost (17 USD/unit versus 0.3 for traditional stoves), inflexibility to fuel types and inefficiency for short heating tasks, the new technology is still not widespread [IE02].

Biomass energy technologies in the non-domestic sector - Here, some of the most significant technologies are considered.

Brick and tile production are the next important biomass consumers after domestic cooking. Here, different types of kilns are used, depending on the type of fuel source. Coal-fuelled kilns are constructed with or without permanent walls and work with an updraft principle in both cases. A small amount of fuel wood is also usually needed to ignite the coal. Wood-fuelled kilns are always built with permanent walls. Larger factories use both updraft kilns and multi-chamber cross draft kilns [FAO92]. Wood-fuelled kilns are predominantly used in the south and south-central parts of Vietnam. Common sizes of kilns are about 3 m wide by 4 m height, and have a length varying from 4 to 12 m (internal dimensions). In general, such kilns have low to medium efficiencies. Small kilns have the lowest efficiencies; large kilns have medium efficiencies due to their high ratio of amount of products to the kiln surface (heat loss) area.

Lime kilns of different sizes and shapes are often used in the north and north-central parts of Vietnam. A common type is a vertical shaft kiln with an internal diameter of about 2 m and a height of about 3 m. These typically small kilns usually have low efficiencies.

Ceramic and pottery are produced in coal, oil, wood or electricity-fuelled kilns. In small scales, wood and some coal are usually used. For glaze products, wood is preferred to avoid negative effects of sulphur species contained in the coal. Generally, kilns have a long, semicylindrical construction with about 2 m wide by 1.5 m high, sometimes up to 20 - 30 m long and are quite efficient.

In food-and agro-processing sectors, biomass energy technologies are applied in small-scales, often manual operations, such as producing noodles from rice, making tofu from soybeans or drying tea leaves. The fuel sources used vary, depending not only on the local availability, but also on specificity of products as well as processing activities.

3.3.4.5. Biomass energy technologies - prospects for improvements

In the domestic sector, higher efficient equipment is needed to better conserve biomass sources. In turn, energy conservation can result in saving time required for collection of fuel wood, saving money spent for fuel and decreasing disturbance to the environment. It is calculated that slight improvements in efficiency, e.g. from 12% to 14% in the case of residue-burning stoves, could reduce about 3 - 4 million tons of biomass consumed per year. Such an increase in efficiency is easily attainable, for example as shown by the improved stoves with a higher efficiency of about 25%.

Experiences from other developing countries show that biomass-using small industries in the non-domestic sectors continue to be an important part of the economy, and improvements in current technologies are necessary [FAO92]. An institution should be established to steer the development of these local industries.

3.3.4.6. Prospects for new technologies

New biomass technologies in the market - Biomass can be used as fuel for power generation too. Proven technologies regarding this aspect as already introduced in section 3.2.3 include gasification and direct combustion. Prospects for the application of these technologies exist in Vietnam and here some points are highlighted.

Prospects for Vietnam - The main barrier to the application of new biomass technologies in Vietnam is the availability of biomass supply due to the characteristic of biomass as a scattering resource with low calorific energy content. Obviously, these technologies ideally suite agro-industrial processing centers, where biomass residues are accumulated near the consumers.

Considering the rice processing industry in Vietnam, there would be a promising prospect for new biomass technologies. The Institute of Energy in Hanoi estimated that a ton of rice paddy could produce 250 kg hush with a calorific value of 3,300 kcal/kg. For gasification in gas turbine systems, this residue would generate theoretically 350 kWh. As the processes of grinding and polishing rice require from 30 to 60 kWh, about 300 kWh surplus can be pumped into the central grid. In 1997, the hush yield was 6.88 million tons. Counting only plants which have capacity higher than 10 tons/shift, the potential energy would reach 1,102 GWh, or 275 MW at 4000 hours /year [IE00b].

Aside from this, the sugar industry also appears promising. According to a survey of the Institute of Energy in Hanoi, there were 24 sugar factories in Vietnam in 1997, which handled a total of 2.5 million tons of cane and produced 220,000 tons of sugars (in addition to some 300,000 tons of sugars from very small operations). Three of the existing sugar factories doubled (or even more) their production by the year 2000. Twelve large, modern and efficient sugar factories are presently being planned or under construction. The bagasse left after sugar production represents a source for power generation. It is usually burned to produce steam for the thermal requirement in sugar processing operations and to generate electricity to run the factories themselves. The existing factories produce steam in boilers at 20 bar. A study from the Institute of Energy shows that an increase of steam pressure in boilers from currently 20 bar to 45 bar would provide enough steam and electricity to run a typical factory. The excess electricity (about 50 kWh per ton) can be made available to other users by interconnecting the cogenerator with the utility grid. Scaling this figure to 70,000 tons of cane capacity per day in the existing and planned new sugar plants projected to be online in 2000 (considering only those with a capacity of more than 1,500 tons of cane per day), up to 80 MW of low cost capacity would be generated from the total capacity of 70,000 tons cane/day, i.e. up to 300 GWh would be added to the grid annually. It is estimated that such changes in steam pressure output require some technical modifications that cost less than 100 USD per kW.

For a long-term development, increases of plantation forests for fuel wood supply need to be considered. This trend is being deployed actively in other countries such as India, China, the Philippines, etc. [DOE97]. Currently, capital investment per kW of biopower is still expensive. However, with advances in technologies and improvements in the increment rate from plantation forests, biopower has a good chance of competing with fossil fuel-based energy.

3.3.5 Biogas resource assessment

3.3.5.1. Methodology

Biogas potential can be determined by the following formula [IE00b]:

$$G = \sum_{i=1}^{n} G_i = \sum_{i=1}^{n} Q_i * R_i * T_i * DM_i * Gy_i \tag{3.9}$$

where G_i is the biogas potential of input i; Q_i is the annual quantity of input i; R_i is the residue index of input i, i.e. the amount of dung production per animal head per year or the ratio of residue to the total crop produced; T_i is the percentage of substrate i available as input to biodigestors (is dependent on other competitive uses of the substrate, on transportation, storage and extraction modes); DM_i is the dry matter content of input i in percent; Gy_i is the specific gas yield of input i.

Inputs for biodigestors can be classified into two groups: animal based and crop based sources.

Animal based sources are excreta from human, animal and wastes from processing factories such as seafood processing factories and slaughterhouses.

Crop based sources are commonly used for biogas production such as rice straw, maize stalks, sweet potato stalks. However, these sources are also used for other purposes, for example, as fuel for domestic cooking, feeding animals, making fertilizer, etc.

In practice, waste from animals is preferred as it is easier to collect, digests more quickly and there are almost no other competitive uses.

3.3.5.2. Biogas potential from animal based sources

Animal waste is readily available in rural areas, and usually comes from pigs, cows, buffaloes, poultries and also humans; however only a part of that can be used for biogas production. An important controlling parameter is the collection value (R_i) which is defined as the portion of animal excrement (i) available as input for biogas production per year (Table

3.19). Two other controlling parameters are the dry matter content (DM_i) and the specific gas yield (Gy) for each input i as recommended by experts [IE00b].

Table 3.19: Specific information of various inputs for biogas production

Animal type	Annual manure (kg/head)	Dry matter (%)	Specific gas yield (l/kg.DM)	Collection factor (%)
Pig	1500	20	200	56
Cow	6000	18	150	21
Buffalo	7500	17	150	18
Poultry	15	35	200	28
Human	90	30	200	37

The total biogas potential from animal waste is estimated based on the data given in table 3.19 and the number of animal provided by statistics in 1995 (table 3.20) [GOS00]. The biogas is then converted into PJ using the net calorific value of 5,373 Kcal/m^3 [IE00b].

Table 3.20: Theoretical biogas potential from animal waste in Vietnam in 1995

Animal type	Quantity (thousand heads)	Biogas potential (Mill m^3)	Biogas potential (PJ)	Share (%)
Pig	16,306.4	547,895.040	12.330	59
Cow	3,638.9	123,795.378	2.786	13
Buffalo	2,962.8	101,327.760	2.295	11
Poultry	142,069.1	39,779.348	0.940	4
Human	58,322.0	116,527.356	2.622	13
Total		**929,324.882**	**20.973**	**100**

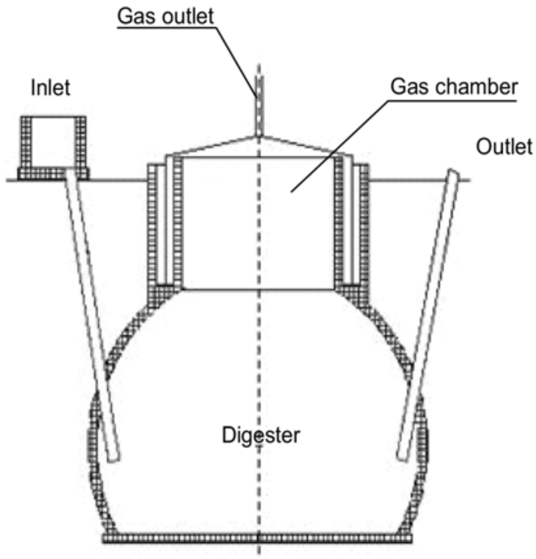
3.3.5.3. Current biogas technologies in Vietnam

Biogas technologies were first introduced in Vietnam some 20 years ago. Three main types of biogas production technologies have been evaluated.

The traditional type of biodigestor with a fixed dome made of bricks and cement was developed from a chinese design (Figure 3.11A). Briefly, this digestor consists of a gas-tight chamber on top the reactor, a straight inlet pipe that ends at mid-level of the height of the reactor and a gas outlet pipe exists at an inspection cover on the top. The gas produced during digestion is stored under the dome and displaces some of the digester contents into the effluent chamber, leading to gas pressures in the dome of between 1 and 1.5 m of water. This creates quite high structural forces and is the reason for the hemispherical top and bottom. Surely, this kind of biodigestor requires know-how and relatively high-quality materials, the investment cost is, therefore expensive.

The second type of biodigestor is called a float gasholder that was developed from an indian design (Figure 3.11B). This biodigester consists of a drum, originally made of mild steel. The reactor wall and bottom are usually constructed of brick, although reinforced concrete is sometimes used. The gas produced is trapped under a floating cover which rises and falls on a central guide. The pressure of the gas available depends on the weight of the gasholder per unit area and usually varies between 4 to 8 m of water pressure. The reactor is fed semicontinuously through an inlet pipe, and displaces an equal amount of slurry through an outlet pipe.

A



B

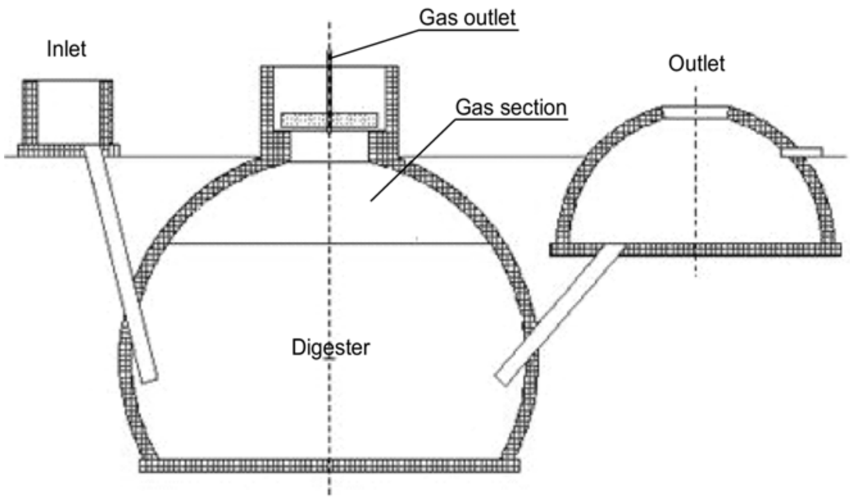


Figure 3.11: Biodigester
A-Fixed dome type; B-Floating holder type (adopted from [Ho02])

The simplest, low-cost type of biogas system is the flexible plastic tube biodigester that is constructed based on a taiwan design. It consists of a polythene tube of varying length, and does not necessarily require any masonry construction. The model was first introduced in Vietnam by the University of Agriculture and Forestry (NOAF).

3.3.5.4. Biogas development activities in Vietnam

There are several governmental and non-governmental organizations involved in the R&D and dissemination of biogas technologies in Vietnam.

The Institute of Energy (IE) since 1976 has conducted several research aspects on biogas, including design, construction and fabrication of biodigesters. IE has successfully developed two biogas plant samples following the chinese and the indian designs. As of February 2002, the institute has installed or was involved in the installation of 333 biogas plants. In addition, IE also provides training and technical support for technicians and users and does researches in applying biogas as a clean fuel for other uses such as electricity generation, tea processing, fruit storage and egg hatching.

IE has successfully modified a 4-stroke petrol engine to use biogas as fuel. In operating gensets, 1m^3 of biogas can replace 0.85 liters of petrol. It has been proven experimentally that a digester of a 10 m^3 volume coupled with a 450 VA genset could generate enough electricity to run 3 electric bulbs of 100W and 2 electric appliances (television or radio sets of 75 W) for 5 continuous hours per day [Ho02].

Dongnai province has a team of technicians working on construction of biogas plants. As a result of local regulations concerning hygiene in animal raising farms, every month the team has been requested to build about 10 digesters of different designs. Since 2000, the team has built about 2,000 units [IE00b].

Cantho University, as a center of renewable energies, continues to propagate a model of fixed dome biogas plants in southern provinces. This model was constructed in a cooperation program with a German partner.

The National Institute of Animal Husbandry (NIHH) is involved in the development and propagation of 2 main types of biogas plants; the low cost polyethylene tube biodigesters and the fixed dome biodigesters (developed from a chinese design). So far, about 120 polyethylene tube biodigesters and about 100 biodigesters of the other designs have been installed by NIHH; these are mainly distributed in northern provinces [BuNg].

The SaREC S2 VIE 2 Project involves the University of industry in Ho Chi Minh City and the Hue University of Agriculture. This project mainly concentrates on the spreading of low cost polyethylene tube biodigesters.

The University of Agriculture and Forestry (NOAF) is the first organization that introduced the low cost polyethylene tube biodigester in Vietnam. The initial project was funded by SidaSAREC and FAO with aims to promote sustainable use of local resources in the livestock-based farming system [DuLe]. Until now, the NOAF has transferred the technology to more than 40 provinces throughout the country, and also to Cambodia, Laos and Thailand. The installation number increases year to year and as of 2001, more than 15,000 units of this technology have been set up to Vietnam. The University has built an efficient network involving nationwide representatives of concerning organizations.

The Vietnam Gardeners Association (VGA) has developed a biogas field work with an integrated farm management approach (VAC) to highlight the role of the closed cycle waste-biogas-fertilizer in bioreactors for rural areas. VGA has sold and successfully installed nearly 3,000 biogas production units.

Center for rural development and support has developed its market in the Hatay and Namdinh province; the model was developed from a chinese design, made of composite from local sources. This is supported by the National Program on Clean Water and Environment. The center set an objective of 1,000 units. Since early 2000, about 600 units have been installed.

In addition, farmers in many rural areas have invested in biogas digesters themselves without support from governmental or international programs. The exact number of digesters built in this way is however unknown.

Counting to 2000, about 15,000 of biodigestors have been installed in Vietnam. Of which, 12,000 are plastic tube biodigesters, 700 fixed dome units and 2,300 units of the floating gas holding type [IE00b].

3.3.6 Hydro resource assessment

3.3.6.1. Hydro potential

According to reports from the institute of energy, theoretical hydropower potential in Vietnam is 300 TWh/year, of which the technical potential is 82 TWh (17,700MW) [IE00b] [IE00a]. This technical potential is, however, unequally distributed among regions. A high potential is located in the North, making 51 TWh/year, while the south and the central parts bear only 18.5 TWh/year and 10.6 TWh/year, respectively. Technical potential of hydropower in ten main rivers in Vietnam is presented in table 3.21.

Table 3.21: Technical hydropower potential of major rivers in Vietnam

No	Name of river	Potential capacity (MW)	Estimated power generation (TWh)	Percentage (%)
1	Da	6258	31.60	44.7
2	Dong Nai	2400	11.60	16.4
3	Lo	1068	4.75	6.7
4	Srepok	496	2.63	3.7
5	Ca	560	2.56	3.6
6	Ma	320	1.26	1.8
7	Ba	402	2.07	2.9
8	Xe Xan	1485	7.99	11.3
9	Vu gia - Thu Bon	985	4.58	6.5
10	Tra Khuc	360	1.69	2.4
	Total of 10 rivers	**14334**	**70.73**	**88.4**
	Total of all rivers in Vietnam	**17700**	**80.00**	**100.0**

The hydropower potential is classified into two categories, large and small.

Large hydropower potential means capacities higher than 10 MW. A total of 154 sites have been identified with this category, of which 8 sites with a capacity above 500 MW, 13 sites with a capacity from 200 MW to 500 MW, 56 sites - from 50 MW to 200 MW, and 81 sites from 10 MW to 50 MW. Currently, only about 50 sites have been exploited which represent 15% of the overall potential. Ongoing efforts are focused on the exploitation of potential on the Da, Xe Xan and Dong Nai river basins which have a total capacity of 10,143 MW.

Small hydropower potential means capacities less than 10 MW. Within this range, hydropower plants are further divided into small hydro (> 0.1 MW), mini (> 5 kW) and micro hydro (<5 kW) that differ from each other in the investment cost and the annual availability

(Table 3.22). This potential, if harnessed fully, could realize 10 billion kWh of energy annually [EVN99].

Table 3.22: Small hydropower potential in Vietnam

Capacity range	Number of sites	Capacity (MW)
Small hydro (100 kW - 10 MW)	500	1408.8
Mini-Hydro (5 kW - 100 kW)	2,500	125
Micro-Hydro (100 W – 5 kW)	1,000,000	75
Total small hydro potential		**1608.8**

3.3.6.2. Efforts in the development of large-scale hydropower plants

Capacity of the present hydropower plants in Vietnam is just 15% of the available technical potential. Hydropower potential will be more tapped to satisfy the increasing energy demand in the country. According to the master plan on power expansion stage V for the 2000 - 2020 period, hydropower plants are expected to contribute 29% to the total generation capacity by the year 2020. In the first stage, efforts are focused on exploitation of the potential in the Da, Xe-Xan and Dong-Nai river basins which have a total capacity of 10,143 MW [IE00a]. One of the most important projects is hydropower plant Son-La with a capacity of 3,600 MW and represents the biggest hydropower plant in Southeast Asia. The feasibility of this plant is expected to finish in 2003 and electricity is projected to come online in 2013. The main motivation for the construction of this power plant is the relatively low per kW investment capital (1,000 USD/kW) in comparison to common costs (in the range of 1,500-1,800 USD/kW). However, facts still exists and there still arguments to discuss, for example, mass resettlement of the local families, dangers of catastrophic failures, the national security concerns, the decommissioning of the dam, and the huge capital investment; hence, scale and progress of the project are influenced. It is expected that the project will be delayed at least 4 years later than the initial proposal [Hydro98] [Pub].

3.3.6.3. Efforts in the development of small hydropower plants

Since 1996, about 66.4 MW of small hydropower capacity have been developed in Vietnam [EVN99]. The number of plants, capacities and performance are displayed in Table 3.23.

Table 3.23: Small hydropower installed capacity in Vietnam until 1996

Parameters	Small & mini hydropower	Micro hydropower
Capacity range (kW)	5 - 10,000	0.2 -5
Number of plants	400	120,000
Total capacity (MW)	41.4	25
Annual energy (GWh/year)	85 - 120	18 - 20
Plant factor	0.23 - 0.33	0.08 - 0.09

Most plants with capacities above 100 kW are well managed and operate with higher plant factors since they supply electricity for district towns with high population densities. The load demand is a mix of commercial users, lighting for industry and householders.

Plants with capacities ranging from 5 - 20 kW are mainly in old ages and suffer damages due to the lack of proper maintenance. There are difficulties in getting funds for purchasing spares for these plants, therefore, they cannot be put back into operation anytime soon.

Micro-hydropower plants with typical capacities of 200 W to 5 kW are most widely used. Since 1996, more than 120,000 units have been installed and most of them operate in the operation mode "run of river." Their availability for generating power is, therefore, limited during stream flooding periods and dry seasons [EVN99].

For the period 1998 - 2005, several projects have been planned by the Institute of Energy to upgrade existing small hydro power plants and create a basis for the exploitation of hydropower for rural electrification (Table 3.24).

Table 3.24: Priority in the development of small hydropower for the period 1998-2005

	Low scenario			High scenario		
	Site number	Capacity (MW)	Cost (Mill USD)	Sites number	Capacity (MW)	Cost (mill USD)
Rehabilitation & upgrading of existing stations:						
- Small Hydro	80	5	3.0	100	8	4.8
- Micro Hydro	40000	10	2.0	50000	13	2.5
New developments						
- Small Hydro	50	5	6.2	120	40	50.0
- Micro Hydro	60000	15	3.0	80000	20	4.0
Total cost (US$ mills)			**14.2**			**61.3**

3.3.7 Geothermal resource assessment

3.3.7.1. Geothermal potential

About 300 thermal manifestations, mostly in the form of hot water springs, fumaroles or mud volcanoes, have been identified in Vietnam. These manifestations are distributed all over the country [Hoang97]. The northwestern region is concentrated by about 45% of all geothermal locations. The south-central region is less abundant but more concentrated with hot founts. About 30 geothermal locations have been identified to be suitable for power generation, which would have a total capacity of 472 MW [IE03]. The best locations and expected capacities are shown in table 3.25.

Table 3.25: Geothermal potential for power generation of selected sites in Vietnam

Sites	Reservoir temperature (°C)	Expected installed capacity (MW)
Mo-duc (Quang-ngai province)	187	21.4
Nghia-thang (Quang-ngai province)	140	18
Hoi-van (Binh-dinh province)	141	18
Tu-bong (Khanh-hoa province)	151	18
Danh-thanh (Khanh-hoa province)	131	14
Le-thuy (Quang-binh province)	184	23.3
Kim-da (Nghe-an province)	163	20
Son-kim (Ha-tinh province)	189	20
Huyen-co (Quang-tri province)	189	20
Duong-hoa (Thua-thien-Hue province)	151	18

The first 5 geothermal locations listed in the above table are currently surveyed by ORMAT, an American energy company, for the development of power-generating plants in the near future.

3.3.7.2. Power generation technologies for geothermal energy

There are a number of geothermal power technologies available, including simple back pressure plants with atmospheric exhaust, conventional condensing plants, binary cycle, combined cycle binary plants, Kalina Cycle, multi flash plants, etc. The selected technology represents an important factor affecting the specific investment cost of geothermal power plants. In addition to this, temperature, depth and type of the geothermal resource, topography of the site, chemistry of the geothermal fluid, size of the plant to be built, and local infrastructure are definitely significant factors in deciding the investment cost. To cover uncertainties, the World Bank has recommended investment costs as shown in table 3.26 [WB02].

Table 3.26: Unit investment cost of geothermal power plants

Plant size	High quality resource (USD/kW)	Medium quality resource (USD/kW)	Low quality resource (USD/kW)
< 5 MW	1600 - 2300	1800 - 3000	2000 - 3700
5 - 30 MW	1300 - 2100	1600 - 2500	Not suitable
> 30 MW	1150 - 1750	1350 - 2200	Not suitable

The O & M cost is similarly divided according to the plant size. For the 5-30 MW size, the O & M is recommended at 0.6-0.8 cent/kWh.

3.3.8. Summary of renewable energy potential in Vietnam

Table 3.27 summarizes the technical potential of renewable energy resources in Vietnam. This potential is about 2 times the primary energy consumption in Vietnam in 1995.

Table 3.27: Renewable energy potentials in Vietnam

Technical potential	Capacity (GW)	Energy (PJ/year)
Wind energy		
Grid connected wind turbine	160.73	1180.8
Wind home system	0.045	0.3
Solar energy		
Integrated solar PV	1.799	6.5
Solar water heater		42.2
Solar home system	0.02	0.07
Biomass (in 1995)		612.3
Biogas		20.9
Hydroenergy		
Large hydro	17.70	254.9
Small hydro	1.60	17.3
Geothermal		
Geothermal power	0.47	11.8
Sum		**2147.1**

3.4. Modeling renewable energy technologies in the MARKAL Vietnam

This section will discuss the operation characteristics of the selected renewable energy technologies and how these are handled in the MARKAL model. Thus, only representative and major technologies are intensively discussed, the others that do not require special treatment will be ignored.

3.4.1. Wind energy

Grid connected wind turbines - It is well known that wind speed varies continuously with time and is very sensitive to topography. Power from the wind in turn varies with the cube of wind speed. Therefore, in the absence of an efficient storage, wind energy technologies have limited capability to meet peak during daytime peak and nigh-time off-peak loads. These characteristics are necessary to be taken into modeling. In MARKAL, this is possible by using the table PEAK and parameter AF. Table PEAK describes the portion of capacity of a certain technology that can be mobilized to meet the peak load. On the other hand, parameter AF specifies total annual availability of the technology.

In the MARKAL Vietnam, two grades of wind turbines are modeled which are differentiated by the parameter AF (Table 3.28). The selection of parameter AF therefore defines the technical potential and in the present study this parameter is accepted as the upper bound in 2030.

Table 3.28: Main parameters for modeling wind turbines in the MARKAL Vietnam

Technologies	Investment cost (USD/kW)	O&M cost (USD/kW.a)	Lifetime (Year)	PEAK	AF	Upper bound by 2030 (MW)
Grid connected wind turbine 1	900	23.7	20	0.3	0.35	2500
Grid connected wind turbine 2	900	23.7	20	0.3	0.3	1000
Wind home system	1600	72	10	0.3	0.25	45

For the security of the energy system, it is also necessary to set an upper limit to indicate the maximum extent that renewable energies are allowed to enter into the total energy capacity. This requirement can be modeled in the MARKAL model using the ADRATIO table [DDNN96]. In the MARKAL Vietnam, the portion of intermittent renewable energy technologies, in particular wind and solar energies, are limited to be lower than 20% of the total system installed capacity.

Wind home system - Wind home systems are equipped with batteries to allow a continuous electric supply. Modeling of wind home systems in MARKAL therefore would not be critical. In the present study, one type of wind turbine is selected as representative WHS for modeling. Detailed technical and economic information of this type of turbine is presented in annex II - decentralized technologies for isolated areas.

3.4.2. Solar energy

Integrated solar PVs - Output of solar PVs depends on the season and time of day - it decreases significantly by cloud cover or is zero during the night. This characteristic must be taken into consideration when modeling in MARKAL. In the model, the weather dependent performance of PVs can be simulated with the table PEAK and the parameter Seasonal

Capacity Utilization Factor (CF(Z)(Y)). Like above, the table PEAK describes the portion of capacity of a certain technology that can be mobilized to meet peak load. On the other hand, the parameter CF(Z)(Y) specifies the availability of PV technology during a defined season and daytime that are classified into six periods:

+ Summer daytime
+ Summer nighttime
+ Intermediate season daytime
+ Intermediate season nighttime
+ Winter daytime and
+ Winter nighttime

Obviously, the availability of PV technology during the summer would be higher than in the winter and is absent during the nighttime. Two grades of solar PV technology respective to two solar radiation conditions in the North and the South of Vietnam are modeled in MARKAL (Table 3.29). Furthermore, as already mentioned in the wind section, the share of wind and solar energies is limited to be less than 20% of the total system capacity by using the ADRATIO table.

Table 3.29: Main parameters for modeling integrated solar PV in the MARKAL Vietnam

Parameters	Solar PV 1	Solar PV 2
Seasonal Capacity Utilization Factor		
+ Summer daytime	0.84	0.84
+ Summer nighttime	0.0	0
+ Intermediate season daytime	0.5	0.6
+ Intermediate season nighttime	0	0
+ Winter daytime and	0.3	0.6
+ Winter nighttime	0	0
PEAK	0.3	0.3
Initial investment cost (USD/kW)	7200	7200
Annual fixed O& M cost (USD/kW)	38	38
Lifetime (year)	20	20
Upper bound by 2030 (MW)	799	1000

Solar home systems - With batteries as storage devices, solar home systems can in principal meet the basic demand of isolated families and are therefore handled in MARKAL like other conventional conversion technologies. There are also two grades of SHS that correspond to solar conditions in the North and in the South which are differentiated by the availability factors (Table 3.30; see also annex II for more explanations).

Table 3.30: Main parameters for modeling SHS in the MARKAL Vietnam

Parameters	SHS 1	SHS 2
Availability factor	0.3	0.4
PEAK	0.3	0.3
Initial investment cost (USD/kW)	5900	5900
Annual fixed O& M cost (USD/kW)	140	140
Lifetime (year)	20	20
Upper bound by 2030 (MW)	10	10

Solar collector - Similarly, there is no strict requirement in modeling the operation of solar collector.

3.4.3. Biomass

Biomass fired power plants - Three advanced technologies for electricity generation introduced above are modeled in the MARKAL Vietnam. Characteristic parameters of these technologies are shown in table 3.31 [DOE97].

Table 3.31: Main parameters for modeling biomass fired power plants in the MARKAL Vietnam

Technology	Investment cost (USD/kW)	Fixed O&M cost (USD/kW)	Efficiency (%)	Life time (year)	First year introduced	Upper bound by 2030 (MW)
Bagass fired power plant	100	43.0	23	20	2005	100
Hush fired power plant	2000	68.7	36	20	2005	300
Fuel wood fired power plant	2000	68.7	36	20	2005	-

3.4.4. Biogas

Biogas digester - Biogas digester is modeled in MARKAL as a process technology (technology that does not produce electricity and/or heat directly) with detailed parameters presented in table 3.32. According to a survey on technology costs in the market, a typical 10 m^3 digester costs about 370 USD. This digester would deliver 3,300 liters of biogas per day if the feeding rate would be maintained at 100 kg per day.

Table 3.32: Main parameters for modeling biogas digester in the MARKAL Vietnam

Technology	Investment cost (USD/GJ)	Variable O&M cost (USD/GJ)	First year introduced	Residual capacity (PJ/year)	Upper bound by 2030 (PJ/year)
Biogas digester	3.86	0.48	1995	0.13	21

3.4.5. Hydropower

Hydropower plants - Five different forms of hydropower plants are modeled in the MARKAL Vietnam according to the arguments mentioned above. Two forms are for hydropower plants of large size (one for conventional plants and one for the Son-la plant due to different investment costs) and three plants of small size. In Vietnam, water availability for operation of hydropower plants depends on the season (dry and rainy) and this is included in MARKAL as an important factor which is controlled by two parameters, ARAF and SRAF [BeGo97]. Parameter ARAF describes the maximum annual availability factor for the plant, whereas parameter SRAF (Z) indicates seasonal reservoir availability in season Z. There are, however, no strict requirements for mini and micro hydro power plants. Main information inputs for modeling hydropower plants in the MARKAL Vietnamare presented in table 3.33.

Table 3.33: Main parameters for modeling hydropower plants in the MARKAL Vietnam

Technologies	Investment cost (USD/kW)	Fixed O&M cost (USD/kW)	Variable O&M cost (USD/GJ)	First year available	ARAF	SRAF in summer	Bound by 2030 (MW)
Sonla hydro power plant	1000	30.5	0.14	2015	0.425	0.89	2400
Large plants	1500	30.5	0.14	1995	0.425	0.89	14000
Small power plants	1250	30.5	0.14	1995	0.40	0.89	1400
Mini hydro power plant	600	25	-	1995	0.25	-	125
Micro hydro power plant	250	12	-	1995	0.12	-	75

3.4.6. Geothermal

Geothermal power plants - Binary cycle system seems to be the most suitable technology for Vietnam [Hoang]. This technology uses heat transfer media which has a lower boiling point than water, such as organic fluids, for enabling power to be generated from lower temperature resources. This technology is modeled in the MARKAL Vietnam on the basis of main parameters indicated in table 3.34.

Table 3.34: Main parameters for modeling geothermal power plants in the MARKAL Vietnam

Parameters	Estimated values
Investment cost (USD/kW)	2000
Variable O&M cost (USD/GJ)	1.94
First year available	2005
Annual availability	0.75
Bound by 2030 (MW)	400

Chapter IV

DEVELOPMENT OF THE VIETNAM MARKAL MODEL

In this chapter we describe the specifications of various exogenous parameters for the establishment of the Vietnam MARKAL model. The exogenous parameters are grouped into three categories: energy resources, energy service demands and technologies. These are necessary components to build the Reference energy system (RES) of Vietnam as introduced in chapter II.

4.1. Costs and reserves of primary energy resources

MARKAL requires the costs of all primary energy resources (either they are extracted or imported, conventional or renewable) to be defined along with constraints on their availability. Table 4.1 and 4.3 summarize the projected costs and the annual maximum production limits for all energy sources used in the model. They are discussed in details below.

4.1.1. Conventional energies

Coal - Vietnam has a proven recoverable reserve of 3.88 billions tons of coal and an estimated reserve of 6.6 billion tons [Vncoal02]. The coal reserves are concentrated mainly in the north-eastern province of Quang-Ninh, extending about 125 km (from Uong-Bi in the West to Cai-Bau island in the East). The coal deposits are assessed geologically young, however the intense tectonic pressure changed the bituminous coal to semi-anthracite coal in the East and anthracite coal in the West [WB98].

Current production from Quang Ninh represents over 90% of the total coal production and is mainly concentrated on open-pit mines and underground mines within the depth of 100m because of low production cost. While many open-pit mines run close to or higher than their rated capacity, many underground mines are run at just 50% of their capacity because of their inefficient mining techniques. In the long run, exploitation needs to be carried at deeper layers because mines near the surface are relinquished whereas the demand for coal increases. Surveys at higher depths (150-300 m) are thus required to enable future exploitation and selection of appropriate efficient mining technologies. The upper bounds of coal production in milestone years have been projected to be 30 million tons by 2020 and 35 million tons by 2030 [Vncoal02].

In 1995, Vietnamese coal had an average cost of 25 USD per ton (or 1.07 USD per GJ). It is projected to increase at a constant rate of 1.86% per year, reaching 47.65 USD per ton by 2030 (2.03 USD/GJ) due to growing production costs [WB98]. Since the demand for coal in the country is increasing, total domestic coal production would be mostly consumed internally and the coal price is, therefore, independent from the international market.

Apart the local production, coal can be imported. The cost evolution for future years has been adopted from a study of the World Bank [WB98].

Gas - Gas resource in Vietnam is estimated to be 2100-2800 billions m^3 of oil equivalent (OE). However, the proven reserve is only 610 billions m^3, of which non-associated gas represents the dominating part [VPI02]. Gas is consumed mainly for generating power, producing fertilizer and producing steel. Presently, only gas from the oilfield White Tiger (Vung-Tau province, southern Vietnam) is used for generating power in two power plants Ba-Ria and Phu-My owing to the pipeline system of Petrovietnam. Gas production in the future depends on the domestic demand as well as export possibilities. Its upper production however can not be bigger than 18000 million m^3/year by 2020. Preliminarily estimated gas production potential and cost for milestone years until 2030 are presented in table 4.1 [VPI02] [WB98].

Table 4.1: Production bounds and cost for primary conventional energy resources

	1995	2000	2005	2010	2015	2020	2025	2030
Extraction of domestic coal								
Upper bound (PJ)	195.77	271.97	421.84	567.40	642.42	701.51	808.89	937.84
Upper bound (thousand tons)	8350	11600	17992	24200	27400	29920	34500	40000
Cost (USD/GJ)	1.07	1.17	1.28	1.41	1.54	1.69	1.85	2.03
Extraction of gas								
Upper bound (PJ)	7.00	60.29	252.46	527.54	640.58	678.26	678.26	678.26
Upper bound (million m^3)	186	1600	6700	14000	17000	18000	18000	18000
Cost (USD/GJ)	1.81	1.99	2.20	2.43	2.68	2.96	3.27	3.61
Extraction of crude oil								
Upper bound (PJ)	320.37	690.82	745.25	904.35	912.72	753.62	753.62	753.62
Upper bound (thousand tons)	7652	16500	17800	21600	21800	18000	18000	18000
Cost (USD/GJ)	2.95	3.07	3.20	3.33	3.47	3.61	3.76	3.91
Extraction of uranium dioxide								
Cost (USD/GJ)	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Import of oil products								
Diesel (USD/GJ)	4.57	4.76	4.97	5.18	5.41	5.64	5.89	6.14
Gasoline (USD/GJ)	4.89	5.10	5.32	5.55	5.79	6.04	6.30	6.58
Kerosene (USD/GJ)	4.75	4.95	5.17	5.39	5.62	5.87	6.12	6.39
Fuel oil (USD/GJ)	3.49	3.63	3.78	3.93	4.08	4.25	4.42	4.60
Jet fuel (USD/GJ)	4.80	5.00	5.22	5.44	5.68	5.93	6.18	6.45
LPG (USD/GJ)	4.75	4.95	5.17	5.39	5.62	5.87	6.12	6.39
Import of crude oil								
Cost (USD/GJ)	3.69	3.84	4.00	4.16	4.33	4.51	4.70	4.89
Import of natural gas								
Cost (USD/GJ)	3.28	3.41	3.55	3.69	3.84	3.99	4.15	4.32
Import of hard coal								
Cost (USD/GJ)	1.83	1.90	1.98	2.06	2.15	2.23	2.32	2.42
Import of Electricity								
Upper bound (PJ)	-	-	18.00	36.00	54.00	72.00	81.00	90.00
Cost (USD/GJ)	12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50

Oil - A reserve of 900-1200 millions m^3 of recoverable oil equivalent (OE) is estimated, of which about 540 million m^3 is proven reserve [VPI02]. Oil production in Vietnam has grown rapidly in recent years. Between 1990 and 1995, the crude oil production grew at an annual rate of 23%. For future years, two scenarios of oil production have been proposed by the oil industry. The high scenario implies optimum exploitation conditions whereas the base scenario reflects the prudent view of production activities. For simulation purposes, the expected outputs that correspond to the high scenario has been adopted as the upper bounds (Table 4.1). The production cost correspondingly is assumed to increase at the rate of 1%/year from 20 USD/bbl in 1995 [WB98].

Imported crude oil and oil products (gasoline, diesel, jet fuel, fuel oil, kerosene and LPG) are also considered as energy resources in MARKAL. Generally, no restriction is set on the import levels, except those identified in specific import constraint cases. The average price of crude oil in the world market in 1995 was 25 USD/bbl; it is projected to increase at a rate of 0.81% annually, reaching 33.16 USD/bbl in 2030 [WB98]. Oil products are projected to have cost evolution according to the World Bank forecast [WB98].

Uranium - Exploration of uranium in selected parts of the country began in 1955, however a systematic regional program has been undertaken only after 1978. Uranium has now been explored in the entire country, with a number of occurrences and anomalies subjected to more intensive investigation. During 1997-1999, exploration activity was concentrated on the Nong-Son basin in the Quang-Nam province, central Vietnam [WEC]. Proven reserves are 320867 tons classified into the categories as follows (Table 4.2):

Table 4.2: Uranium reserve in Vietnam

Uranium categories	Quantity (tons)
Reasonably Assured Resources (RAR)	137
Estimated Additional Resources I (EAR-I)	16563
Estimated Additional Resources II (EAR-II)	15153
Speculative Resources (SR)	289038

No exploitation of uranium has been observed so far. However, if the proposal for the first nuclear power plant is approved, the uranium reserve could be intensively exploited. The first promising location is Tabhing-PaLua within the Nong-Son basin [IE99]. For the modeling purpose, the cost of uranium dioxide (UO_2) is assumed at the international price at 930 USD/kg [WNAb] and remains constant during the whole investigation period (Table 4.1).

Electricity - Apart from the self-produced source, electricity can also be also imported to meet the domestic requirement. Electricity at more competitive prices from neighboring countries represents a good source, for example, from Laos with a maximum capacity of 2,000 MW in the period from 2010-2015, or from Vannam (China) with a potential capacity of 2,000 MW in the period from 2015-2020 [IE00a].

4.1.2. Renewable energies

Assessment of renewable energy resources has been made in chapter III. This sector focuses on restrictions on the exploitation of these resources. Due to these constraints, except the case for biomass sources, the upper bound of which is express as the potential, for all other renewable energy sources the upper bounds are the maximum rates of technology introduction

(Table 4.3). A brief discussion and summary of the renewable energy potential is given below.

Hydropower - Vietnam has abundant hydropower resources, particularly in the central and northern regions. The gross theoretical potential has been estimated at 300 TWh/yr, with an economically feasible potential of some 82 TWh/yr equivalent to 17,700 MW. Hydropower potential is classified into two categories, large and small. Large hydropower potential means capacities higher than 10 MW. Overall, 154 sites have been identified with this category. Small hydropower potential means capacities less than 10 MW. Within this range, hydropower plants are further divided into small hydro (> 100 kW), mini (> 5 kW) and micro hydro (<5 kW) that differ from each other in investment cost and annual availability.

In 1998, hydropower contributed 2,826 MW, equivalent to 50.5% of the overall installed capacity (represented 16% of its overall potential), of which small plants made up 66.4 MW. For future exploitation, large hydropower plants are projected to grow gradually to reach the upper bound of 16.4 GW by 2020 and this level will be maintained until 2030. For small hydropower plants, three upper bounds respective to three plant sizes are proposed (Table 4.3).

Wind - Wind resource in Vietnam has been estimated at an exploitable potential of 160.76 GW. Except some wind turbines of small capacities, Vietnam currently has no wind farms in operation. Considering current development plans of this sector, the upper limit capacity for a possible installed large-scale wind farm has been set at 200 MW by 2005 [IE00a], with an average growth rate of 20% per year. However, due to the intermittent output of wind power, the contribution of this energy form is also limited to guarantee the security of the electric system. In the MARKAL Vietnam, the combined portion of wind and solar power is limited to be lower than 20% of the total system installed capacity. As of small wind turbines, its potential is mostly dependant on the number of households without access to electricity and their willingness to pay. Here, an upper limit of 300,000 households is assumed. From the viewpoint of energy demand these are equal to a capacity of 45 MW.

Solar - Vietnam has good conditions for development of solar energy. Different technologies of solar energy are available in the world market, this study will, however, focus on three of them that seem most suitable for Vietnam, namely the integrated solar PV, the solar home system (SHS) and the solar water heaters. One advantage of solar energy technologies is that neither noise nor pollution is produced; hence solar systems are often installed near consumers to reduce construction costs. Thus, identification of suitable locations for application of solar energy is just the search for suitable rooftops. Usually, rooftops of domestic residences and commercial buildings are good places for installation of grid-connected PV and solar collectors. Potential consumers of solar home systems are families (houses and buildings) without access to the national electricity network. Once the number of these potential consumers is determined, energy requirements can be estimated expressed as capacity (for PV) or energy (for solar collector). It is estimated that technical potential for integrated solar PVs and solar water collectors would be 1,799 MW and 42.2 PJ, respectively. For SHS, similar to that applied to small wind turbines, 300,000 households equalling 20 MW are assumed.

Biomass - This is an important energy resource in Vietnam, especially in rural areas. In 1998, biomass provided two-third of primary energy supplies in the country. There are two main sources, fuel wood and agriculture residues, availability of which is linked with crop production and forestry resources, and therefore depends largely on land-use patterns of regions. Estimation of biomass resources is based on the areas covered by a defined plant, the plant volume per area, the plant growth and its residue index (excluding the amount used in other non-energy uses). In table 4.3, data on the upper bounds on availability are set equal to the amount available in that respective year whereas cost of biomass is taken from a recent study at the Hanoi University of Technology [HUT99].

Biogas - Biogas is produced from different inputs which can be distinguished as animal or crop-based sources. In practice, waste from animals is preferred for biogas reactors because it is easier to collect, digests more quickly and there are almost no other competitive uses. In order to estimate the biogas potential, the quantity of biogas generating material and its specific gas yield are first determined. In Vietnam, this information is collected from the National Statistic Book and experiment results of specialized laboratories as well. Biogas potential in Vietnam has been estimated to be 20.9 PJ and is assumed constant during the entire investigation period.

Table 4.3: Production bounds (upper bounds) and cost for renewable energy resources

	1995	2000	2005	2010	2015	2020	2025	2030
Extraction of agri. residue								
Upper bound (PJ)	293.10	363.43	400.00	419.99	419.99	419.99	419.99	419.99
Upper bound (mill tons)	19.52	24.23	26.67	28.00	28.00	28.00	28.00	28.00
Cost (USD/GJ)	0.55	0.56	0.57	0.58	0.58	0.59	0.60	0.61
Extraction of fuel wood								
Upper bound (PJ)	319.56	327.63	338.88	350.81	363.48	376.92	391.20	406.35
Upper bound (mill tons)	21.30	21.84	22.59	23.39	24.23	25.13	26.08	27.09
Cost (USD/GJ)	1.42	1.44	1.46	1.49	1.51	1.53	1.55	1.58
Biogas capacity								
Upper bound (PJ)	20.90	20.9	20.9	20.9	20.9	20.9	20.9	20.9
Cost (USD/GJ)	0.38	0.38	0.39	0.39	0.40	0.41	0.42	0.42
Hydro power capacity (MW)								
Large (MW)	2804	3246	4381	9050	11500	16400	16400	16400
Small (MW)	45	50	200	500	700	900	1100	1300
Mini (MW)	6	10	20	30	40	50	60	70
Micro (MW)	20	25	30	35	40	45	50	55
Wind power capacity (MW)								
Large (MW)			200	360	650	1170	2100	3750
Small (MW)	0.1	1	5	10	20	30	40	45
Geothermal power capacity								
Upper bound (MW)			100	200	300	400	400	400
Solar Photovoltaic								
Integrated solar PV (MW)			5	50	200	300	500	1000
Solar home system (MW)	0.2	0.5	1	5	10	15	20	20
Solar water collector (PJ)								42.2

Geothermal -Vietnam possesses a relatively abundant geothermal resource with about 300 thermal manifestations in the form of hot water springs, fumaroles or mud volcanoes. However, exploitation of this source is limited to several simple applications such as drying and processing agricultural products. Hot springs are used for medical purposes or mineral water production. Though more than 30 from all identified geothermal locations are suitable for power generation, which would bring a total capacity of 472 MW [IE03], geothermal has not been exploited for power generation in Vietnam. Recently, a number of geothermal sites have been surveyed by ORMAT, an American energy company, and the first construction is already under preparation. For simulation in the model MARKAL, capacity from geothermal is regulated so that it won't be higher than 100 MW by 2005 and 400 MW by 2030.

4.2. Energy service demands

Forecasts on energy demands in Vietnam are made on the basis of six standard consumption sectors: Industry, Urban resident, Rural resident, Commerce, Agriculture, and Transportation. Within each sector, major end-uses are identified and analyzed separately. End-use demands are presented in terms of their activities or useful energy, and depending on the assumed scenario that a variety of demand technologies providing different levels of output per unit of input energy are available for MARKAL to select from. Thus, MARKAL will decide the most suitable mix of energy forms and therefore final energy demand itself. Here two scenarios are assumed: The *Business As Usual* scenario (BAU) and the *energy efficiency* scenario (EFF). In the BAU scenario, only current, standard technologies are included while in the EFF scenario, both standard technologies and improved technologies are available. Table 4.4 presents the general economic assumptions underlying the energy service demand projections in Vietnam. The leading idea of this projection is to achieve a rapid and sustainable development with a view to avoid the danger of being increasingly lagged behind other countries in the region [Son01]. GDP is thus projected to increase at the annual growth rate of 6.87% between 2000 and 2030, whereas the population increases at a gradually decreasing rate. A part from this, urbanization tends to increase significantly (Table 4.4)

Table 4.4: General economic assumptions

Category	Data source	1995	2000	2005	2010	2015	2020	2025	2030	1995-'30
Population (Million)	[Son01]	72.3	77.7	83.0	88.1	93.1	97.7	102.1	105.7	
Population GR (%)		1.44	1.33	1.21	1.10	0.99	0.88	0.70		1.1
Urbanization	[Son01]	21.3	24.0	28.1	33.0	38.7	45.1	51.5	57.7	
GDP (Billion USD)		20.62	28.84	40.83	57.81	81.28	114.32	156.84	211.16	
GDP GR (%)	[Son01]	6.9	7.2	7.2	7.1	7.1	6.5	6.1		6.9
per capita GDP (USD)		285	371	492	656	873	1170	1536	1997	
per capita GDP GR (%)		5.4	5.8	5.9	5.9	6.0	5.6	5.4		5.7
ppp factor	[CIA]	5.30	5.00	4.50	4.05	3.65	3.28	2.95	2.66	
per capita ppp GDP (USD)		1511	1856	2214	2657	3183	3837	4535	5308	
per capita ppp GDP GR (%)		4.2	3.6	3.7	3.7	3.8	3.4	3.2		3.7

The GDP is also presented in ppp (purchasing power parity) to better reflect the real value and also facilitates a cross-checking service demand among countries with similar conditions.

Industrial sector - this sector is divided into 4 major energy intensive sub-sectors: steel, cement, nitrogen fertilizer, and pulp & paper plus one "other industry" sub-sector covering all the remaining industries. Projection of energy service demands in the industry sector was achieved by using a combination of two methods. For four major energy consuming industries (steel, cement, nitrogen fertilizer, and pulp & paper), industrial output was projected and a variety of demand technologies which provide different levels of output per unit of energy input were modeled in MARKAL. The other industry was modeled as a single entity with a final energy demand for three energy carriers (electricity, motor fuels, and heat production fuels).

Urban residential and rural residential sector - These sectors are handled separately because of their significantly different energy service demands; this way, the trend of urbanization would also be included in the model.

In the urban residential sector, main energy end-use categories are: lighting, cooking, hot water, electric appliances (TVs, computers, refrigerators, etc.) and air conditioning. Energy demand for lighting was projected based on the projected urban population, per capita floor area and the energy demand for lighting in previous years. Energy demands in other categories were projected based on the per-capita energy demand and their evolution tendency resulted from improved living conditions.

In rural residential sectors, three main energy end-use categories (cooking and water heating, lighting and electric appliances), are considered. Energy demands for water heating and for cooking are merged together because usually the same cooking devices are used for both activities. Energy demand for air conditioning is similarly included in electric appliances as it is electrically powered. The approach of forecasting energy service demand in this sector is similar to that applied for the urban residential sector, but an attention was paid to fuel structure available in rural areas, especially on the electrification rate.

Agriculture - Energy consumption in the agriculture sector serves for 4 main end-use categories: soil preparation, irrigation, fishing and agro processing. Future energy demands for these sectors were projected according to the historical data and expected degree of agriculture mechanization (for soil preparation), cultivation land area and the share of land irrigated by pumping systems (for irrigation), fish caching output, development of motorized ships (for fishing) and GDP share of this sector (for agricultural product processing). In this sector, energy service demands are estimated in terms of final energy demand arguing that Vietnam is still in the initial stage of mechanization and that the energy consumption of this sector is small compared to other sectors.

Commercial sector - Energy demand of this sector was projected based on the energy consumption per m^2 of the commercial floor area which in turn was forecasted according to its relation to the urban residential floor area. Commercial sector energy demands were characterized according to lighting, air conditioning, electric appliances and thermal use.

Transportation sector - Like in the industry sector, energy service demands in this sector are represented by their activities rather than the final energy to allow a better comparison of different end-use technologies. Activities are separated for freight and passenger transportation which are developed in dependence on the GDP growth, population growth, and the expected changes in transport modes. In this study, freight transportation demands are modeled according to four categories: air, ship, train, and bus, while passenger transportation demand includes: car, bus, motor bicycle, air, train, ship.

Total final energy demand - Figure 4.1 illustrates the development of the final energy demand in the period from 1995-2030 corresponding to the BAU scenario which is estimated on the basis of assumed end-use efficiencies. These results are not used in the Vietnam MARKAL model developed for this study but instead, the projected end-use demands are used as inputs for the model. In the MARKAL model runs, the actual final energy demand will depend on the mix of end-use technologies selected by the model. Figure 4.2 provides a comparison of the expected evolution of per capita final energy demand in Vietnam between 1995-2030 (under two scenarios) with historical data from several developing countries [NEDO97]. The graphic shows that the forecast is in line with the common trend in the developing countries in the world. (see annex I for detailed forecast)

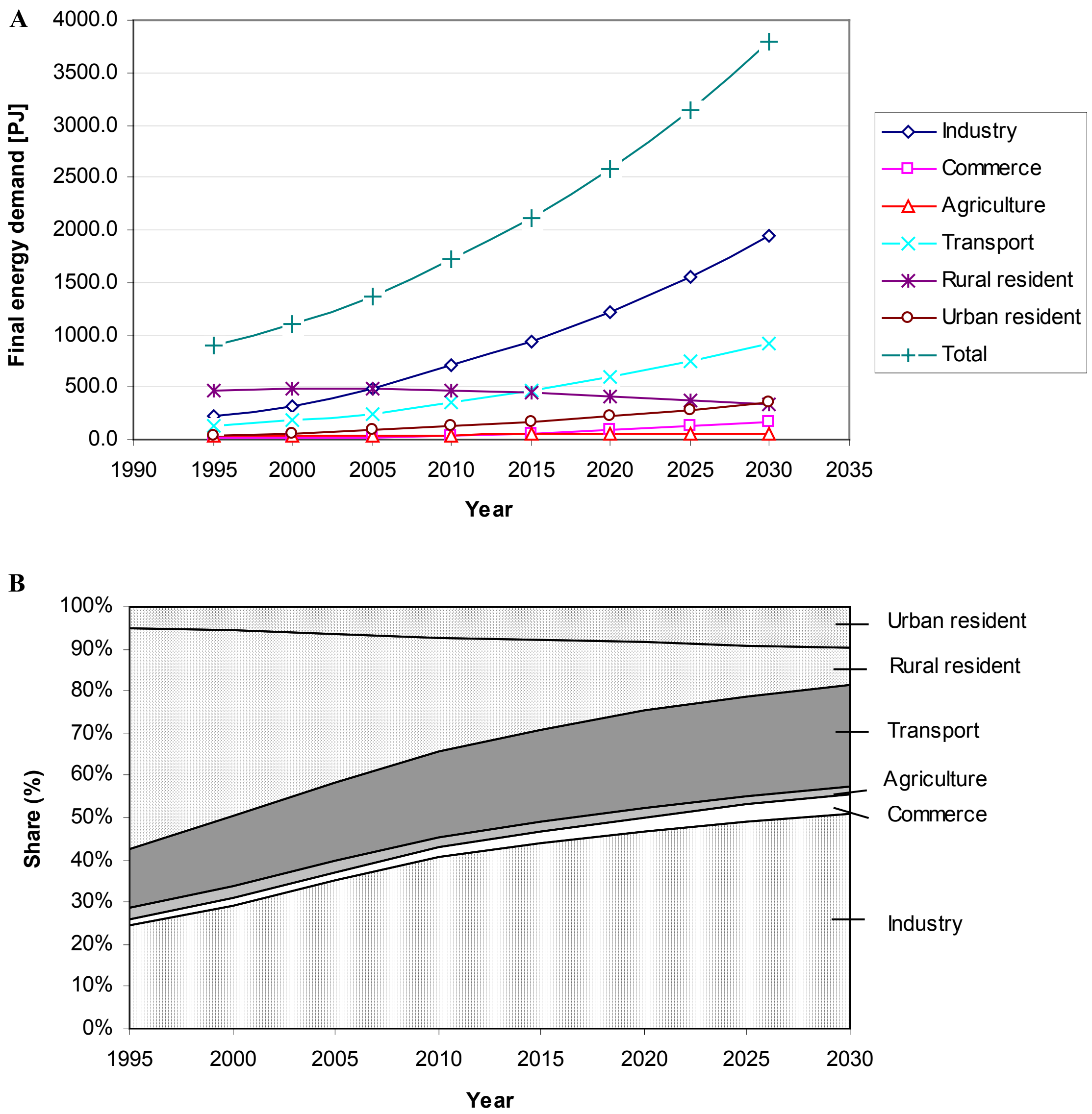


Figure 4.1: Development of final energy demand under BAU scenario
A - in absolute values; B - in shares

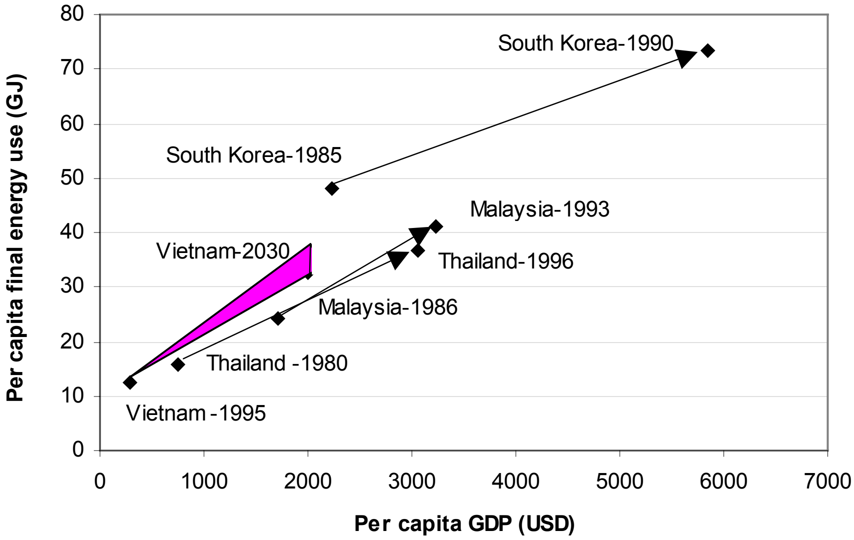


Figure 4.2: Expected evolution of per capita final energy demand (of two scenarios) in Vietnam between 1995-2030 and historical data of selected developing countries

4.3. Technologies

Technologies are classified into three groups in MARKAL: Process technologies, Conversion technologies and Demand technologies. Process technologies and Conversion technologies convert primary energy sources into final energy carriers whereas demand technologies convert final energy carriers into energy services.

4.3.1. Conversion technologies

In this category, there are a total of 29 representative technology types (Table 4.5), each of which is specified by technical and economic parameters (Table 4.6). Technical parameters are efficiency, lifetime, residual capacity, plant availability, capacity, production bound, and the first year when the technology is introduced. Economic parameters include investment cost per unit of production capacity, fixed and variable O&M costs, and investment bounds. Various literatures have been drawn upon for the values used to defined technologies (see list of literatures for technologies).

Table 4.5: 29 conversion technologies *

Energy source	Conversion technologies
Coal (2)	• Two technologies (one for the existing plants and one for the future plants)
Oil (7)	• Two fuel oil power plants (one for existing plants and one for future plants) • Two diesel fired gas turbines (one for existing plants and one for future plants) • One grid connected diesel power plant • Two decentralized diesel power plants (one for existing, one for new plants)
Gas (2)	• One simple-cycle gas turbine • One gas turbine combined cycle
Renewable energies (17)	• Three grid connected hydropower plants (one small, 0.1-10 MW; one medium, >10 MW and one big plant in Sonla) • Two stand alone small hydro technologies (one is 5-100 kW; one <5 kW) • Two grid connected wind farm (one for very good wind speed sites; one for medium wind

	speed sites) • One stand-alone wind turbine • Two grid connected integrated solar PV (one for solar condition in the South; one for solar condition in the North) • Two stand alone solar home systems (one for solar condition in the South; one for solar condition in the North) • Four biomass technologies (two fuel wood gasification-centralized and decentralized; one agricultural residue direct combustion; one bagass direct combustion) • One geothermal power plant
Nuclear (1)	• One technology

* total number of technologies in each categories is presented in parentheses

Table 4.6: Main parameters of conversion technologies

Conversion technologies	First year available	Efficiency %	Plant availability %	Investment cost $/kW	Fixed O&M cost $/kW-yr	Variable O&M cost $/GJ
Grid connected technologies						
Conventional technologies						
Existing pulverized coal power plant	1995	28	64	1150	22.0	1.39
New pulverized coal power plant	2000	38	75	1150	20.0	1.11
Existing steam FO power plant	1995	30	57	900	12.5	0.78
New steam FO power plant	2000	28	75	900	12.5	0.78
Simple cycle gas turbine	1995	40	75	550	20.0	1.00
Gas turbine combined cycle	2000	44	75	600	14.0	1.10
Diesel	2000	34	75	800	15.9	0.78
Existing DO fired gas turbine	1995	33	66	550	20.0	1.20
New DO fired gas turbine	2005	38	75	550	20.0	1.20
Nuclear power plant	2015	100	85	2000	50.0	2.40
Renewable energy technologies*						
Large hydro (>10MW)	1995	100	42.5	1600	30.5	0.14
Large hydro (>10MW) - Sonla	2015	100	42.5	1000	30.5	0.14
Small hydro (<10MW, > 0.1 MW)	1995	100	40	1250	30.5	0.14
Geothermal power plant	2005	100	-	2000	28.5	1.94
Integrated solar PV - North	2005	100	*	6900	50.0	-
Integrated solar PV - South	2005	100	*	6900	50.0	-
Wind farm 1	2005	100	35	900	23.7	-
Wind farm 2	2015	100	30	900	23.7	-
Fuel wood gasification	2005	36	70	2000	68.7	1.44
Stand alone technologies						
Conventional technologies						
Existing diesel genset	1995	31	10	500	30.0	0.01
New diesel genset	2005	31	60	500	30.0	0.01
Renewable energy technologies*						
Mini hydro (<100 kW, > 5 KW)	1995	100	25	600	18.0	-
Micro hydro (<5 kW)	1995	100	15	250	12.0	-
Solar home system - North	1995	100	30	5700	140.0	-
Solar home system - South	1995	100	40	5700	140.0	-
Wind home system	1995	100	25	1600	72	-

Conversion technologies	First year available	Efficiency	Plant availability	Investment cost	Fixed O&M cost	Variable O&M cost
Fuel wood gasification	2005	36	70	2000	68.7	1.44
Bagass fired steam turbine	2005	23	50	100	43.0	1.44
Agricultural residue fired steam turbine	2005	36	50	2000	68.7	1.44

* see chapter III for discussion on renewable energy technologies

4.3.2. Process technologies

In MARKAL, all the energy transformation processes are different from those producing electricity, and district heat (conversion technologies) are grouped as process technologies. In Vietnam, this group includes a petroleum refinery process, a natural gas plant and a biogas digester. The main parameters for these technologies are given in table 4.7.

Table 4.7: Main parameters of process technologies

Process technologies	First year available	Efficiency	Plant availability	Investment cost	Fixed O&M cost	Variable O&M cost
		%	%	$/GJ/yr	$/kW-yr	$/GJ
Petroleum refinery plant	2005	94	90	1.17	-	0.25
LPG production plant	1995	94	80	0.35	-	-
Biogas digester	1995	100	85	3.86	-	0.48

4.3.3. Demand technologies

Demand technologies use the final energy carriers to satisfy energy service demands. Most of the demand technologies are developed and are described below, but in some cases dummy technologies are used, which simply convert final energy directly into an energy service with efficiency set to 100%. Dummy technologies are used in those areas where end-use technologies are diverse and use the same final energy carrier (usually electricity) or where no reduction on the fuel consumption from the end-use demand is expected.

Two groups of demand technologies are distinguished, standard (S) and improved (I) technologies, corresponding to two scenarios of energy demand (the *BAU* scenario and the EFF scenario). The *BAU* scenario includes only current, standard technologies while the EFF scenario considers both standard and improved technologies.

Industrial demand technologies - There are four major energy-consuming industries: steel, cement, paper and fertilizer production and one general, so-called “other industry” sector which includes all the remaining industrial activities. Table 4.8 summarizes characteristic parameters of these industries as energy consumers. (See also annex I for discussion on the current situation in these industries and their respective prospects)

The steel industry - Five processes are modeled in MARKAL (Figure 4.3). The first one is blast furnace reduction (BFR). This is the classical process for the reduction of iron ore to raw iron. The disadvantage of this process is that it consumes a lot of energy. Unfortunately, this technology is used in the sole crude steel plant in Vietnam. The second process, direct reduction with gas (DRG), is more promising as it is more efficient. The first plant according to this technology is being constructed in Vietnam. If the gas resource is insufficient or the distance from the gas field to the plant is too far prohibiting in the use of gas, coal can be gasified to replace gas. This process is called direct reduction with coal (DRC). The raw steel from the three above processes are then rolled in the rolling process (RL) to become products like bar steel or shape steel. Since raw steel can be imported as well, here the amount of imported raw steel is limited to less than 30% of total steel production. In addition to the above sources, steel produced from scrap steel in electric arc furnaces plays an important role as they are cost effective. As the availability of crap steel depends on the consumption of steel, here the amount of steel produced according to the electric arc furnace is limited to less than 40% of total steel production.

The cement industry - includes three demand technologies: wet, dry and advanced-dry processes. (Figure 4.3). The wet-process rotary kilns are very energy intensive. The dry-process rotary kilns consume less energy and represent the likely choice for new plants in the future. The advanced dry process technology is a fluidized bed kiln which is expected to be introduced to Vietnam after 2005.

The paper industry - Three technologies are included in MARKAL to model the energy consumption in the pulp and paper industry (Figure 4.3). The standard one is based on the current inventory of existing plants, while improved ones (modern and advanced ones) are based on the data from a study in China [China01]. The improvement in efficiency of existing plants results from upgradation of existing capacity as discussed in [Thuong99].

The urea fertilizer industry - Three urea fertilizer technologies which are characterized by feedstock (coal, natural gas and coal-Texaco) are modeled in the MARKAL–Vietnam. Among the three available processes, natural gas based technologies are preferred because of the high energy efficiency. Coal based technologies are less efficient but when gasified, coal represents an attractive feedstock.

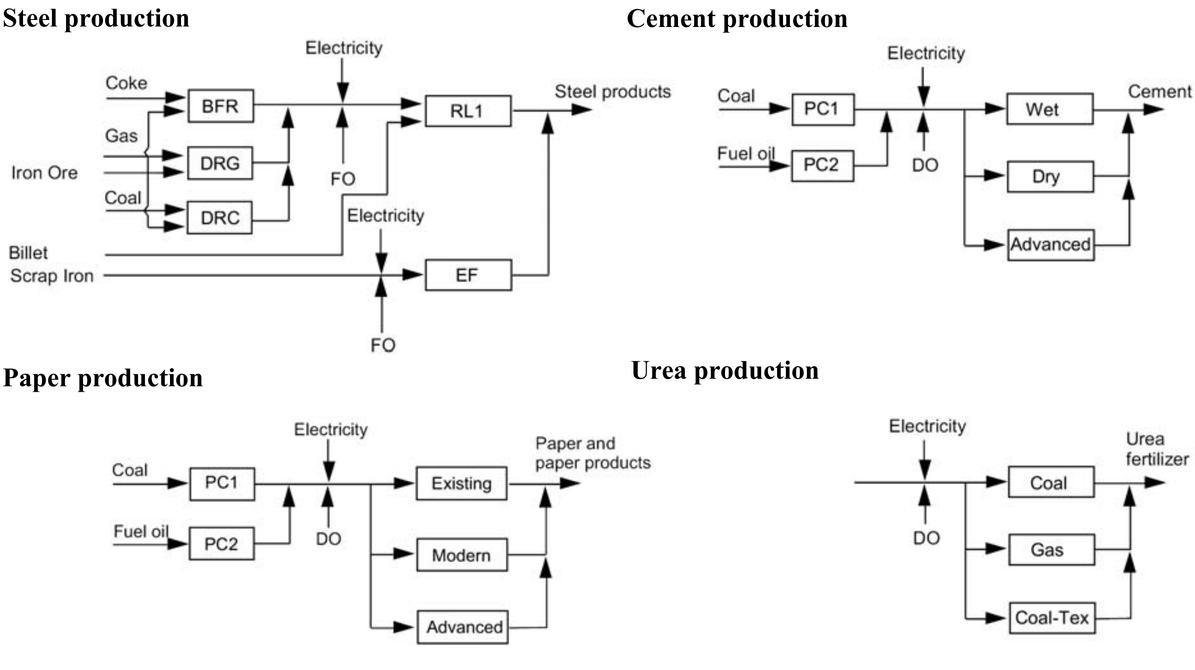


Figure 4.3: Technologies for industrial demand categories
(PC1 & PC2 are dummy processes)

Table 4.8: Industrial demand categories and related technologies

Industry & production processes	Abb.	Scenario	First year available	Energy efficiency (tons/GJ)					Inv. cost (USD/t/yr)
				1995	2000	2010	2020	2030	
Steel									
Blast furnace	BFR	S	1995	0.0264	0.0264	0.0264	0.0267	0.0269	-
Direct reduction - gas	DRG	S	2005	-	-	0.0492	0.0508	0.0525	-
Direct reduction - coal	DRC	S	2010	-	-	0.0349	0.0357	0.0366	-
Electric arc furnace	EF	S	1995	0.1702	0.1702	0.1777	0.185	0.194	-
Rolling	RL	S	1995	0.355	0.355	0.368	0.382	0.396	-
Cement									
Wet process	Wet	S	1995	0.1037	0.1089	0.12	0.132	0.146	96
Dry process	Dry	S	1995	0.237	0.237	0.237	0.237	0.237	138
Advanced process	Advanced	I	2010	-	-	0.294	0.294	0.294	138
Paper									
Existing process	Existing	S	1995	0.0217	0.0226	0.0244	0.0264	0.0286	1442
Modern process	Modern	S	2000	-	0.057	0.057	0.057	0.057	1442
Advanced process	Advanced	I	2010	-		0.085	0.085	0.085	1627
Urea fertilizer									
Existing process	Coal	S	1995	0.012	0.013	0.013	0.013	0.013	433
Gas process	Gas	S	2005	-	0.0288	0.0288	0.0288	0.0288	260
Coal gass. process	Coal-Tex	S	2010	-	-	0.021	0.021	0.021	300

Other industry - The "other industry" category is modeled in MARKAL using three dummy technologies to satisfy the energy demands for electricity, heat and motor fuel. As efficiencies of these technologies are 100%, no cost data needs to be provided for the model.

Urban residential demand technologies - Various technologies are available to satisfy five energy service demands, i.e. lighting, electric appliance, hot water, cooking and air conditioning. Electric appliances and lighting are modeled as dummy technologies, where their saving potential is captured by using conservation technologies. For air conditioning demand, the concerned end-use technologies include the existing air conditioners and the efficient ones. ADRATIO is used to control the penetration of efficient air conditioning. Cooking technologies consist of coal, biomass, improved biomass, gas, kerosene and electricity. Technologies for hot water supplies include gas, electric and solar (Table 4.9).

Rural residential demand technologies - End use demand in the rural residential sector are broken down into 3 groups: lighting, electric appliance and cooking plus hot water. Similar to urban residential sector demands for lighting and electric appliances are satisfied by using dummy technologies and conservation technologies are used to model additional energy efficiency improvement. Cooking & hot water demand technologies include eight stove types: coal, fuel wood, improved fuel wood, gas, kerosene, agricultural residue, improved agricultural residue and electric (Table 4.9).

Table 4.9: Commercial, residential and agricultural demand technologies

Demand technologies	Scenario	Year first available	Energy efficiency (GJ/GJ)	Investment cost ($/GJ-yr)	O & M cost ($/GJ-yr)
Urban Residential Sector					
Lighting	S	1995	100	N.U	N.U
Cooking - electric stove	S	1995	60	1.31	0.65
Cooking - gas stove	S	1995	70	4.91	0.98
Cooking - fuel wood stove	S	1995	12.5	0.16	0
Cooking - fuel wood improved stove	S	1995	25	0.33	0.10
Cooking - kerosene stove	S	1995	45	0.55	0.33
Cooking - coal stove	S	1995	22.5	0.33	0
Electric appliance	S	1995	100	N.U	N.U
Electric hot water heater	S	1995	90	5.2	0.26
Gas hot water heater	S	1995	65	5.8	0.26
Hot water solar collector	S	1995	100	12.2	1.05
Air conditioner	S	1995	78	6.17	-
Efficient air conditioner	I	2005	100	6.56	-
Rural Residential Sector					
Lighting	S	1995	100	N.U	N.U
Kerosene lamp	S	1995	0.55	36.82	-
Biogas lamp	S	2000	11	40.91	-
Cooking - electric stove	S	1995	60	1.31	0.65
Cooking - gas stove	S	1995	70	4.91	0.98
Cooking - fuel wood stove	S	1995	12.5	0.16	0
Cooking - fuel wood improved stove	S	1995	25	0.33	0.05
Cooking - agriculture residue stove	S	1995	10	0.16	0
Cooking - agri. residue improved stove	S	1995	22	0.33	0.05
Cooking - kerosene stove	S	1995	45	0.55	0.33
Cooking - coal stove	S	1995	22	0.33	0
Electric appliance & air conditioning	S	1995	100	N.U	N.U
Commercial Sector					
Lighting	S	1995	100	N.U	N.U
Electric appliance	S	1995	100	N.U	N.U
Air conditioner	S	1995	78	6.171	-
Efficient air conditioner	I	2005	100	6.557	-
Agricultural Sector					
Electric motors	S	1995	100	N.U	N.U
Irrigation	S	1995	100	N.U	N.U
Soil preparation	S	1995	100	N.U	N.U
Agro - processing	S	1995	100	N.U	N.U
Fishing	S	1995	100	N.U	N.U
Fishing - lighting	S	1995	100	N.U	N.U

I: technology is included in EFF scenario only, S: technology that is included in both scenarios, N.U: not used

Commercial sector demand technologies - In this sector, energy demands are divided into four categories, air conditioning, lighting, electric appliances and thermal use. Air conditioning is modeled similarly to that in the residential sector by using an existing and an improved technology. Demand for electric appliances, lighting and thermal use are satisfied by using dummy technologies. Conservation technology is used for lighting to model the saving potential that is beyond those incorporated in the development of the demand data (Table 4.9).

Agricultural sector demand technologies - Energy demands in this sector are relatively small, they are, therefore, satisfied by using dummy technologies (Table 4.9).

Transportation sector demand technologies - Demand technologies for the two categories, freight and passenger transportation, are listed in table 4.10**.** Under the BAU scenario, the efficiencies of different vehicle types are assumed to improve stably over the analysis period [Thuong99] [Transport92]. This is explained by the fact that more efficient vehicles enter the fleet and the transportation activities are better organized.

Table 4.10: Transportation Demand Technologies

Demand technologies	Year first available	Energy efficiency			
		1995	2010	2020	2030
Freight transportation (1000 t-km/GJ)					
Truck - diesel	1995	0.319	0.332	0.352	0.375
Truck - gasoline	1995	0.239	0.249	0.264	0.281
Train - diesel	1995	1.194	1.194	1.194	1.194
Train - steam	1995	0.265	0.265	0.265	0.265
Air	1995	0.039	0.039	0.039	0.039
Ship - FO	1995	1.405	1.478	1.555	1.635
Ship - diesel	1995	1.405	1.478	1.555	1.635
Passenger transportation (1000 pass-km/GJ)					
Air	1995	0.390	0.406	0.423	0.440
Bus - gasoline	1995	2.687	2.798	2.913	3.033
Bus - DO	1995	2.986	3.109	3.237	3.371
Bus - CNG	2010		2.483	2.483	2.483
Car - gasoline	1995	0.498	0.513	0.529	0.545
Car - diesel	1995	0.515	0.526	0.536	0.547
Motor bicycle	1995	1.095	1.140	1.187	1.236
Train - diesel	1995	3.583	3.583	3.583	3.583
Train - steam	1995	0.796	0.796	0.796	0.796
Ship - FO	1995	1.493	1.539	1.586	1.635
Ship - diesel	1995	1.493	1.539	1.586	1.635

Conservation technologies - These technologies are used to represent the proportion of energy that can be conserved and therefore are introduced into the model in the *EFF* scenario only (Table 4.11). The cost and saving potentials shown in table 4.11 are based on [Thuong99] [HSV99] whose reports summarized the economic potential for saving in Vietnam. Saving potential for biomass is first estimated in the present study. Obviously, the first year that these technologies are introduced is 2005.

Table 4.11: Conservation technologies in Vietnam

Conservation technology	Energy saving (PJ)				Inv. cost (USD/GJ.)
	2005	2010	2020	2030	
Other industry - Coal	0.318	0.903	3.150	7.118	0.816
Other industry - FO	0.274	0.771	2.835	7.354	3.112
Industry-Electric lighting	0.13	0.476	2.113	6.975	-
Other industry - Electric motor	0.186	0.679	3.018	9.962	-
Other industry - Electric kiln	0.113	0.412	1.830	6.042	-
Industry - Agriculture residue	0.614	1.235	1.925	1.094	-
Industry - Fuel wood	0.94	2.31	5.28	6.14	-
Urban residential - lighting	0.378	1.136	4.024	8.718	8.694
Rural residential - lighting	0.12	0.35	0.67	1.26	8.964
Commercial - lighting	0.10	0.34	1.88	6.19	8.694
Electric appliance - rural	0.002	0.08	0.17	0.27	-
Electric appliance - urban	0.20	0.68	1.99	4.65	-

4.4. Other exogenous parameters

Electric system - The electric system in Vietnam has been organized into two sub-systems to enable the economics of decentralized technologies to be included in the model. The first sub-system is the national network with large sized power-generating plants that provide electricity to almost all customers (industry, commerce, urban residents, etc.). The second sub-system is designed to provide electricity to rural areas, and also to those who are currently without access to the national network. Fed to this sub-system are either stand-alone power plants (small hydro power plant, wind turbines etc.) or through the link with the first sub-system. The amount of electricity imported through the link will be decided by the model on the basis of cost comparison and technical conditions. The cost of transmission, distribution and the associated loss for both sub-systems are provided in table 4.12. Furthermore, an investigation of decentralized technologies which are broken down into family size and commune size technologies is carried out in annex II to determine proper parameters for MARKAL.

Table 4.12: Assumptions of the electricity systems*

Parameters	Unit	1995	2000	2005	2010	2015	2020	2025	2030
System 1									
Transmission efficiency	%	0.76	0.80	0.82	0.84	0.86	0.87	0.87	0.87
Peak reserve capacity	%	0.31	0.30	0.29	0.28	0.28	0.28	0.28	0.28
Transmission investment cost	USD/kW	300	300	300	300	300	300	300	300
Distribution investment cost	USD/kW	350	350	350	350	350	350	350	350
System 2									
Distribution investment cost	USD/kW	200	200	200	200	200	200	200	200

*: The data is estimated on the basis of information from [EVN].

Electric load profile - In MARKAL, electric loads can be differentiated according to three seasons: intermediate, summer and winter, which in turn are distinguished between day and night. Although these descriptions are not enough to show a typical load in reality e.g. peak load at 6 PM, they are adopted whenever possible.

Discount rate - Based on several sources, a discount rate of 10% is selected as most appropriate for analysis of the long-term technological choices in Vietnam.

Emission factors - The study considers three main greenhouse gases (GHGs): carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2O). Since appropriate national emission factors are not available, the emission coefficients of the Intergovernmental Panel on the Climate Change (IPCC) Reference Approach has been adopted [IPCC96]. These coefficients are based on accounting for the C in fuels supplied to the economy, irrespective of technologies consuming the fuel or whatever transformations the fuel went through before being finally consumed. The values of the emission factors of the various fuels used are given in annex IV.

4.5. The Vietnam Reference Energy System (RES)

By gathering the all above specified data together, the reference energy system of Vietnam could be built. It is graphically represented in figure 4.4.

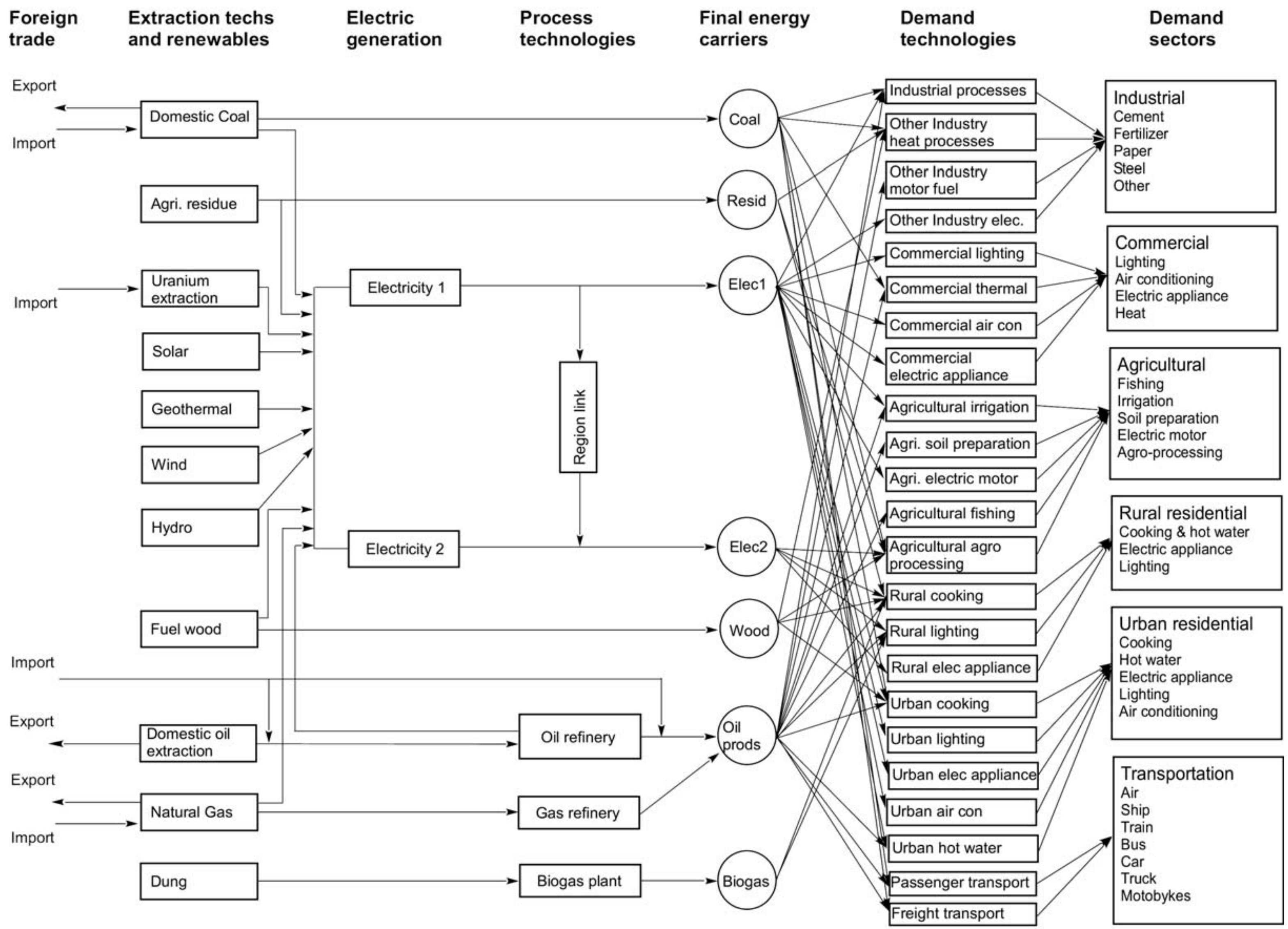


Figure 4.4: Reference Energy System (RES) of Vietnam

Chapter V

SCENARIO DEFINITION

The scope of the study is composed of two parts corresponding to two energy demand levels.

Part 1: Business as usual energy demand (BAU) - Here the end-use demand has been forecasted with an assumption that the current trends of energy consumption are kept moving toward the future.

Part 2: Efficiency energy demand (EFF) - Here the end-use demand has been forecasted with full considerations of the saving potentials that are represented by the addition of some end-use advanced improved technologies and conservation technologies.

Each of the above demands can be satisfied by multiple sets of technologies. A combination of a set of technologies and a demand is called a scenario which is depicted in figure 5.1.

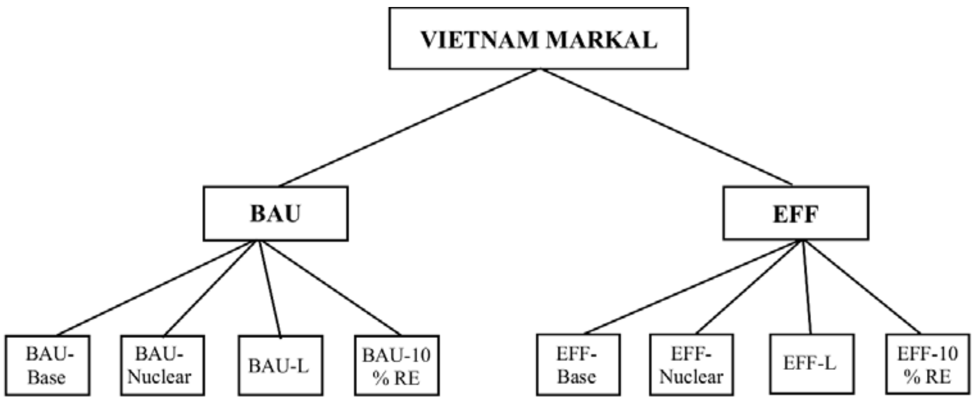


Figure 5.1: Structure of considered scenarios

A total of eight scenarios will be investigated.

Scenario 1: BAU energy demand with base technologies (BAU–Base)

Scenario 2: BAU energy demand with nuclear as a power plant candidate (BAU–Nuclear)

Scenario 3: BAU energy demand with a learning curve effect (BAU–L)

Scenario 4: BAU energy demand with 10% renewable energy (BAU–10% RE)

Scenario 5: EFF energy demand with base technologies (EFF–Base)

Scenario 6: EFF energy demand with nuclear as a power plant candidate (EFF–Nuclear)

Scenario 7: EFF energy demand with a learning curve effect (EFF–L)

Scenario 8: EFF energy demand with 10% renewable energy (EFF–10% RE)

5.1. Description of considered scenarios corresponding to the BAU energy demand

5.1.1 BAU energy demand with base technologies (BAU–Base)

This scenario investigates the energy system in the context that the current trend in the energy supply system maintains toward the future, i.e. without strong policy intervention. This case therefore serves as the basis (Basecase) for analyzing different strategies of energy supply and emission control. The main assumptions and parameters for this case have already been defined in the previous sections.

5.1.2 BAU energy demand with nuclear scenario (BAU–Nuclear)

While nuclear power plants have been closed down in European countries and North America, interests for these are still growing in Asian countries, including Vietnam [WNAa]. According to the power master plant stage V, a nuclear power plant will be needed in 2019. In 1998 as a preparation step, the Ministry of Industry signed a Memorandum of understanding (MOU) with Canadian and South Korean partners to develop the first nuclear power plant in Vietnam. According to this, the Canadian Atomic Energy Company and Daewoo Corp. will cooperate with the Institute of Energy and the Vietnam Atomic Energy Agency as local partners to complete a one-year pre-feasibility study at an estimated cost of 1 million USD [IE00a] [TP02].

Nuclear power plants require high capital investment but this can be compensated by the low cost of day to day operations, as such nuclear power plants are often designed to operate at base load. In addition, long construction time, usually 8-10 years, means that care should be taken in the planning model. Obviously, nuclear plants help to avoid many problems associated with the combustion of fossil fuels, but the high waste disposal and the risk of radioactive contamination still often overshadow the advantages. This builds up a huge psychological barrier that needs to be overcome while implementing any nuclear program.

This scenario examines the overall system in the case where a nuclear power plant is included as a candidate power plant. Due to the sensitive features of nuclear energy, development of nuclear power plants here will be subject to careful control. A maximum contribution of 2.4 GW is allowed for this energy form and the first plant will be introduced no earlier than 2020.

5.1.3 BAU energy demand with a learning curve effect (BAU–L)

R.William and G. Terzian analyzed the empirical relationship between cumulative industry-wide production and the unit price for photovoltaics in [WiTe93]. The study indicated that between 1976 and 1992, inflation-adjusted prices dropped by 18% with every doubling of cumulative production. The cost of wind turbines similarly has fallen 4% with every doubling of cumulative production between 1982 and 1997 [IEA00]. This is resulted from the accumulation of knowledge and experience in the manufacturing, installing and operating processes of technologies & is called the learning effect [Carpros] [IEA00]. For competitive assessment of the possible contribution of renewable energy, the learning effect therefore must be taken into consideration.

Mathematically, the learning effect is represented by a learning curve which defines the unit cost of a given technology as a function of the cumulative capacity as a measure of the knowledge accumulation [SeeKram99]. It can be expressed as the equation:

$$SC(C) = SC_0 * (C / C_0)^{-b} \tag{5.1}$$

where:

SC: Unit cost as a function of cumulative capacity C

b: Learning index

C_0 : Initial cumulative capacity (at t = 0)

SC_0: Initial specific cost (at t = 0)

Various studies have been made to obtain the learning curves for various technologies and to include learning curves in energy system modeling [SeeKram99] [TsengLee99] [IIASA97]. According to their findings, for each technology, two distinct phases are visible: the research, development, and demonstration (RD&D) phase, and the commercialization phase. Technologies belonging to RD&D phases are wind turbine and photovoltaics. Cost reduction in this phase is significant owing the "learning by doing" and also "learning by using" effects. Of course improvements in technologies get slowed down with time mainly due to the "learning by using" effect and economy of scale. Technologies in the commercialization phase are called mature technologies. Examples of this are gas turbine and advanced coal power plants.

Three cases have been analyzed for modeling the learning effect at IIASA, the high growth, the moderate growth and the econological driven case [Messner97]. In our study, results from the moderate case have been adopted, and for the Vietnamese context following assumptions are made:

- Learning trend for power generation technologies which are observed internationally will also occur in Vietnam due to imports of technologies and technical know-how.
- The path of learning will be of typically exponential shape as commonly recorded.
- The percentage of reduction in the unit cost in Vietnam will be the same as the percentage projected in the referred study over the 1990-2050 period.

Table 5.1 provides the projected unit costs for different technologies obtained by using the following equations

$$GR_{1990-2050,IIASA} = \left(\frac{C_{2050,IIASA}}{C_{1990,IIASA}} \right)^{(\frac{1}{60})} - 1 \tag{5.2}$$

and

$$C_{n,Vietnam} = C_{2000,Vietnam} * (1 + GR_{1990-2050,IIASA})^{(n-2000)} \tag{5.3}$$

where:

$GR_{1990\text{-}2030,\ IIASA}$ is growth rate of investment cost between 1990 & 2050 concluded by IIASA,

$C_{1990,\ IIASA}$, $C_{2050,\ IIASA}$ are investment costs in year 1990, 2050 considered in IIASA,

$C_{2000,\ Vietnam}$, $C_{n,\ Vietnam}$ are investment costs in year 2000, and n^{th} year for Vietnam.

Table 5.1: Effect of learning curve on various technologies

Technology	Investment cost USD/kW in 2000	Investment cost USD/kW in 2030
PV-Grid connected	7200	4509 (*)
PV-Decentralized	5900	3695 (*)
Wind large scale	900	722 (*)
Wind decentralized	1800	1443 (*)
Geothermal	2000	1500 (**)
Biomass gasification	2000	1136 (**)

* estimated according to the moderate case of IIASA [Messner97].

** estimated based on the assumptions of the American Department of Energy [DOE97].

5.1.4 BAU energy demand with an objective of 10% renewable energy (BAU–10% RE)

Presently, the cost of electricity from renewable energies per unit is generally still higher than that from fossil fuel. However, conventional cost calculations often exclude environmental externalities. For a fair assessment of renewable energies, such benefits should be considered as well. Nowadays, when the question on climate changes is critically rising, developing countries would have a chance to replace fossil energy sources by clean energies through the so-called Clean Development Mechanism (CDM). According to this mechanism, enterprises in industrialized (Annex I) countries invest in the establishment of state of the art technologies in developing countries. The lower technology baseline in developing countries would imply that such an investment would result in greater potential reductions in CO_2 that would have a similar investment in Annex I countries. In return for this investment, the Annex I countries would get benefits in form of CO_2 reduction as compared to the host country baseline. This CDM would thus be a more cost-effective mechanism for mitigating climate change than if the Annex I country had to implement an equivalent reduction at home. Host developing countries in return are given with modern technologies at specially subsidized prices [UNEPb].

This mechanism is captured in the study by fixing the share of renewable energies to 10%. The resulting increment cost together with the environmental benefits (compared with the basecase) as the result will then be used to calculate the cost per ton of avoided emission (CO_2). This value will then be compared with those from Annex I countries.

$$CEA = (MCOE_{10\%RE} - MCOE_{Basecase}) / (MER_{Basecase} - MER_{10\%RE}) \qquad (5.4)$$

where:

CEA is the cost of avoided emission,

$MCOE_{10\%RE}$ is the marginal cost of energy for the case 10%RE,

$MCOE_{Base}$ is the marginal cost of energy for the basecase,

$MER_{10\%RE}$ is the marginal emission rate for the case 10%RE,

MER_{Base} is the marginal emission rate for the basecase.

5.2. Description of considered scenarios corresponding to the EFF energy demand

Scenarios corresponding to Part II are different to scenarios of Part I only in the type of energy demand scenario adopted. Descriptions of corresponding scenarios are similar to that of Part I and therefore not included here.

Chapter VI

RESULTS AND ANALYSIS

In this section, the results of different scenarios discussed in section V will be evaluated. The scenarios corresponding to the first energy demand - Business as Usual (BAU) are described and analyzed in section 6.1 whereas section 6.2 devotes to the analyzes of the results of other scenarios corresponding to the energy efficiency demand (EFF).

6.1. Part 1: Business As Usual energy demand (BAU)

6.1.1. BAU–Base scenario

In this reference case, the current trends in the energy sector (both energy production and consumption) have been assumed to continue. Some observations based on the results are given below (more concrete results are found in annex V).

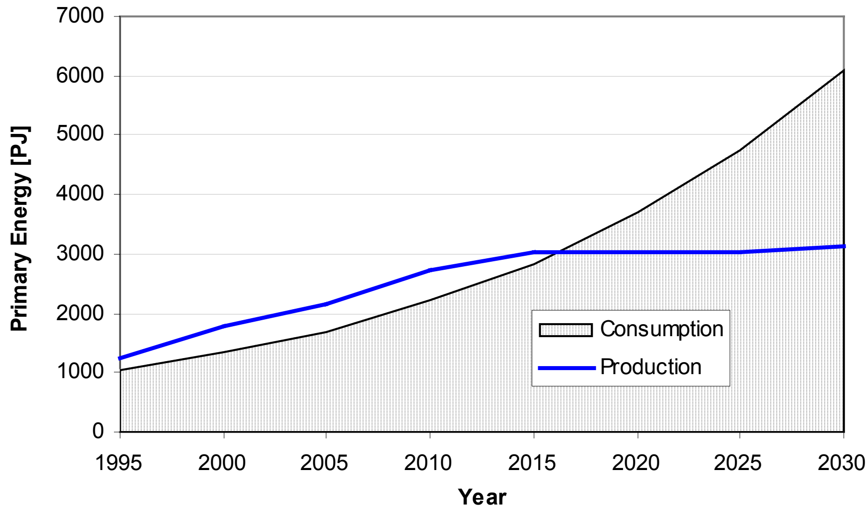


Figure 6.1: Development of primary energy consumption and production in the BAU–Base scenario

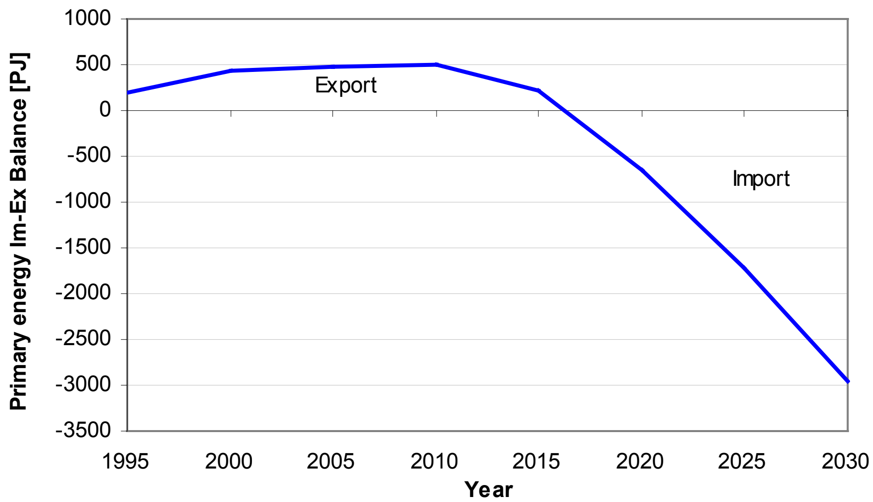


Figure 6.2: Primary energy import - export balance in the BAU–Base scenario

As indicated in figure 6.1, the development of primary energy consumption is expected to grow from 1,040 PJ in 1995 to 6,102 PJ in 2030, i.e. at an average growth rate of 5.2%. This growth reflects the least-cost energy supply for Vietnam in the investigation period from 1995-2030. On the other hand, in the same period, the primary energy production grows at the rate of 2.7%, explicitly from 1,252 PJ in 1995 to 3,307 PJ in 2030. As the result, the energy import - export balance of Vietnam will change significantly (Figure 6.2). Thus, from a net energy exporter, Vietnam will need to import energy after 2015. Proportion of the imported energy will increase significantly after 2020 when the primary energy production is not able to satisfy the fast growing energy consumption. This leads to the state that by 2030, about 48% of energy consumption in Vietnam must be imported and coal will make up the major part (Figure 6.2). Such an energy deficit will have negative effects on the country's balance of payment and the availability of foreign currency resources.

Big changes also occur in the structure of energy consumption. Coal proportion increases from 10.6% (110.6 PJ) in 1995 to 48.7% (2884.6 PJ) in 2030. Similarly, gas increases from 1% (7 PJ) in 1995 to 11% (678.3 PJ) in 2030. Average annual growth rates of coal and gas consumption are 9.8% and 14%, respectively. In contrast, the share of biomass decreases from 57% in 1995 to just 8% by 2030 (Figure 6.3 A & B).

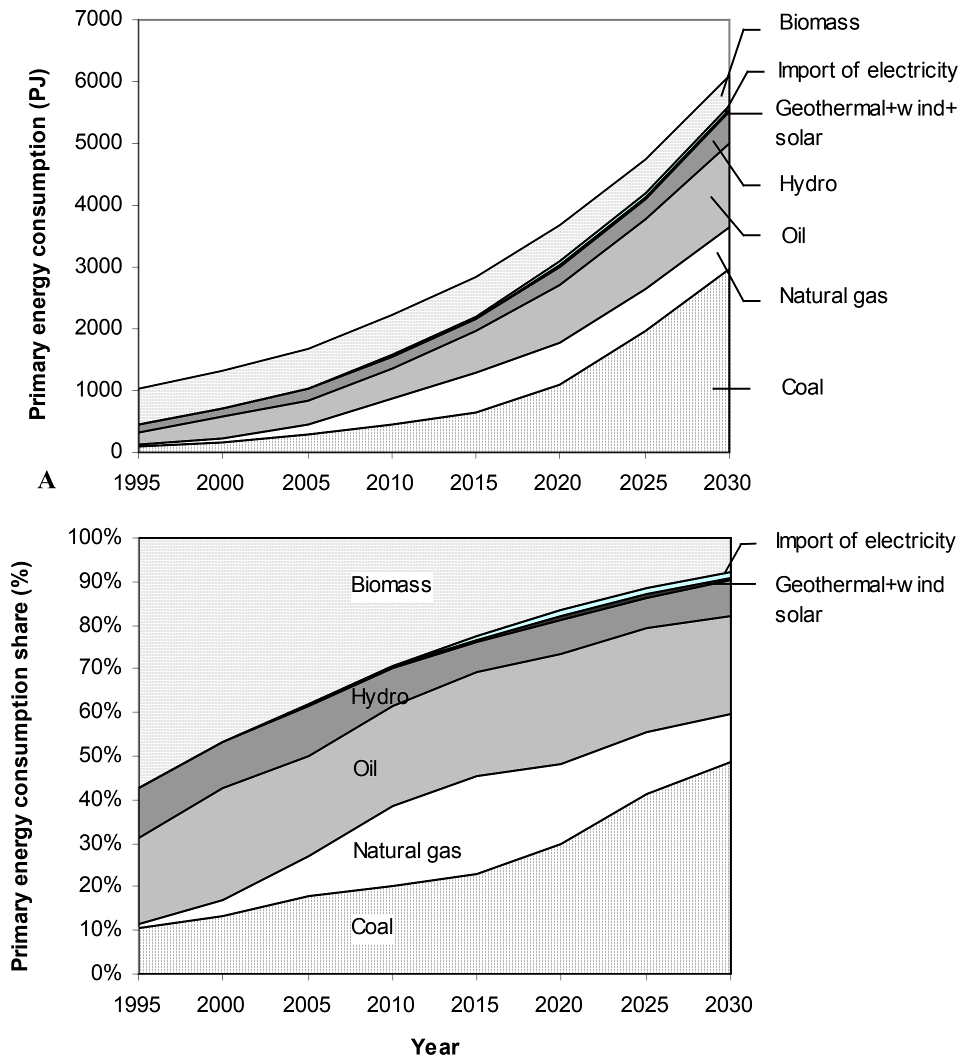


Figure 6.3: Development of primary supply in the BAU–Base scenario
A - in absolute values; B - in shares

The switch from biomass to gas and coal is mainly caused by the developments of consumption sectors. Biomass as a traditional fuel in rural areas becomes less consumed while coal and oil as energy sources in many other sectors, especially the industry and the production of electricity, are more and more demanded (Figure 6.5). As indicated in figure 6.4, the share of the residential sector in the final energy demand is expected to reduce from 57% in 1995 to 18% in 2030, while the shares of all other sectors increase. Most significant changes occur in the industry sector (from 24% to 52%) and the transportation sector (from 14% to 23%). In absolute figures, the final energy demand in the industry sector will increase from 221.43 PJ in 1995 to 2,000 PJ in 2030 (6.5% per year); in the transportation sector, from 124.88 PJ in 1995 to 897.6 in 2030 (5.8% per year), and in the residential sector, from 518.67 PJ in 1995 to 702.5 PJ in 2030 (0.9% per year).

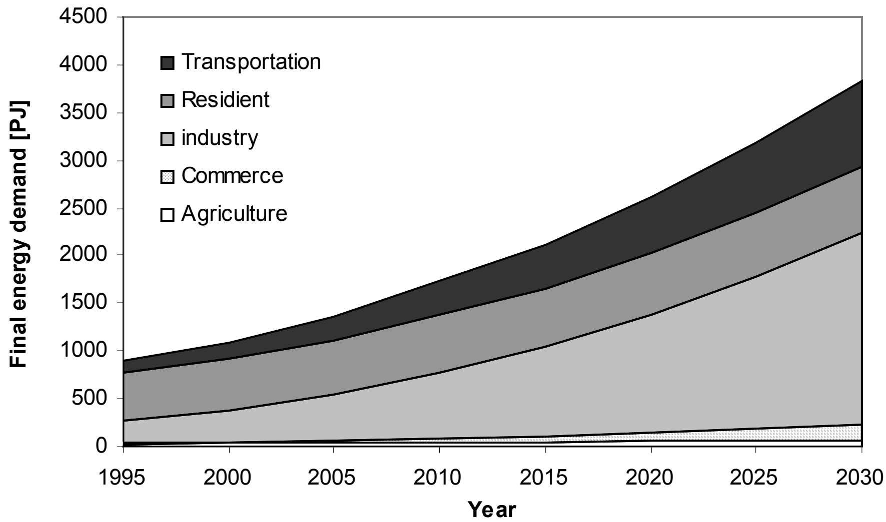


Figure 6.4: Final energy demand development between 1995-2030 of the BAU case

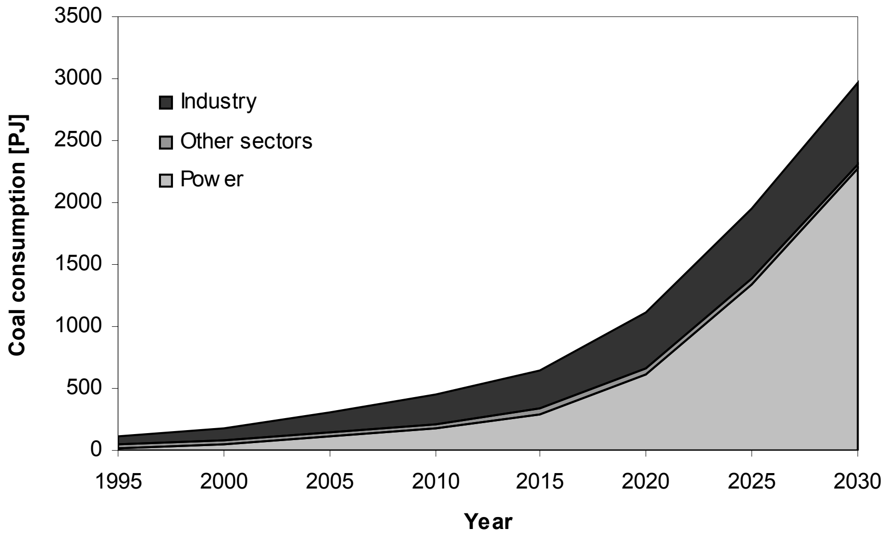


Figure 6.5: Distribution of coal use by sectors between 1995-2030 in the BAU–Base scenario

Concerning the electric sector, there is also a structural change. As can be seen in figure 6.6, the share of hydropower in the total electricity production output reduces from 73% in 1995 to 12.8% in 2030, whereas coal undergoes a drastic growth from 12.7% (6.6 PJ) in 1995 to 68% (861 PJ) in 2030. This reflects the generally attractive economy of coal technologies over other technologies. Change also happens in contribution of gas based power plants. The share of 52.8% in 2015 recommends that these plants offer an economically attractive option for electricity production, even better than coal and hydro. However, It does not seem economically viable with imported gas as its capacity does not increase after 2015 when local production of gas reaches its upper bound.

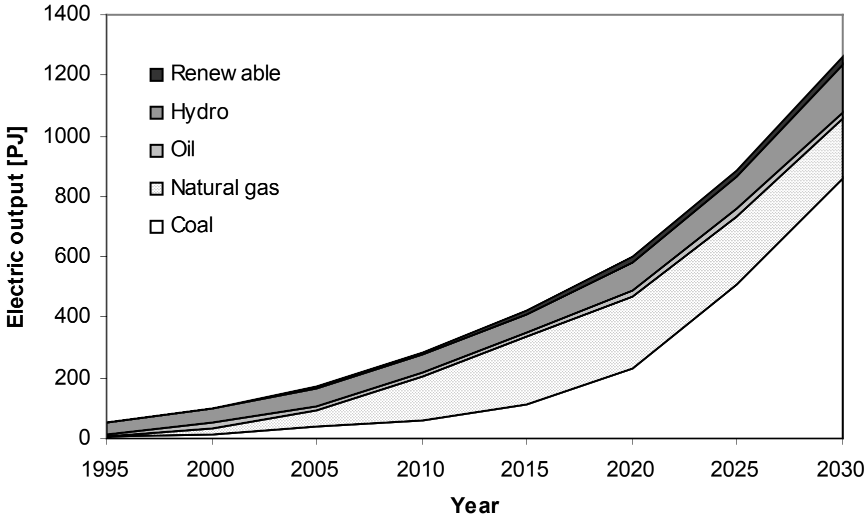


Figure 6.6: Development of electricity production by energy carriers in the BAU–Base scenario

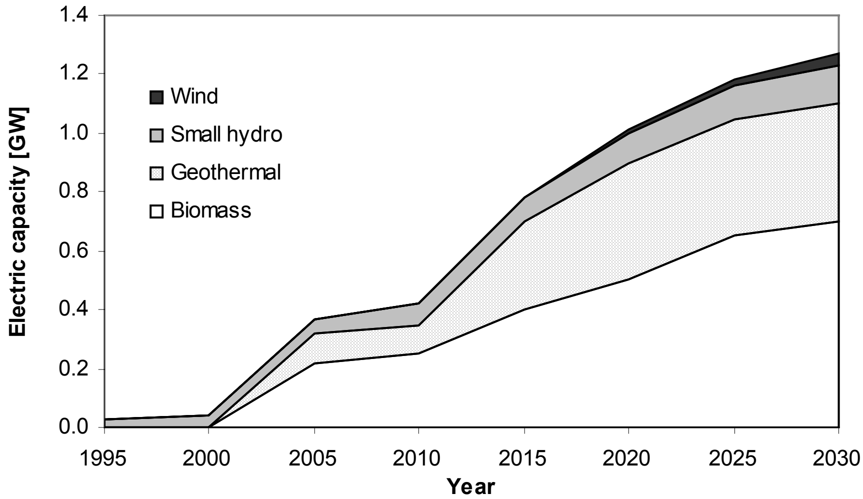


Figure 6.7: Development of renewable energy technologies in the BAU–Base scenario

Renewable energies (excluding large hydropower plants) would generate 22.87 PJ of electricity (1.27 GW), occupying 2% of the output of the total energy system in 2030 (Figure 6.7). The main contributors are biomass and geothermal with capacities of 0.7 and 0.4 GW, respectively and followed by small hydropower. PVs are not chosen even as decentralized technologies because of their relatively high investment cost. Small wind turbines with a total capacity of 40 MW by 2030 are selected but large wind farms are not due to the high transmission cost. This is because the cost of the transmission line is the same for all electricity generation technologies regardless of how much it is used. Hence, when allocated to kWh, this cost portion will not favor wind turbines with a capacity factor below 0.35 and a lifetime of 20 years as opposed to conventional power plants e.g. coal with capacity of 0.8 and a longer lifetime (30 years).

Regarding general renewable energy (including also biomass for heating, large hydro plant), there is an increase of about 1% per year between 1995-2030. With the profound reduction in the consumption of biomass as stated above, this growth indicates a strong increase in the consumption of other renewable energies of which the main contributor is hydro energy. Such increase however does not match the country's energy consumption trend. As such, its share will reduce (from 69% in 1995 down to 17% in 2030) (Fig 6.3). By 2030, the renewable energy consumption represents just 48% of its technical potential. The majority of untaped potential lies in wind energy.

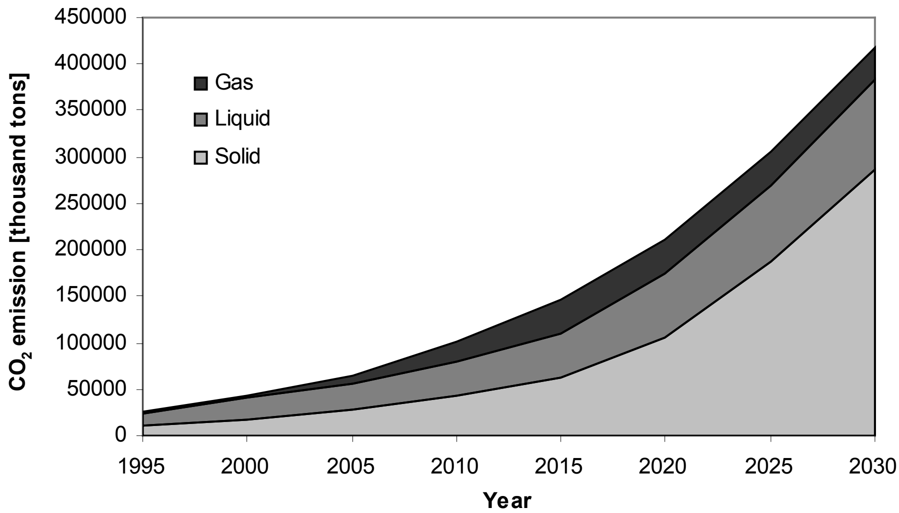


Figure 6.8: Development of CO_2 emission in the BAU–Base scenario

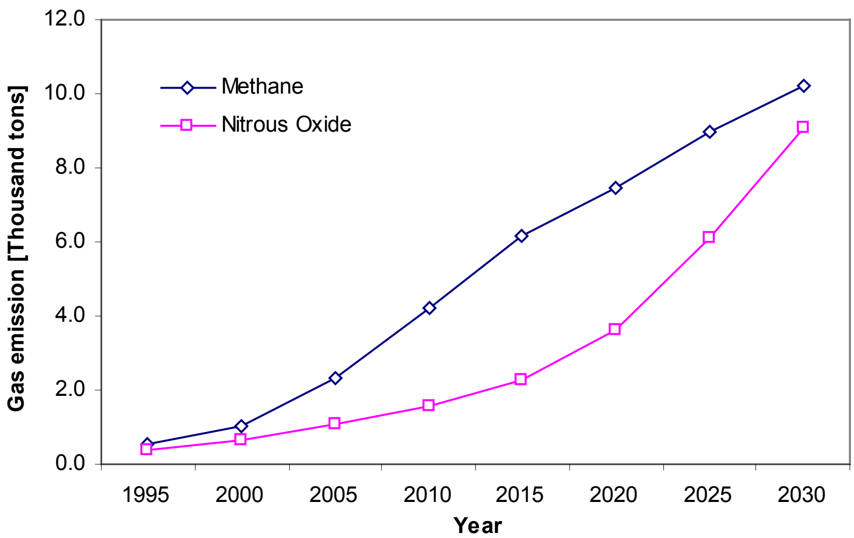


Figure 6.9: Development of CH_4 and N_2O emission in the BAU–Base scenario

Figure 6.8 shows the expansion of CO_2 emission from the energy sector in Vietnam according to fuel types over the studied time period. The total CO_2 emission from the energy sector is expected to increase from 25.03 million tons in 1995 to 418 million tons by 2030. Counting per capita, the increase would be from 0.3 tons in 1995 to 4 tons in 2030, equivalent to a growth rate of 7.2% per year. Compared to the CO_2 emission in developed countries these figures are still quite low (the emission per capita in Germany in 1990 was 15.1 tons, England 10.2 tons, and France 9.5 tons [Schaf03]). However, if the rate of 7% continues, there are only 20 years left until the CO_2

emission of Vietnam reaches the level of Germany in 1990. Proper measures therefore need to be taken correctly in the development stage to control the CO_2 emission. Among the CO_2 emission causes, coal is the main culprit since it is increasingly used in the energy and industry sectors.

The emission of CH_4 is much lower. In 1995 the energy sector emitted only 0.53 thousand tons of CH_4 which is expected to increase to 10.2 thousand tons by 2030 (Fig 6.9). The main sources of CH_4 emission are coal and biomass, of which coal would contribute the major part because the consumption of biomass in Vietnam is decreasing gradually. Similar to CH_4, the emission of N_2O in Vietnam is not much (Figure 6.9), however it increases at a considerable rate of 9.4% per year, from 0.39 thousand tons in 1995 to 9.07 thousand tons in 2030.

6.1.2. BAU–Nuclear scenario

The inclusion of nuclear energy into the system does not change the technological choice of the program significantly. A nuclear power plant of 1.2 GW would first be added in 2020. The capacity would then be doubled to 2.4 GW in 2025.

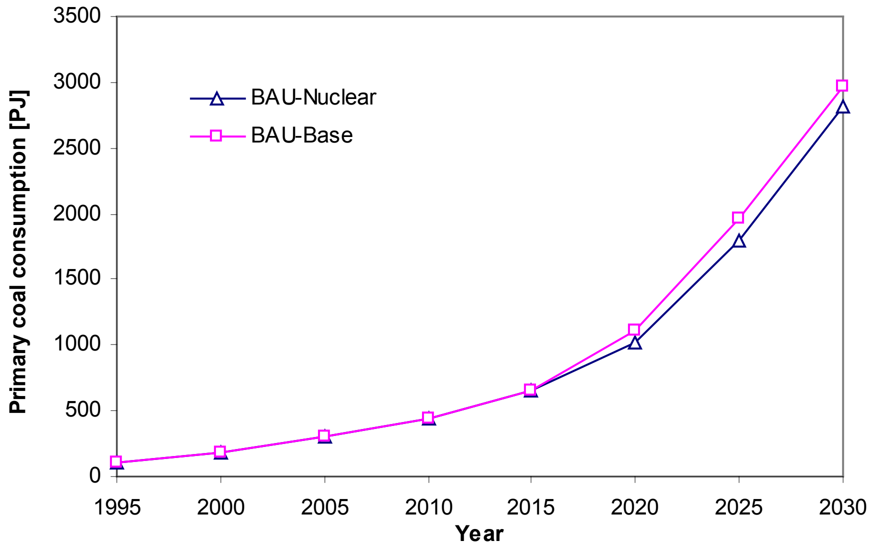


Figure 6.10: Coal consumption in the with nuclear scenario (BAU–Nuclear) and without nuclear scenario (BAU–Base)

Apparently, the introduction of nuclear power will reduce coal consumption (Figure 6.10) and therefore less coal will be imported. Compared with the coal demand in the BAU–Base scenario, there will be 84.6 PJ and 160.6 PJ of coal decreased in 2020 and 2030, respectively. Consequently, the dependency on foreign energy will decrease by about 3% compared to the base case (from 48% to 45%). Concerning the environmental consequences, the decrease in coal import and consumption results in reduction of greenhouse gas emission. As shown in figure 6.11, the CO_2 emission by 2030 in the BAU–Nuclear scenario will be 4% lower than the BAU–Base scenario, explicitly 15.5 thousand fewer tons of CO_2 will be emitted into the environment.

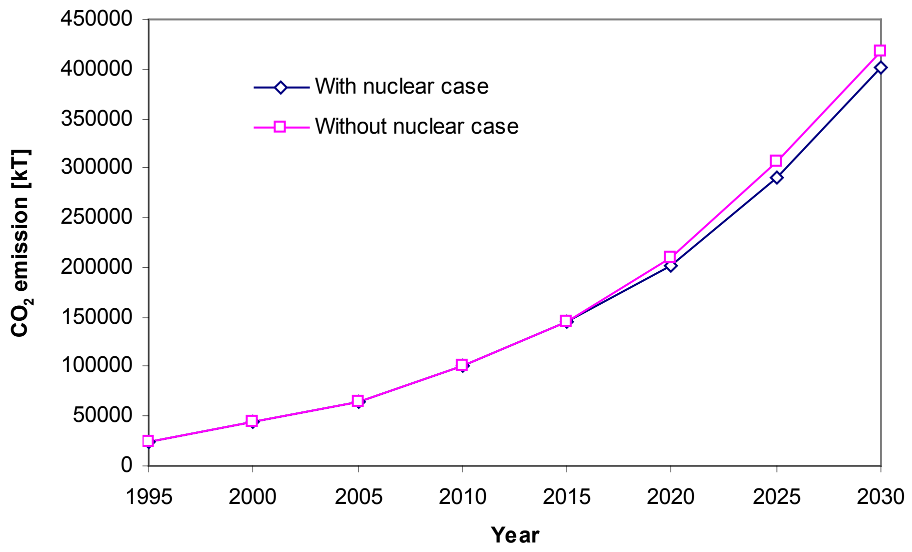


Figure 6.11: Development of CO_2 emission in the with nuclear scenario (BAU–Nuclear) and without nuclear scenario (BAU–Base)

6.1.3. BAU–L scenario

Along with the introduction of the learning effect, only two more renewable energy technologies become competitive, the centralized fuel wood gasification and the decentralized solar photovoltaics with capacities of 200 MW and 10 MW by 2030, respectively. Relatively slow improvement speed and the transmission cost (for the centralized technologies) are assumed to be the reasons for the incompetitiveness of other technologies. Because of such small developments, the overall picture of renewable energies would not change much within the investigated period. Figure 6.12 shows that biomass and geothermal remain the main contributors, representing more than 80% of the total installed capacity by 2030.

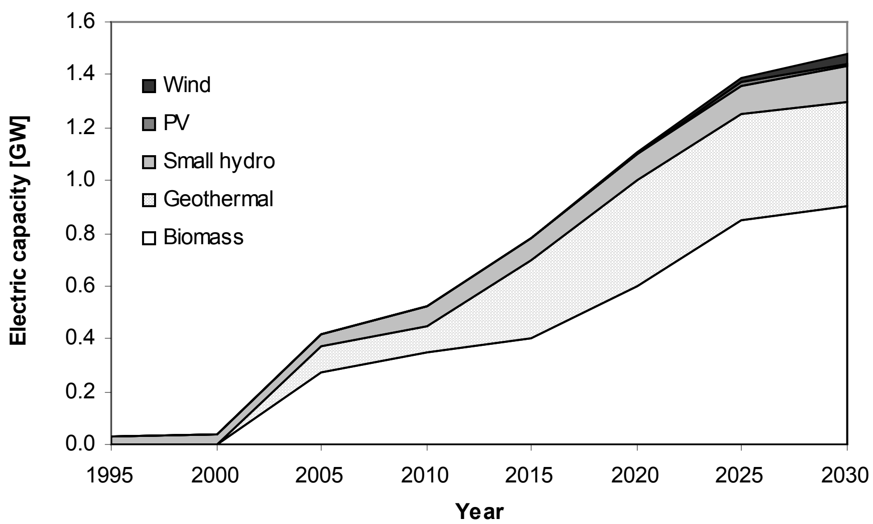


Figure 6.12: Development of renewable energy technologies in the BAU–L scenario

6.1.4. BAU–10% RE scenario

When an objective of 10% of electricity coming from renewable energy sources by 2030 is fixed, the structure of selected renewable energy technologies changes considerably as shown in figure 6.13.

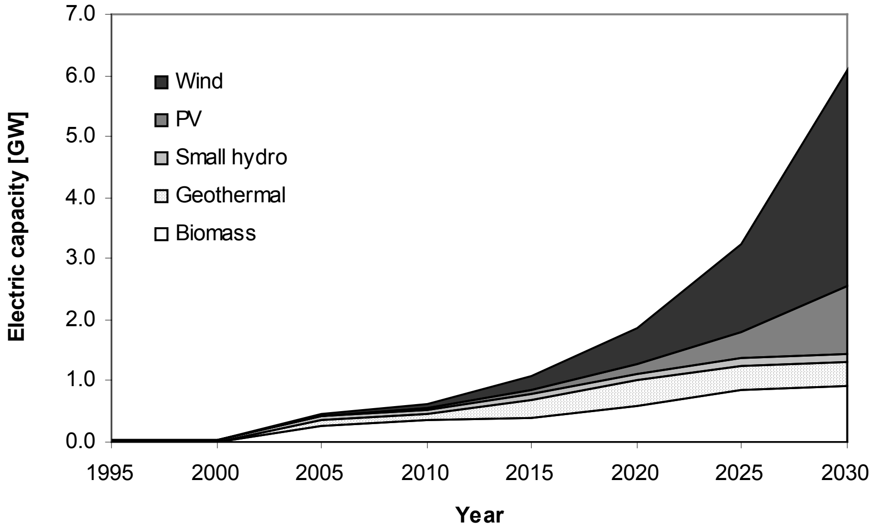


Figure 6.13: Development of renewable energy technologies in the BAU– 10% RE scenario

Wind becomes the biggest renewable energy technology with capacity equaling the maximum allowable level of 3.54 GW by 2030, indicating that the learning effect makes wind more and more competitive over other renewable energy technologies. This also means that if the current trend continues over the next period, wind will be able to compete directly with conventional energies. PV as a centralized building integrated technology is also selected but only when wind reaches its maximum allowable level, meaning that solar technologies can not compete with wind. As the result of this contribution, the dependency on foreign energy will be reduced to 45.3% from 48% of the BAU–Base scenario. Furthermore, coal consumption for production of electricity is reduced and CO_2 emission is, therefore, decreased (Figure 6.14).

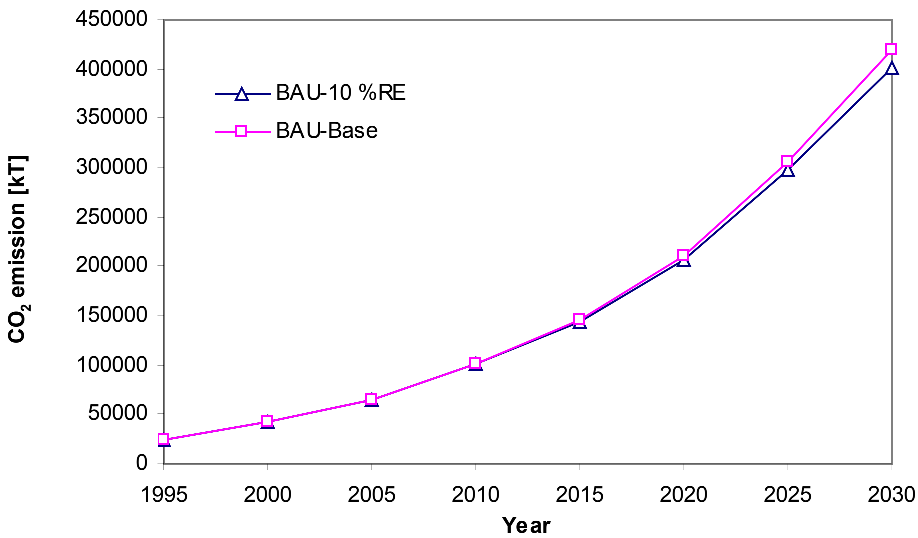


Figure 6.14: Development of CO_2 emission in the BAU–10% RE scenario against that of the BAU–Base scenario

On the other hand, the not yet competitiveness of renewable energy in comparison to conventional technologies means that more cost will incur when the contribution of renewable energy is fixed. It is possible then to calculate the cost of CO_2 by dividing the incremental cost by the amount of avoided CO_2. Here it is 16.9 USD per ton CO_2.

6.2. Part 2: Energy efficiency energy demand (EFF)

6.2.1. EFF–Base scenario

The introduction of improved demand technologies and conservation technologies obviously lowers the final energy demand (Figure 6.15). The reduction in final energy demand in turn, leads to a reduction in the primary energy consumption; hence, a smaller amount of primary energy import would be required (Figure 6.16).

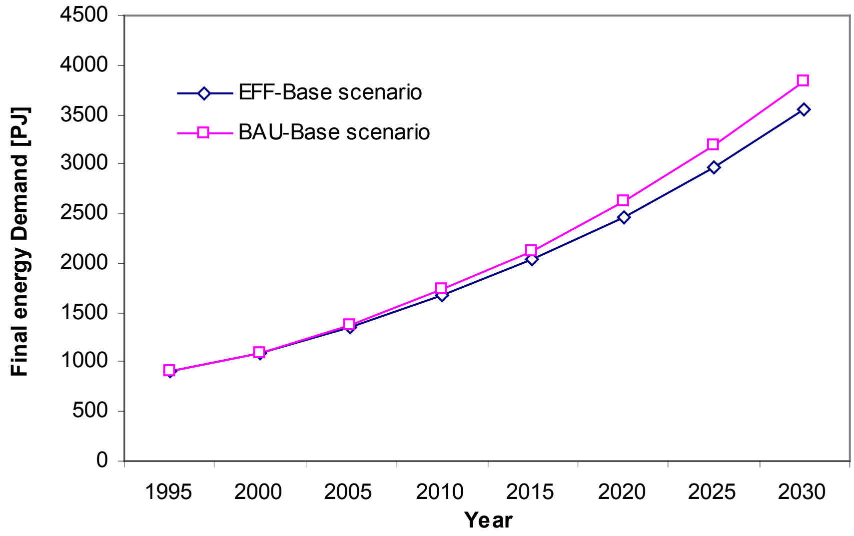


Figure 6.15: Final energy demand corresponding to the BAU–Base scenario and the EFF–Base scenario

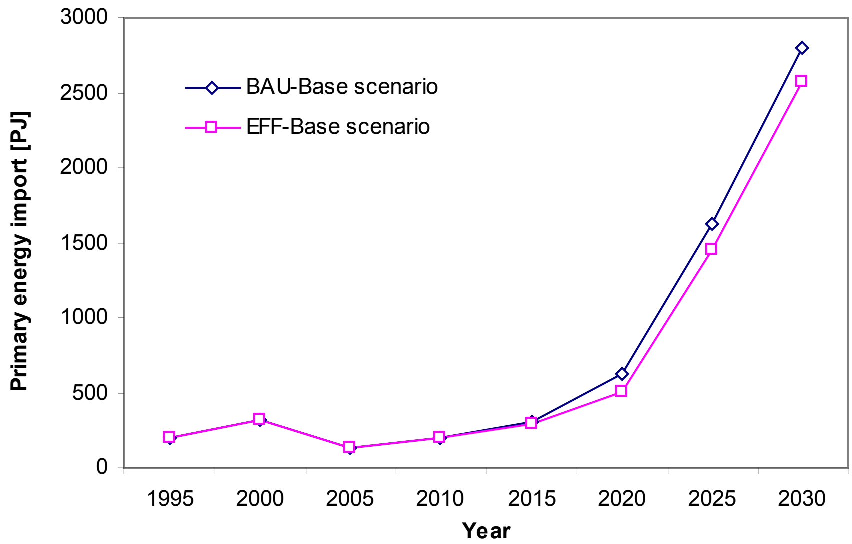


Figure 6.16: Primary energy import corresponding to the BAU–Base scenario and the EFF–Base scenario

The reduction in final energy demand, however, does not change the selection of electricity generation technologies but only lowers the magnitude. Thus, by 2030 coal remains the main fuel source for electricity generation, followed by gas and hydro. As the result, the emission will be lower (Figure 6.17). The shadow cost of this emission reduction, however, could not be calculated because data for some conservation technologies are not sufficient.

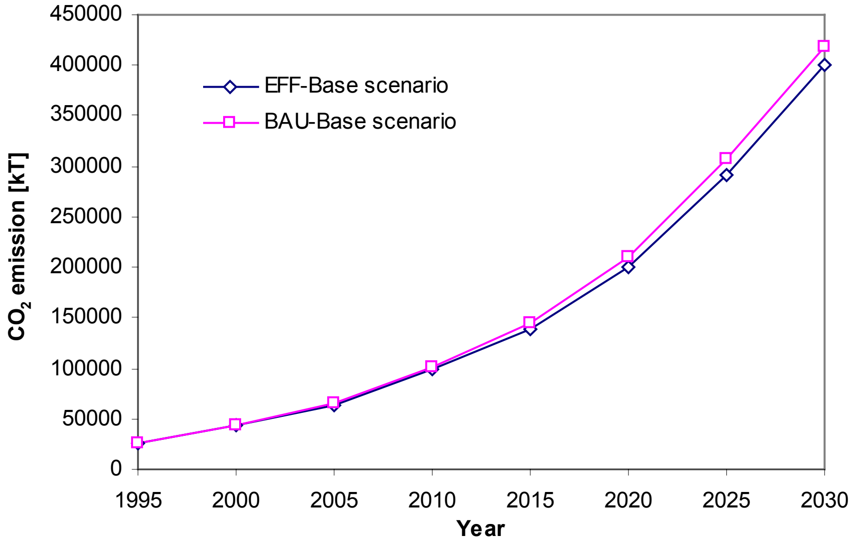


Figure 6.17: CO_2 emission corresponding to the BAU–Base scenario and the EFF–Base scenario

6.2.2. EFF–Nuclear scenario

Similar to the BAU–Nuclear scenario (part 1), a nuclear power plant will first be added in 2020 with a capacity of 1.2 GW, which will then be doubled to 2.4 GW in 2025. This replacement results in the reduction of coal consumption and less CO_2 emission to the environment (the cost of the avoided CO_2 is estimated to be 5.5 USD/ton). Thus, the introduction of nuclear energy brings a double benefit: a lower system cost and a lower CO_2 emission level.

6.2.3. EFF–L scenario

Decentralized PV with a capacity of 10 MW by 2030 and fuel wood gasification as centralized technology with a capacity of 200 MW by 2030, become competitive when the learning curve effect is introduced. This is similar to what can be observed in the BAU–L scenario that was previously represented.

6.2.4. EFF–10% RE scenario

When 10% of electricity from renewable energy by 2030 is fixed, there is a change in the selection of renewable energy technologies as compared to the BAU–10% RE scenario. Wind is still the biggest renewable energy technology with a peak of its maximum allowable level of 3.54 GW by 2030, biomass with 0.9 GW, small hydro with 0.15 GW, geothermal with 0.4 GW. Only the capacity from solar is reduced, from 1.11 GW in the BAU–10% RE to 0.57 GW by 2030. This indicates that solar technologies are not as competitive as other renewable technologies, therefore when there is a reduction in demand it will be the first to be withdrawn from the list of mobilized capacity. The development of renewable energy capacity is represented in figure 6.18.

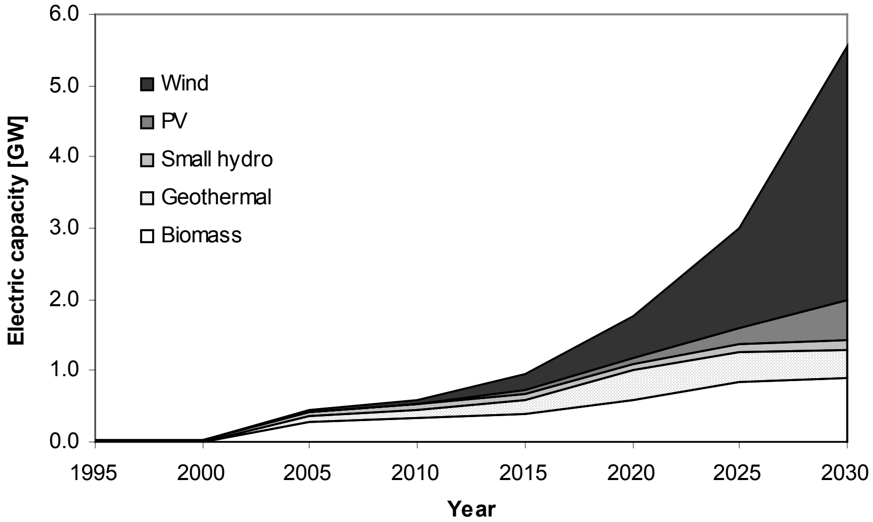


Figure 6.18: Development of renewable energy capacity in the *EFF– 10% RE scenario*

In the same manner as what has been done in the BAU–10% RE, the avoided cost of CO_2 is estimated. It is 3.2 USD/ton. Compared to the BAU–10% RE it is much lower. The decrease in required capacity of solar PV is the reason for this reduction (from 1.11 GW to 0.57 GW) since PV is very expensive but very limited in operation - it can be operative only during the daytime.

6.3. Potential of CDM in Vietnam

The potential of CDM is examined by comparing the avoided costs of CO_2 corresponding to the two above renewable energy scenarios[9] with that of some industrialized countries (annex I countries).

This value for the Netherlands, UK, Italy, and Japan is respectively 10.8, 14.3, 66.6, 96.4 USD/t whereas it is in the range of 3.2 - 16.9 USD/t for Vietnam [ECN00]. This indicates thus the potential of CDM in Vietnam.

[9] In reality, potential of CDM for a country can be diverse. It could be a DSM programme or a new type of power plant…etc.

Chapter VII

SUMMARY AND CONCLUSIONS

The present study aimed at optimizing the long term energy supply and demand in Vietnam with special consideration of the potential of renewable energy resources. In fulfilling this broad objective, MARKAL was chosen to be adapted to the specific energy conditions in Vietnam. In connection with this objective, various activities were undertaken as important contributions of the present study:

(i) Assessing the potential of renewable energy resources in Vietnam,

(ii) Identifying proper technologies for Vietnam,

(iii) Making long-term forecast of the energy demand for Vietnam,

(iv) Establishing database on energy technologies including conventional technologies and renewable technologies,

(v) Establishing the reference energy system (RES) for Vietnam,

(vi) Identifying ways to model renewable energy resources in MARKAL,

(vii) Cost-benefit analysis of the energy sector in Vietnam through developing multiple futuristic scenarios,

(viii) Assessing green house gas emissions for above generated scenarios,

(ix) Assessing proper decentralized technologies for isolated areas.

The following methodologies were contributed:

- *Methodology for assessing the potential of renewable energy resources in general and in Vietnam*: Renewable energies such as solar and wind are widespread, but exist at low densities. To make use of these energy resources, suitable sites need to be identified which not only have good resources but also must guarantee minimum disturbances to the surroundings. In the case of wind turbine, these conditions mean that wind turbines should be located within a certain distance from living areas to reduce noise and shadow effects. For solar PV, however these conditions are not applied because PVs practically cause neither noise nor pollutions. In addition, from the investor point of view, the investment cost should be as low as possible. Thus, for wind, the distance between the wind turbines to loads and existing transmission lines are usually taken into consideration. All these above mean that different methodologies must be developed respectively for each renewable energy and if possible these resource assessments should be carried out with the help of a GIS program.

- *Methodology for assessing the decentralized renewable energy technologies for isolated areas*: If the load is small and located far from the central grid, decentralized technologies, especially those of renewable energies, are technically and economically attractive alternatives. However, to decide among various decentralized technologies which is the most economical and suitable for a certain area, the study proposed a methodology for comparative assessment. Apart from technical and social aspects, levelized cost (LC) is a criteria for assessing the economics of a given technology. This section therefore helps (i) identify proper parameters for simulation of decentralized technologies in MARKAL (ii) identify upper limits for respective technologies and (iii) create maps of levelized cost for some typical decentralized renewable energy technologies as a guideline for the selection of suitable technologies for a certain isolated area in Vietnam.

- *Methodology makes a long-term energy demand forecast*: The purpose of the present study is to optimize demand and supply in Vietnam. Therefore, efforts are made in forecasting demands as detailed as possible and representing them in a useful demand or in quantity so that suitable technologies which determine demand consumption and the type of energy used can be selected. Especially in the case of renewable energy, such representations have helped identify their most potential consumers. A combination of different methods (energy intensity, energy elasticity, expert's opinions, cross-comparison with historical data from countries with a similar level of GDP per capita) for forecast have been used, depending on the end-uses. Special attention is paid to the residential sectors, in particular for those currently without access to electricity because these would be a potential market for renewable energies. In order to do this, rural and urban resident sectors are considered separately and non-electrified households are identified.

- *Methodology for modeling renewable energy technologies in MARKAL*: MARKAL is designed for long term energy planning. Like other economy scale models, the model was originally designed and applied in developed economies at the time when renewable energies accounted for only a small portion of the overall energy use and environmental problems were not seriously concerned. Therefore, renewable energy systems did not represent the central focus of MARKAL and there are no separate functions to handle renewable energy technologies in the model. Nevertheless, the model provides several parameters that could be applied to specify the existence of renewable energy technologies. The overall approach is that first characteristic of technologies are identified, then possible parameters are looked at to take these features into account. The local dependence of renewable energy technologies has been captured by multiple grades of technologies.

Interpretation of the results

Renewable energy potential

The results of the study indicate that Vietnam has a good potential for renewable energies. From the five investigated resources i.e. wind, solar, biomass, hydro and geothermal energy, wind appears to be the most promising because (i) the technical potential is rather big (160.76 GW) (ii) there are some excellent wind areas and (iii) wind energy technologies are experiencing much improvement in technologies and cost. In addition to this, bagass, hush and geothermal potential are important sources as their technologies are already competitive.

Results of various scenarios

Result of the BAU–Base scenario

(i) Aggregate primary energy consumption increases almost six fold over the 1995-2030 period, i.e. at an average growth rate of 5.2% per year. This is accompanied by structural changes. The contribution of coal increases from 10.6% in 1995 to 48.7% in 2030 and gas from 1% in 1995 to 11% in 2030. In contrast, the share of biomass decreases from 57% in 1995 to just 8% in 2030. Oil remains the main energy carrier which accounts for 26% in 2030.

(ii) Primary energy production grows in the same period at the rate of 2.7% per year. As the result, the energy import-export balance of Vietnam will change significantly. From a net energy exporter, Vietnam will need to import energy after 2015. The share of imported energy will increase significantly after 2020. By 2030, about 48% of energy consumption in Vietnam must be imported and coal will represent the major part.

(iii) Final energy demand will increase nine fold together with the switch in the structure of the consumption sectors. The dominated share of the domestic sector is replaced by industry and transportation sectors. The GDP in the same period increases more than 10 folds so overall, the energy intensity is reduced from 43.9 MJ/USD to 18.2 MJ/USD.

(iv) Within the electricity sector, the electric generation output grows 24 folds over the 1995-2030 period whereas generation capacity increases 14 folds. Also a structural change in capacity mix can be observed. Hydropower capacity reduces from 65% in 1995 to just 20% in 2030, whereas coal undergoes a drastic growth from 15% in 1995 to 60% in 2030. This reflects the generally attractive economy of coal technologies over other technologies. Change also happens in the capacity contribution of gas power plants. The share of 46% in 2015 suggests that these plants offer an economically attractive option for energy production. However, it does not seem economically competitive with imported gas as its capacity does not increase after 2015 when local production of gas reaches its upper bounds.

(v) By 2030, electric capacity from new renewable energy technologies represents 2% of the total power generation mix, of which geothermal and biomass occupy the biggest parts, reaching their allowable limits. Wind energy seems to be competitive but is not selected by the model mainly due to its inability to cover the transmission cost connecting with the construction of wind farms. Nevertheless, both wind and solar energy as decentralized technologies are selected.

(vi) The share of renewable energy decreases from 69% in 1995 down to 17% in 2030. In absolute values, there is an increase of about 1% per year between 1995-2030. With the profound reduction in the consumption of biomass as stated above, this growth indicates a strong increase in the consumption of other renewable energies and here the main contributor is hydro energy. By 2030 the renewable energy consumption represents 48% of its technical potential. The majority of untaped potential lies in wind energy.

(vii) In most cases, using decentralized technologies is more economical than extending the grid, and among available technologies, renewable energy technologies are more efficient.

(viii) Emission of CO_2 increases from 25.03 million tons in 1995 to 418 million tons by 2030 – 12.5 times mainly as the result of increasing coal consumption. Representing this figure per capita, the CO_2 emission increases from 0.3 tons in 1995 to 3.9 tons in 2030, equivalent to a growth rate of 7.2% per year.

(ix) The emission of CH_4 and N_2O is much lower but their growth rates are significant.

Results of the other scenarios

End-use efficiency improvement represents the least-cost option to meet the energy service demand and thus should be pursued regardless of what energy supply strategy is adopted.

The introduction of a nuclear power plant brings three benefits (i) total investment cost is reduced, (ii) emission level is reduced and (iii) foreign energy dependency is reduced.

The technology learning effects make PV and wind turbines as decentralized technologies more attractive. These improvements are, however, not fast enough considering the large scale exploitation of renewable energy technologies.

Compared to biomass fired power plants and integrated solar PV, wind turbines are the most cost effective; hence, they are the first to be selected after all other conventional technologies reach their upper limits. This indicates that if the current trend continues, wind energy will soon be able to compete directly with conventional energies.

At the current rate of improvement, the per unit cost of electricity generated from renewable energies is generally still higher than that from fossil fuels. Hence, investments in renewable energies will incur new cost to the system (compared with the base case). On the other hand, renewable energies reduce the emission of CO_2. It is then possible to assess the economics of renewable energy by the avoiding cost of CO_2 emission which is derived by dividing the incremental cost by the avoided CO_2. In Vietnam, this indicator is estimated to be in the range from 3.2 to 16.9 USD/ton CO_2.

The avoided cost of CO2 in Vietnam is lower than that of some selected industrialized countries. This indicates the potential of CDM for Vietnam.

Limitations and outlook for future researches

Limitations of MARKAL

- Since economic and energy demand projections are exogenous in the original MARKAL model, there is no feedback between the technology mix and the technology drivers. For example, a change in the technology mix toward better efficiency cannot reduce total demand or change fuel prices.

- Due to the nature of LP, MARKAL always chooses the least cost solution. Energy services with the lowest cost will take the entire market, and the competitors with only slightly greater costs will be excluded. However, in reality, factors other than price often affect decisions for fuel choices. These factors can only be addressed in MARKAL to a limited degree by means of a technology-based discount rate.

- With the objective to simulate the decisions needed for definition of the necessary energy supplies to satisfy the future energy demand, MARKAL does not capture detailed characteristics of technologies, for example, the hourly load profile, an important parameter considering the intermittent output of renewable energy technologies. This leads to a rough assessment of the influence of renewable energy technologies within the entire system.

- MARKAL can answer the questions: (i) when to invest in new generating units (ii) what type of generating units to install and (iii) what capacity of generating units to install but it can not answer the question (iv) where to invest in new generating units.

Limitations of the study

One of the difficulties in conducting this study is the provision of reliable data of the energy sector since up to now, there has not been any independent energy statistical organization in Vietnam. Therefore, data used in the study has been collected from different sources such as Vietnam Petro, Vina Coal, Electricity of Vietnam (EVN), General Offices of Custom and numerous research studies, international and domestic publications. In the course of processing this dataset, special attention has been paid to synchronizing the data consistently. The quality of the dataset is therefore decided by the above mentioned data sources. In cases where official data is not readily available, the used data is estimated based on internationally accessible information and a database from various organizations and publications, taken into account the specific conditions in Vietnam.

Emission levels have been estimated roughly not at the technological level and therefore could imply high uncertainty.

Some forms of renewable energies are not included such as wave energy, ocean thermal gradient, tidal and hydrogen, because their exploitation technologies are not advanced and can not be suitable for Vietnam.

For renewable energies, cost is the main factor affecting the selection of the representative technology. This can be unrealistic considering the dependence of technologies on the local renewable energy resource and the local demand.

Most technologies with the same input/output are represented by one representative in MARKAL. In reality, the situation could be different depending on locations.

Outlook

The study offers the overall picture of renewable energy potential and points out the extent that renewable energy technologies can penetrate into the energy market of Vietnam. Based on obtained results, planners and policy makers can visualize proper policies and guidelines to promote renewable energy technologies for a more sustainable and securer energy system.

The version of the MARKAL Vietnam can be applied for various energy related studies including the assessment of air pollution control strategies. An expansion of the model can be made by linking the model with the MACRO model so that end-use demand can be adjusted internally depending on the concluded supply solutions.

Besides CO_2, CH_4 and N_2O, there are several pollutants that are also emitted in the process of generation and consumption of energy. These pollutants can influence the choices of fuels and technologies in studies where the purpose is to control the emission. It is therefore necessary to include these pollutants in the model and, as already mentioned above, efforts should be made to represent the emission factors at the technology level.

In the context that Vietnam has a large reserve for coal while most coal must be imported in the next future; it is of concern to carry out explorations for a more extensive exploitation. Currently, coal production is mainly concentrated on open-pit mines and underground mines within the depth of 100 m.

Although the share of renewable energy is modest, its presence presents significant benefits: energy security improvement, emission reduction, job creation, rural living condition improvement. On the national scale, the use of renewable energy technologies indicates the responsibility of Vietnam toward to global common task for environmental protection. It is therefore necessary to create a suitable framework for this development.

ANNEX I

ENERGY DEMAND FORECAST

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1. Objective and Methodology

The objective of this section is to forecast demands for energy services in Vietnam during the 1995-2030 period to provide input for the optimization program MARKAL.

Future demands for energy services are forecasted at five-year intervals up to 2030 and an energy intensity model is used to generate the forecast. Energy intensity is the ratio of aggregate energy consumption to some aggregate measure of economic activity, typically GDP. Thus, energy intensity may be interpreted as an indicator of how much energy was consumed in any given activity versus the expense of the activity. This method is highly selected because it relates to the energy requirement with the macroeconomic developments that Vietnam is striving for. Future energy intensities are forecasted on the ground of:

- Historical trends in energy intensities,
- Forecast of GDP,
- Assumptions on trends that could effect the demand for energy, and
- Historical data of various countries at similar levels of per capita GDP.

Trends affecting the demands for energy assumed in this study are:

- Rapidly growing commercial energy consumptions pushed by a rapid pace of economic growth, industrialization, urbanization, and improved living conditions.
- Fuel substitution in industry and home uses.
- Improved efficiency of energy fuel utilization, particularly in the industrial and residential sectors.

Energy requirement depends on the structure of the economy as much as on the energy intensities of sectors or activities. To better capture the structure effects, demands are classified into six standard consumption sectors:

- Industry
- Urban resident
- Rural resident
- Commerce
- Agriculture
- Transportation

Within each sector, major end-uses are identified and analyzed separately. End-use demands are presented in terms of their activities or useful energy. These are then fed into MARKAL and depend on the assumed scenario that a variety of demand technologies providing different levels of output per unit of input energy are available for MARKAL to select from. Thus, MARKAL will decide the mix of energy and final energy demand itself. Two scenarios assumed are: the *Business As Usual* (BAU) scenario and the *Energy Efficiency (EFF)* scenario. In the BAU scenario, only current, standard technologies are included while in the EFF scenario, both standard technologies and improved technologies are available.

For a number of sectors, energy demand in terms of useful energy cannot be determined (or the determination does not make sense) due to several reasons such as statistic calculation, the consumption level in relation to the overall consumption, or diverse end-use technologies etc. In these cases, final energy is forecasted. Because such sectors are simulated by "dummy" technologies (efficiency = 100%), in MARKAL, a reduction factor in final energy must be applied to distinguish energy demand in the EFF scenario from the *BAU* scenario.

While presenting both scenarios in parallel could cause confusing, only the BAU scenario is dealt with and presented in details. Energy demand results of the other scenario are found in the last section of this appendix. In the course of forecast, potential for energy efficiency technologies will be discussed however.

Detailed assumptions for the projection of the energy service demands are presented below.

2. General assumptions

Table A1.1 presents the general economic assumptions underlying the energy service demand projections in Vietnam. The leading idea of this projection is to achieve a rapid and sustainable development with a view to avoid the danger of increasingly lagging behind other countries in the region [Son01]. GDP is thus projected to increase at the annual growth rate of 6.87% between 2000 and 2030 whereas the population increases at a gradually decreasing rate. Apart from this, urbanization tends to increase significantly (Table A1.1). Interpreting in the Vietnamese context, this does not mean a migration to a city, but rather a transition from some forms of land based employment and non-commercial energy use to some forms of industrial or service-based employment with commercial purchase of energy and other services. The GDP is presented in purchasing power parity (ppp) to better reflect the demand for some activities and to enable a comparison of service demands between countries with similar socio-economic conditions.

Table A1.1: General assumptions underlying the energy service demand projection in Vietnam (1995-2030)

Category	Data source	1995	2000	2005	2010	2015	2020	2025	2030	'95-30
Population (Million)	[Son01]	72.3	77.7	83.0	88.1	93.1	97.7	102.1	105.7	
Population GR (%)		1.44	1.33	1.21	1.10	0.99	0.88	0.70		1.1
Urbanization	[Son01]	21.3	24.0	28.1	33.0	38.7	45.1	51.5	57.7	
GDP (Billion USD)		20.62	28.84	40.83	57.81	81.28	114.32	156.84	211.16	
GDP GR (%)	[Son01]	6.9	7.2	7.2	7.1	7.1	6.5	6.1		6.9
per capita GDP (USD)		285	371	492	656	873	1170	1536	1997	
per capita GDP GR (%)		5.4	5.8	5.9	5.9	6.0	5.6	5.4		5.7
ppp factor	[CIA]	5.30	5.00	4.50	4.05	3.65	3.28	2.95	2.66	
per capita ppp GDP (USD)		1511	1856	2214	2657	3183	3837	4535	5308	
per capita ppp GDP GR (%)		4.2	3.6	3.7	3.7	3.8	3.4	3.2		3.7

The breakdown of GDP shares by major economic sectors is shown in table A1.2. The industrial & construction sector is expected to increase significantly from 29.9% to 45.7% whereas the service sector is assumed to increase slightly from 43.8% to 45.8%. The share of agriculture in the total GDP decreases significantly because this sector is assumed to grow rather slowly due to the declining potential for future agricultural productivity gains.

Table A1.2: Vietnam - GDP share by sector in 1995-2030

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Agriculture	percent	26.2	23.2	19.9	16.9	14.3	11.9	10.0	8.5
Industry & construction	percent	29.9	35.4	40.7	44.2	46.2	46.1	46.0	45.7
Services	percent	43.8	41.4	39.4	38.9	39.5	42.0	44.0	45.8

3. Energy demand of the industrial sector

Energy demand of the industry is divided into 5 sub-sectors including 4 key industries: cement, urea fertilizer, steel, pulp & paper and one general industry covering mainly light industries, electronics, etc.

In 1995, the sector produced 5.8 million tons cement, 0.1 million tons urea fertilizer, 470 thousand tons steel and 216 thousand tons of pulps and paper [GOS00].

Energy consumption in the industry sector in 1995 was 5283 KTOE, which made up 25% of the total final energy consumption. Within energy consumption mix, biomass (agriculture residue and fuel wood) took the biggest share - 51%, followed by coal and heavy fuel oil (FO). Biomass was mainly used for producing building materials such as bricks, tiles, limestone, etc. and processing food and food stuff. Coal was used for making coke in the cement industry and for heat production. Similarly, FO was used mainly in cement production. The energy intensity of this sector in 1995 was 0.86 kilogram of oil equivalent per USD (kgoe/USD).

The economic development strategy by the government sees industry as a key element in its drive for economic development and modernization [Son01]. The structure of Vietnam‘s industrial sector is expected therefore to experience a significant change over the next 30 years [Hao01]. Greater diversity in the output of industrial goods, improvements in product quality and value, and changes in fuel structure will all lead to an improvement in the industrial sector energy intensity. In the B*usiness as usual* (BAU) scenario it is assumed that the overall level of the industrial energy intensity per unit of industrial GDP decreases from the 1995 value of 0.86 kgoe/USD to a value of 0.48 kgoe/USD in 2030. As the result, the final energy demand would increase from 5283 KTOE in 1995 to 46377 KTOE by 2030 as indicated in table A1.3.

Table A1.3: Industry sector energy intensity projection

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	’95-30
GDP share	billion USD	6.2	10.2	16.6	25.5	37.5	52.6	72.1	96.5	
GDP share GR	percent	10.6	10.2	9.0	8.0	7.0	6.5	6.0		8.2
Energy intensity	kgoe/USD	0.86	0.75	0.69	0.66	0.59	0.55	0.51	0.48	
Final energy demand	KTOE	5283.34	7664.63	11537.7	16787.7	22184.6	28795.6	36849.5	46377.3	
Final energy demand	Petajoules	221.2	320.9	483.1	702.9	928.8	1,205.6	1,542.8	1,941.7	
Final energy demand GR	percent	7.7	8.5	7.8	5.7	5.4	5.1	4.7		6.4

This figure is then divided into those for sub-sectors. For this, two methods are used in combination. For the major energy consuming sectors (steel, cement, urea fertilizer, paper) industrial outputs are projected rather than energy and a variety of demand technologies (depending on assumed scenario) providing different levels of output per unit of input energy are available for MARKAL to select from. Thus, MARKAL will decide the mix of energy input and therefore its final energy demand itself. For the „other industries“ sector - comprising of light manufacturing, machinery, electronics, and other industries- final energy demands are modeled as a single entity.

The projected outputs of the four major sub-sectors in Vietnam are given in table A1.4. The bases for these projections are development strategies of respective industries in the 2000-2010 period with reference to 2015 and 2020 and experts' opinions. Figures for the next periods (i.e. after 2020) are projected according to the trend in the 2000-2020 period. As can be observed, output from each sub-sector is expected to increase, but their growth-rates will decrease over time. They are discussed in details below.

Table A1.4: Industrial activity by sub-sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Cement	1000 tons/year	5,828	13,000	21,906	34,801	48,356	62,305	76,536	90,901
Urea fertilizer	1000 tons/year	100	45	800	2,000	2,600	3,350	4,197	5,107
Pulp & paper	1000 tons/year	216	377	638	1,051	1,618	2,333	3,242	4,297
Steel	1000 tons/year	450	1,400	2,804	4,414	6,791	9,978	13,671	18,295

3.1 Steel

Steel is the basic element for the industrial development in most countries. Steel production was first introduced to Vietnam in the 60s with the construction of a 100,000 tons per year plant according to the traditional technology called Blast furnace. In the 1970s, the Electric Arc Furnace was brought into the South of Vietnam to make use of the available scrap steel [Steel00]. Total steel capacity as of 1990 was reported at 180,000 tons/year. Since 1990, the steel industry has undergone significant changes in both capacity and technology. Foreign investors have been allowed to build plants in Vietnam. Thus, between 1990 and 2000, steel production grew at an annual rate of 32%. In 2000, the total rolling production output reached 1,400 thousand tons, three folds higher than the 1995s figure. According to the master plan on steel development of the ministry of industry, this rate is expected to decline although still at a high level. The growth rate will initially be about 15%, then slow down to 9.5% in 2005 [Hao01] [Steel00] and gradually down to 6% in 2025. Over the entire period from 2000-2030, the production of steel is expected to increase by a factor of 13. Despite this strong growth presented per capita, this figure is just equivalent to 179 kg, still far comparable to those from developed countries such as Japan - 600 kg steel per capita in 1997 [NEDO97], Germany - 218 kg in 1950 [Chate82] or China - 94.5 kg in 1995 [China01].

Major processes used in the steel industry include concentrating and processing of iron ore, producing coke from coal, adding coke to iron ore to make iron, steel making, casting raw steel, and rolling, finishing, and milling steel products. Energy, in the form of heat, is used in each of these steps, with additional energy (usually electricity) used to provide lighting and to drive motors and presses used to move and finish materials.

In 1995, the steel industry consumed 128 KTOE. Translating into consumption per ton, this consumption equaled 0.285 toe/ton, which is low compared to those from other neighboring countries (China: 0.73, The Philippines: 0.8 [APERC01]) which was partly due to the fact that part of crude steel was imported. In fact, in 2000, the crude steel capacity by both traditional Blast Furnace and Electric Arc Furnace was 400,000 tons/year while the rolling capacity amounted to 2 million tons/year [Steel00]. The reason behind this dissimilarity is mainly because of the attractive price of billet in the international market. In particular, some factories in the neighboring countries whose investment costs have been fully amortized offer billet at a price as low as a production price, just enough to run their factories. These factors make investors reluctant in investing in a billet production line which is known to be capital and energy intensive. Furthermore, local crude steel was not interesting for rolling factories because of their prices, usually 10 to 15% higher than the regional standards [Steel00].

3.2 Cement

In Vietnam, cement production belongs to the most important industries. As in the case of steel, the growth of cement consumption is very closely linked to economic growth. From 1990-2000, cement production grew at the rate of 18% and is expected to grow more than twice as much by 2010 [Hao01] [Cement00]. Although a lower growth rate is forecasted after 2010, the production output in 2030 will be about seven times higher than the 2000s level.

Cement production involves heating limestone to produce calcium oxide, or lime, and followed by addition of silicates to yield clinker - a raw cement. Clinker is then ground to size and blended to yield various cement-type products. The major end-uses of energy in this sub-sector include process heat for producing clinker from limestone and other minerals, plus motive power (usually supplied by electric or diesel motors) for grinding, moving, and blending intermediate and final products.

In 1995, the cement industry consumed 919 KTOE and had an energy intensity of 0.157toe/ton. The current cement manufacturing plants are characterized as small, using either wet or dry processes. Of the total installed capacity of 18.85 million tons per year in 2000, [UNIDO02] only a few are large; 55 others are identified as small, outdated plants. Thus, the energy intensity is expected to improve as small plants are consolidated and wet processes are changed to dry processes. As references, energy intensity in this sub-sector in 1995 was 0.105 toe/ton for Thailand, 0.105 toe/ton for South Korea [APERC01].

3.3 Urea fertilizer

While cement and steel industries are pulses of the economy, agriculture provides the country with food. With 75% of population living in rural areas, agriculture continues to be an important sector in the economic development strategy of the government. Thus, agriculture is set to increase at the rate of 3.5% per year from 1995-2030 [Son01]. However, as the cultivation land budget is running out, use of fertilizer and changes of farming methods are the best ways to increase the agricultural productivity. This is particularly true to Vietnam. For example, the use of urea fertilizer in Vietnam currently is merely 26 kg/ha yielding

36,000 kg, whereas this figure in South Korea, Japan and China is 170 kg/ha, 83 kg/ha and 145 kg/ha, respectively with output of 60,000 kg/ha. Therefore, the demand for fertilizer is expected to increase heavily in the next 30 years.

From the energy viewpoint, urea fertilizer is the most critical as its production requires energy both as feedstock and as fuel. Currently, urea demand in Vietnam is mainly met by import. A series of urea plants are therefore in the pipeline to enhance the security of the economy [Fertilizer00] [Thuy01].

Urea fertilizer is produced from Ammonia which in turn can be produced from either coal or natural gas. Natural gas is preferred because of the higher energy efficiency. Coal based plants have an average energy intensity of 1992 kgoe/ton as in the case of Vietnam, while natural gas based technology is reported to be only 821 kgoe/ton [Kongs98]. Until 1995 there was only one urea fertilizer in Vietnam with a capacity of 100,000 ton/year. It is expected that the production output will grow at a high rate reaching possibly 5,107 thousand tons by 2030 [Fertilizer00] [Thuy01]. Vietnam has a good natural gas reserve. Development of natural gas based urea fertilizer plants is, therefore, realistic and correspondingly contributing to reduction of energy intensity in this industry.

3.4 Paper

Consumption of paper in Vietnam is expected to grow rapidly in the future and the production of paper is assumed to increase correspondingly to meet the demand. According to [Paper00] the production, output by 2010 will reach 1,050 thousand tons from the level of 377 thousand tons in 2000. The production outputs after 2010 are forecasted following the trend in the 2000-2010 period. By 2030, a production output of 4.3 million tons is expected. Presenting per capita, this figure is equivalent to 42.3 kg/year. As a check, this figure was 23.1 kg/year for China in 1995 and 17 kg/year for Thailand in 1992 [NEDO97].

In 1995, the paper industry in Vietnam consumed 237 KTOE, and had an energy intensity of 1,099 kgoe/tons which is very high because of outdated technologies and small-scale plants. By comparison, energy use per ton of paper in 1995 was 425 kgoe/ton for the Philippines, and 420 kgoe/ton for China [APERC01]. Thus, prospects for lowering the unit energy consumption are rather positive. Apart from problems on outdated technologies, the paper industry is facing a limited supply of raw material. A number of projects on raw material development for the paper industry are therefore underway [Lang96].

3.5 Other industries

In 1995, “other industry” sector consumed 3,800 KTOE, representing 72% of final energy consumed in this sector. Biomass took the greatest share - about 71% with main uses in local industries such as low-quality building material production and food and food stuff processing.

While production output in key industries is forecasted as growing at a decreasing rate resulting in a lower energy share, energy consumption in the “other industries” sector is expected to grow at a rather stable rate to support the economic development target. According to [Hao01], by 2005 a series of new industries will be established and upgraded. In particular, aluminum and bronze industries will be established. The final energy projection for this sub-sector is shown in table A1.5.

Table A1.5: Overall energy demand in the sector "other industries" in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Other industries	Petajoules	159.1	221.1	313.5	419.9	548.5	713.6	928.3	1,203.7

This overall sub-sector demand is broken down into three demand categories: electricity, heat production fuel and motor fuel. In 1995, the constituents of energy carriers in the 'other industries' sub-sector consisted of electricity, coal, kerosene, fuel oil, diesel oil, LPG, agricultural residue and fuel wood with shares as indicated in table A1.6. In the course of development, the proportions of almost all commercial energy are expected to increase while the proportion of biomass is expected to decrease. Especially the gas from 2000 will be included. Table A1.6 shows how the mix of energy carriers is projected to change, and table A1.7 provides the figure classified according to three categories: electricity, motor fuel and heat production fuels (which combines coal, kerosene, gas, LPG, fuel oil, agriculture residue and fuel wood).

Table A1.6: Fuel composition in the sector "other industries" in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Coal	Percent	12.6	17.2	20.3	21.5	22.1	22.1	21.0	19.7
Kerosene	Percent	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5
DO	Percent	0.6	1.0	1.3	1.7	2.3	2.7	3.3	3.9
FO	Percent	7.7	9.1	10.2	10.7	11.2	11.5	11.7	11.8
LPG	Percent	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4
Gas	Percent	0.0	0.3	3.1	3.1	3.0	3.0	3.0	3.0
Other oil products	Percent	0.5	0.7	0.7	0.6	0.6	0.6	0.5	0.5
Electricity	Percent	7.0	10.9	14.4	19.6	26.8	34.2	43.0	50.2
Agr. Residue	Percent	37.1	28.5	19.6	14.7	9.5	6.7	3.8	1.5
Wood	Percent	34.0	32.0	30.0	27.5	24.0	18.5	13.0	8.5

Table A1.7: Projections of final energy demand in the sector "other industry" in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Electricity	Petajoules	11.17	24.10	45.14	82.39	147.01	244.05	399.18	604.24
Motor fuel	Petajoules	1.01	2.11	4.19	7.29	12.39	19.33	30.18	46.96
Heat production	Petajoules	146.91	194.86	264.15	330.26	389.15	450.21	498.96	552.47

4. Energy demand of the urban residential sector

Urban and rural residential sectors are projected separately in order to (i) account for their significantly different energy service demands, and (ii) to allow for the trend of urbanization, industrialization and electrification to include in the model. The categories of energy use considered in the urban residential sector are: lighting, cooking, hot water, electric appliances (TV, computer, refrigerators, etc.) and air conditioning which are projected independently. In this sector, demands for lighting, cooking and hot water are calculated in terms of useful energy to facilitate the introduction of high efficient end-use technologies. Demand for electric appliances and air conditioning is however calculated in terms of final energy due to the difficulties in selecting representative technologies.

4.1 Lighting

Lighting service demand in urban residential sectors is satisfied solely by electricity using either incandescent or mercury vapor lamps. In 1995, lighting alone consumed approximately 856 GWh of electricity [IE00a] [Thuong00]. Useful energy demand for lighting is estimated by averaging lighting efficiencies relatively in terms of lumen/W [IE00a]. Average lighting efficiency in 1995 was 17%. Thus, the total lighting service demand in 1995 was 0.52 PJ.

The lighting demand for future periods is expected to grow at the rate of 9% from 1995-2000; gradually decreasing to 7% in 2015, and to 5% in 2025. By 2030, the demand for lighting will reach 5.86 PJ - about 11 times higher than the 1995 figure. Main drivers for such a high growth are increasing urbanization and the larger per capita floor area. Furthermore, the gradual decrease in growth rate reflects a saturation in the demand for lighting per floor area. Table A1.8 shows how the useful energy demand is projected to change between milestone years.

Table A1.8 : Energy demand for lighting in the urban residential sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Urban population	Million	15.4	18.6	23.3	29.1	36.0	44.1	52.6	60.9
Persons per household	Person	4.5	4.3	4.2	4.0	3.9	3.7	3.5	3.2
Number of households	Million	3.4	4.3	5.6	7.3	9.2	11.9	15.0	19.0
per capita floor area (a)	M^2	5.2	6.3	8.1	9.8	12.0	14.2	16.5	19.1
Per household useful energy demand	GJ/hh/year	152.9	188.1	228.0	261.9	295.6	311.8	317.0	307.5
Useful energy demand	Petajoules	0.52	0.81	1.27	1.90	2.73	3.71	4.76	5.86

(a): [JBIC99]

4.2 Cooking

The energy demand for cooking service in the urban residential sector is satisfied by using electricity, gas, kerosene, coal or biomass stoves. In 1995, the useful energy demand for this purpose was 14.6 kgoe/person/year [Lai98] [HUT99]. This value is assumed to increase at the rate of 0.4% to a value of 16.8 kgoe/person in 2030, mainly to account for improved living conditions with new demands for cooking. Table A1.9 presents the projections.

Table A1.9: Energy demand for cooking in the urban residential sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Urban population	Million	15.4	18.6	23.3	29.1	36.0	44.1	52.6	60.9
Per capita useful energy demand	kgoe/person/yr	14.6	14.9	15.2	15.5	15.8	16.1	16.5	16.8
Per capita useful energy demand GR	Percent	0.4	0.4	0.4	0.4	0.4	0.4	0.4	
Useful energy demand	KTOE	225.3	277.5	354.4	450.5	569.9	710.6	865.1	1022.9
Useful energy demand	Petajoules	9.43	11.62	14.84	18.86	23.86	29.75	36.22	42.83

4.3 Hot water

Energy demand for hot water is covered mainly those for bathing and washing. Hot water is usually generated by LPG water heaters and electric water heaters. In Vietnam the latter ones are more popular because of simple installation. In making projection of demand for hot water, the forecast of number of potential users and their daily consumption are needed.

In 1995, about 2% urban families in Vietnam were equipped with hot water heaters [Thuong00]. These families live mainly in the North and northern part of the middle region, where a cooler climate exists. They represent 7% of urban families in these regions. Because living standards in the country are becoming improving more and more, the demand for hot water would increase too. It is expected that by 2030, 4.2 million households (81% of the cooler regions) will be equipped with hot water heaters. Assuming then a gradual increase in per capita demand, projections of demand for hot water are made (Table A1.10). To facilitate the penetration of solar energy as a hot water supplier, useful energy demand is estimated using the end-use efficiency of the reference electric water heater.

Table A1.10: Energy demand for hot water in the urban residential sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Urban population	Million	15.4	18.6	23.3	29.1	36.0	44.1	52.6	60.9
Per capita final energy demand	kWh/capita/yr	1.5	2.3	3.8	6.1	9.4	14.4	22.2	34.2
Final energy demand	GWh	23	44	88	177	338	636	1167	2082
Final energy demand	Petajoules	0.08	0.16	0.32	0.64	1.22	2.29	4.20	7.50
Water heating efficiency	Percent	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
Useful energy demand	Petajoules	0.073	0.142	0.286	0.574	1.095	2.060	3.783	6.748

4.4 Electric appliances

Specific electric consumption for household appliances include the consumption of large household electrical appliances (refrigerators, washing-machines) and miscellaneous electrical and electronic appliances (irons, Hi-fi set, TV, computer…etc). These consumptions depend on how well equipped the household is with such appliances and also on the conveniences existing in the home [Chate82]. They also depend on the technical characteristics of the equipment and its size.

The electricity demand for appliances in the urban residential sector in 1995 was 455 kWh/year per household. This demand is assumed to grow in proportion to the GDP growth rate according to an elasticity of 2.6 in the initial periods, down to 1.3 in the future periods and 0.2 in the final periods. The main reasons for such strong growth, especially in the first periods are:

- Introduction of the market economy clearly improves living conditions and offers a broad range of goods to select. The number of families who could equip themselves with electric appliances increases accordingly.
- As a business custom, many families do their own business at home, particularly whose houses face a street. In these cases, energy consumption should be counted to the commercial sector rather than to the residential sector. This factor has a significant effect on the structure of the overall electricity demand.
- The urbanization process which increases at 4% per year.

The gradual reducing growth rate in demand reflects saturation of demand for household appliances of a portion of people in the urban population. The projections are given in table A1.11.

Table A1.11: Energy demand for electric appliances in the urban residential sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	´95-30
Urban population	Million	15.4	18.6	23.3	29.1	36.0	44.1	52.6	60.9	
Persons per household	Person	4.5	4.3	4.2	4.0	3.9	3.7	3.5	3.2	
Number of households	Million	3.4	4.3	5.6	7.3	9.2	11.9	15.0	19.0	
GDP GR	percent	6.9	7.2	7.2	7.1	7.1	6.5	6.1		
Elasticity		2.6	1.3	0.8	0.4	0.2	0.2	0.2		
Per hh final energy demand	kWh/hh/yr	455	1044	1633	2161	2441	2573	2701	2828	
Per hh final energy demand GR	Percent	18.0	9.4	5.8	2.5	1.1	1.0	0.9		5.4
Final energy demand	GWh	1561	4520	9064	15695	22553	30634	40578	53860	
Final energy demand	Petajoules	5.62	16.28	32.64	56.52	81.21	110.31	146.12	193.95	
Final energy demand GR	percent	23.7	14.9	11.6	7.5	6.3	5.8	5.8		10.6

4.5 Air conditioning

The tropical climate in Vietnam requires cooling which is satisfied by using air conditioners. In 1995, the energy demand for air conditioning according to various surveys was about 121 GWh [Thuong00] [Phan99] [HSV99] [HUT97]. This energy consumption is assumed to grow at a rate proportional to the growth rate of GDP with an elasticity of 2.5, decreasing gradually to below 1 after 2010. By 2030, about 29% urban households are expected to be equipped with electric air conditioners. Table A1.12 shows the projections.

Table A1.12: Energy demand for air conditioning in the urban residential sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
Urban households	Million	3.4	4.3	5.6	7.3	9.2	11.9	15.0	19.0	
GDP GR	percent	6.9	7.2	7.2	7.1	7.1	6.5	6.1		
Elasticity		2.5	1.8	1.2	0.8	0.7	0.6	0.6		
Per hh final energy demand	kWh	35.3	78.6	144.5	218.8	287.8	366.4	443.9	531.8	
Final energy demand	GWh	121	340	802	1589	2659	4362	6669	10129	
Final energy demand	Petajoules	0.436	1.225	2.889	5.722	9.577	15.707	24.013	36.473	
Final energy demand GR	percent	23.0	18.7	14.6	10.8	10.4	8.9	8.7		13.5

4.6 Total final energy demand in the urban residential sector

Total final energy demand of urban residential sector is presented in table A1.13 which is estimated based on the end-use efficiencies of 1995. It is obvious that electricity is the main type of energy being consumed. By 2020, per household, electricity consumption in the urban areas will be about 3,000 kWh, which is higher than the level in 2000 in Thailand [Thai00] although its GDP per capita by then would be similar to that of Thailand in 2000. This is explainable considering the family business custom in Vietnam (see section on electric demand for electric appliances). LPG is also used more and more, ultimately as fuel for cooking.

Table A1.13: Total final energy demand in the urban residential sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Lighting	Petajoules	3.1	4.8	7.4	11.2	16.1	21.8	28.0	34.4
Cooking	Petajoules	37.3	40.0	44.4	51.3	59.0	70.0	81.2	91.4
Hot water	Petajoules	0.1	0.1	0.3	0.6	1.1	2.1	3.8	6.7
Electric appliances	Petajoules	5.6	16.3	32.6	56.5	81.2	110.3	146.1	194.0
Air conditioning	Petajoules	0.4	1.2	2.9	5.7	9.6	15.7	24.0	36.5
Total final energy demand	Petajoules	46.52	62.39	87.63	125.28	166.92	219.95	283.13	363.06

5. Energy demand of the rural residential sector

Energy demand in the rural residential sector is divided into 3 categories: (i) cooking & water heating, (ii) lighting, and (iii) electric appliances. Energy demand for water heating is merged with that for cooking because in most cases the same cooking devices are usually used. Air conditioning demands are similarly included in the electric appliances as it is electrically powered. In 1995, this sector consumed 11,481 KTOE (52% of the final energy), including 495 KTOE of commercial energy. Like in the urban residential sector, energy demand for cooking and water heating as well as lighting is forecasted in terms of useful energy, whereas energy demand for electric appliances is considered in terms of final energy.

5.1 Cooking and hot water

The amount of energy used for cooking depends on many factors such as the type of food cooked, the number of meals cooked, the size of the household, the specific combination of energy sources and cooking equipment employed (type of stove, cooking pans), and the way in which cooking devices are used [Rural03].

Biomass is often used for cooking since it is readily available and best suitable for the low income of a rural population. Though the proportion of fuel sources is different between regions, depending on the local fuel availability, the useful energy demand for cooking (including making food and hot water for family, feeding animals) is in the range of 600 kcal/person/day [Lefe94] [HUT99]. Assuming this figure to be unchanged in the future and provided the rural population, total useful energy demand can be estimated. Detail projections are shown in table A1.14.

Table A1.14: Energy demand for cooking & hot water in the rural residential sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Rural population	Million	56.9	59.1	59.7	59.1	57.0	53.7	49.5	44.8
Per capita useful energy demand	Kcal/capita/day	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0
Useful energy demand	Petajoules	52.02	54.00	54.54	53.99	52.13	49.08	45.27	40.92

5.2 Lighting

Lighting demands in rural energy are satisfied by either electric or kerosene lamps, depending on the availability of electricity. In electrified areas, electricity is firstly and mostly consumed for lighting, then for running basic electric appliances [Thuong00] [HUT99]. The use of electricity for cooking is rare because of high prices in comparison to farmers' incomes. In non-electrified areas, people mainly use kerosene lamps for lighting and on average a family consumes about 3 litters of kerosene per month for lighting [HUT99] [Rural03].

Therefore, the energy demand for lighting in rural areas depends on the types of fuel used, i.e. depends on whether or not the area is connected with the electrical network. It is thus necessary to make separate projections for this demand in electrified and non-electrified areas.

5.2.1 Lighting by electricity

In 1995, 0.28 PJ of useful lighting energy was supplied by electric lamps in rural areas. This figure is expected to increase significantly in accordance with an increasing electrification rate and growing demand for lighting service per household.

As forecasted by [HUT99], the electrification rate will reach 96% in 2030 from 50% in 1995. In making the forecast, an interpolation has been made in the periods in-between. Lighting service demand per household is projected to increase from 55.1 Gj in 1995 to 102.5 Gj in 2030. By 2030, the total energy service demand for lighting would amount to 1.05 PJ. Results of the projections are given in table A1.15.

5.2.2 Lighting by kerosene

Kerosene lamps are generally used in non-electrified areas. As no attempt is made in introducing high efficiency kerosene lamps, energy demand for lighting is estimated in terms of final energy. The demand for kerosene in the period from1995-2030 has been estimated based on the electrification rate and the assumption on energy consumption for lighting per household (Table A1.15).

Table A1.15: Energy demand for lighting in the rural residential sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Number of households	Million	10.2	10.5	11.0	11.4	11.4	11.2	11.0	10.4
Households with electricity access	Million	5.1	7.3	8.3	9.8	10.5	10.7	10.8	10.2
Per household useful energy demand	Gj/hh/yr	55.14	66.97	78.62	86.97	92.49	95.72	99.07	102.56
Useful energy demand	Petajoules	0.2825	0.4874	0.6489	0.8496	0.9705	1.0277	1.0686	1.0464
Households without electricity access	Million	5.0	3.3	2.8	1.6	0.9	0.4	0.2	0.2
Per household kerosene demand	Litter/hh/yr	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Kerosene demand	KTOE	140.1	90.9	77.7	44.2	25.4	12.4	6.1	5.8
Kerosene demand	Petajoules	5.866	3.807	3.255	1.852	1.062	0.521	0.256	0.242

5.3 Electric appliances and air conditioning

Besides being used for lighting, electricity in rural areas is used to run home electric appliances such as radios, TVs, fans, etc. In 1995, the electric consumption for this purpose was 890 GWh. This figure is expected to increase significantly over the next 30 years because the number of households connecting to the grid is increasing and the improved living conditions bring on new demands for electric appliances.

Here the electric demand per household is assumed to grow at a rate proportional with the growth rate of GDP, according to the elasticity of 2 initially, which is then reduced to 1.5 and finally 0.3. The projections are presented in table A1.16.

Table A1.16: Energy demand for electric appliances and air conditioning in the rural residential sector in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
Rural population	Million	56.9	59.1	59.7	59.1	57.0	53.7	49.5	44.8	
Persons per household	Person	5.6	5.6	5.4	5.2	5.0	4.8	4.5	4.3	
Number of households	Million	10.2	10.5	11.0	11.4	11.4	11.2	11.0	10.4	
Households with electricity access	Million	5.1	7.3	8.3	9.8	10.5	10.7	10.8	10.2	
GDP GR	Percent	6.9	7.2	7.2	7.1	7.1	6.5	6.1		
Elasticity		2.00	1.50	0.80	0.45	0.45	0.30	0.30		
Per hh final energy demand GR	Percent	13.9	10.8	5.8	3.2	3.2	2.0	1.8		
Per household final energy demand	kWh/hh/yr	173.8	332.8	555.8	735.5	859.8	1005.4	1107.7	1213.4	
Final energy demand	GWh	890	2422	4587	7184	9022	10795	11948	12380	
Final energy demand	Petajoules	3.21	8.72	16.52	25.87	32.49	38.87	43.02	44.58	
Final energy demand GR	Percent	22.2	13.6	9.4	4.7	3.7	2.1	0.7		7.8

6. Energy demand of the agricultural sector

The Vietnamese economy is based largely on agriculture. This sector occupies a significant portion of social labor. Reforms in institutions and farming methods have been contributing to the great achievements in agriculture. Since 1990, Vietnam has become the third rice exporter in the world.

In Vietnam, agriculture has a priority position in the economic development strategy of the government. This sector is expected to grow at 3.5% per year over the 1995-2030 period [Son01]. Most arable land in the country has been used, suggesting that to reach the target, improvements in productivity and in efficiency of land use are necessary. Undoubtedly, energy is one of the key factors supporting this effort.

Energy consumption in agriculture serves for 4 main end-use categories: soil preparation, irrigation, fishing, and agro-processing. In 1995, the agriculture sector consumed 680 KTOE, from this, 380 KTOE was commercial energy. The energy consumption by this sector is expected to change significantly over the next 30 years.

6.1 Soil preparation

In 1995, 30.2% of cultivation land was prepared by machines [HUT99] consuming 34.4 KTOE of energy. In the future periods, this energy demand will increase due to two reasons. The first reason is the increasing mechanization in agriculture. The second one is that though most arable land has been used (as mentioned above), some usable land is still needed to be reclaimed. The following information is particularly important for deriving the final energy demand in this sector:

Regarding the mechanization process, in 1995, 30.2% of all cultivation land was prepared by farm machines, such as tractors, tillers, threshers and other farm equipment which are mainly powered by diesel. It is expected that by 2030 this figure will increase to 96% [HUT99].

Regarding cultivation land, the total area in 1995 was 8,140 thousand ha which was increased to 9,556 thousand ha in 2000. In the future, the cultivation area can be further increased since part of the current bare land is allocated for cultivation (there is 7.6 million ha of bare land, from that 7 million ha is planed for forest development, about 600 thousand ha left could be used for cultivation [Agri00]).

According to [HUT99], energy consumption for land preparation of one ha of land was 14 kgoe. Assuming this figure to decreases with time to indicate the use of more efficient machines, energy demand for this category can be estimated as follows (Table A1.17).

Table A1.17: Energy demand for agriculture land preparation in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
Land under cultivation	Thousand ha	8139.3	9556.0	9651.9	9748.8	9797.7	9846.8	9896.1	9945.7	
Land prepared by machines	Percent	30	36	47	58	70	81	90	96	
Land prepared by machines	Thousand ha	2458.1	3463.1	4547.2	5649.2	6813.1	8011.2	8937.0	9520.7	
per ha energy use	kgoe/ha	14.0	13.9	13.7	13.6	13.4	13.3	13.2	13.0	
Final energy demand	KTOE	34.4	48.0	62.4	76.7	91.6	106.7	117.8	124.2	
Final energy demand	Petajoules	1.44	2.01	2.61	3.21	3.84	4.47	4.93	5.20	
Final energy demand GR	percent	6.9	5.4	4.2	3.6	3.1	2.0	1.1		3.7

6.2 Irrigation

Another use of energy in the agriculture sector is for irrigation. In 1995, 19% of cultivation land was irrigated by using pumping systems which consumed 44.4 KTOE of final energy, including 5.6 KTOE of DO [HUT99]. To derive the final energy demand for future periods, the percentage of land irrigated by pumping systems has been assumed. It is expected that by 2030, about 44% of cultivation land areas will be irrigated [HUT99].

Irrigation is provided by either diesel pump-sets or electric pump-sets. The proportion of diesel and electric pump-sets varies depending on the level of rural electrification achieved and their relative costs. Assuming that the proportion of land irrigated by electric pumps and diesel pumps is unchanged after 1995 and energy requirement per ha for both methods is also unchanged, final energy requirement for irrigation for future period can be estimated (Table A1.18).

Table A1.18: Energy demands for agriculture irrigation in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
Land under cultivation	Thousand ha	8139.3	9556.0	9651.9	9748.8	9797.7	9846.8	9896.1	9945.7	
Land irrigated by pumping sys	Percent	19	19	21	24	28	33	38	44	
Land irrigated by pumping sys	Thousand ha	1574.8	1787.0	2026.9	2339.7	2743.4	3249.4	3760.5	4376.1	
Growth rate	Percent	2.6	2.6	2.9	3.2	3.4	3.0	3.1		3.0
Land irrigated by elec pumps	Thousand ha	1504.8	1704.8	1943.9	2255.9	2659.1	3164.8	3675.4	4290.6	
Per ha electricity use	kWh/ha	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	
Electric demand	GWh	451.4	511.4	583.2	676.8	797.7	949.4	1102.6	1287.2	
Land irrigated by diesel pumps	Thousand ha	70.0	82.2	83.0	83.8	84.3	84.7	85.1	85.5	
Per ha DO use	kgDO/ha	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	
DO demand	KTOE	5.6	6.6	6.6	6.7	6.7	6.8	6.8	6.8	
Final energy demand	PJ	1.94	2.21	2.47	2.81	3.25	3.79	4.35	5.01	

6.3 *Fishing*

In 1995, the total fish catching output was 929 thousands tons, 70% of that was caught by motorized ships which consumed 247 KTOE. Energy requirements for fishing is therefore decided by (i) the fish catching output, (ii) the percentage of fish caught by motorized ships and (iii) the energy requirement per tons of fish caught. For future periods, these parameters are assumed as follows:

- The current fish catching output is assumed to increase gradually, reaching 1.3 million tons by 2030 [ADB95].
- Parallel to this, a gradual increase in the portion of fish caught by motorized ships is expected. By 2020, 95% of fish output will be caught by motorized ships.
- Energy requirements per ton of fish caught on the other hand are expected to decrease since old ships would be upgraded and new, more efficient ones would be brought in.

Thus, the projections can be made as follows (Table A1.19).

Table A1.19: Energy demand for fish catching in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
Fishing catching output	1000 tons	929	976	1,026	1,078	1,133	1,191	1,252	1,316	
Percentage caught by motorized ships	Percent	70	78	85	90	95	98	98	98	
Fish caught by motorized ships	1000 tons	650	761	872	971	1,077	1,167	1,227	1,289	
Per ton catching fish energy use	kgoe/ton	388	384	380	376	372	369	365	361	
Final energy demand	Petajoules	10.34	11.99	13.60	14.98	16.45	17.66	18.38	19.12	
Final energy demand GR	Percent	3.0	2.5	2.0	1.9	1.4	0.8	0.8		1.8

6.4 *Lighting for fishing*

Another, but less important, energy-consuming activity is lighting in fishing ships. In 1995, this activity alone consumed 17 KTOE of kerosene. It is expected that energy requirements for this activity in the next periods will reduce (not because of lower demand magnitude but rather higher efficiency) as lighting by means of battery become more and more common (Table A1.20).

Table A1.20: Energy demand for lighting in fishing ships

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Lighting demand	KTOE	17.0	16.1	14.5	12.4	10.5	8.9	7.1	5.7
Lighting demand	Petajoules	0.71	0.68	0.61	0.52	0.44	0.37	0.30	0.24
Growth rate	percent	-1	-2	-3	-3	-3	-4	-4	

6.5 *Agro processing*

Usually, agricultural products need to undergo different processing, for example cleaning, drying, packaging etc., before being stored or exported. These require energy and in 1995 this consumption was 14.2 PJ. This demand is expected to increase in proportion to the share of agriculture in total GDP, according to the constant elasticity of 0.7. Details of the projections are given in table A1.21.

Table A1.21: Energy demand for agro-processing in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
GDP share	Billon USD	5.4	6.7	8.1	9.8	11.6	13.6	15.7	17.9	
GDP share GR	percent	4.3	4.0	3.8	3.5	3.2	2.9	2.6		3.5
Elasticity		0.7	0.7	0.7	0.7	0.7	0.7	0.7		
Energy demand	Petajoules	14.19	16.46	18.90	21.55	24.32	27.17	30.04	32.87	
Energy demand GR	Percent	3.0	2.8	2.7	2.5	2.2	2.0	1.8		2.4

Final energy demand within this category is further broken down into either heat production fuels or electricity (Table A1.22).

Table A1.22: Energy demand breakdown for agro-processing

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Heat production	Petajoules	13.66	15.83	18.14	20.63	23.31	26.10	28.89	31.65
Electricity	Petajoules	0.57	0.68	0.82	0.98	1.08	1.15	1.23	1.32

6.6 Summary on energy demand for the agriculture sector

The total energy requirement in the agriculture sector is shown in table A1.23. The following conclusions could be made: (i) The total energy intensity decreases with time, indicating the improvement in productivity and efficiency of energy-consuming activities; this is in agreement with the historical trend. (ii) As a whole, the total energy demand is consistent with the historical elasticity of 0.7 to the share of agriculture in GDP growth [see also Lefe94].

Table A1.23: Total final energy demand in agriculture in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
Land preparation	Petajoules	1.4	2.0	2.6	3.2	3.8	4.5	4.9	5.2	
Irrigation	Petajoules	1.9	2.2	2.5	2.8	3.2	3.8	4.3	5.0	
Fishing	Petajoules	10.3	12.0	13.6	15.0	16.5	17.7	18.4	19.1	
lighting for fishing	Petajoules	0.7	0.7	0.6	0.5	0.4	0.4	0.3	0.2	
Agro-Processing	Petajoules	14.19	16.46	18.90	21.55	24.32	27.17	30.04	32.87	
Total final energy demand	Petajoules	28.62	33.34	38.18	43.07	48.29	53.46	57.99	62.45	
Total final energy demand GR	Percent	3.1	2.7	2.4	2.3	2.1	1.6	1.5		2.3
GDP share	Billon USD	5.41	6.68	8.13	9.79	11.63	13.61	15.70	17.85	
GDP share GR	Percent	4.3	4.0	3.8	3.5	3.2	2.9	2.6		3.5
Energy intensity	kgoe/USD	0.126	0.119	0.112	0.105	0.099	0.094	0.088	0.084	

7. Energy demand of the commercial sector

Forecasts on energy demand in the commercial sector are made in terms of final energy because statistic data is deficient and energy consumption in this sector is relatively small in comparison to that in other sectors.

Energy demand in the commercial sector is forecasted based on the commercial floor area and the energy intensity per floor area unit.

Commercial floor area requirement is projected according to the ratio of commercial floor area to urban residential floor area. Typical values for developed countries range from 0.3 to 0.4 [China01]. This ratio in 1995 in Vietnam was 0.65 which is projected to reach 0.4 by 2015 and then remains constant. As a check, the ratio of commercial floor area to commercial GDP shares decreases from a 1995 value of 5.8 m^2/1000 \$US to a value of about 4.8 m^2 /1000 \$US in 2030. Thus, the commercial sector floor area would grow at about 6.4% per year over 35 years.

In 1995, the commercial sector energy use was 278.4 KTOE, resulting in a commercial sector energy intensity of 5.31 kgoe/m^2. It is expected that commercial sector energy intensity will grow to a value of 8.98 kgoe/m^2 by 2030 to support this sector's development. The overall final energy demand for the commercial sector is displayed in table A1.24.

Table A1.24: Commerce sector final energy demand in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
Urban residential floor area	Million m^2	80.2	117.8	188.3	285.4	430.7	625.4	865.2	1,162.7	
Commercial to residential ratio		0.65	0.58	0.49	0.43	0.40	0.40	0.40	0.40	
Commercial floor area	Million m^2	52.4	68.5	92.0	122.7	172.3	250.1	346.1	465.1	
Commercial energy intensity	kgoe/m^2	5.31	5.90	6.49	7.27	7.92	8.16	8.56	8.98	
Total final energy demand	MTOE	278.4	404.0	596.6	891.6	1,364.3	2,040.4	2,964.1	4,174.7	
Total final energy demand	Petajoules	11.7	16.9	25.0	37.3	57.1	85.4	124.1	174.8	
Total final energy demand GR	Percent	7.7	8.1	8.4	8.9	8.4	7.8	7.1		8.0
GDP share	Billon USD	9.04	11.94	16.10	22.47	32.11	48.07	69.00	96.78	
GDP share GR	Percent	5.7	6.2	6.9	7.4	8.4	7.5	7.0		7.0
Commercial floor/GDP share	m^2/1000USD	5.8	5.7	5.7	5.5	5.4	5.2	5.0	4.8	

Commercial sector energy demands are divided into four categories: lighting, electric appliances, air conditioning and thermal uses (e.g. space heating, hot water). In 1995, the shares in energy demand of the commercial sector was approximately 10% for lighting, 14% for electric appliances, 7% for air conditioning, and 69% for thermal use. The proportion of final energy used for air conditioning is projected to increase to 17% by assuming that the proportion of the air-conditioned commercial floor area would increase and that air conditioning energy intensity (kgoe/m^2) would increase slightly over the period. Similarly, the proportions of final energy for lighting and electric appliances are projected to increase to 23% and 38% respectively based on a slight increase in their energy intensity over the period. Thus, demand for thermal uses would occupy just 22% by 2030 (Table A1.25).

Table A1.25: Breakdown of energy demand in the commerce sector

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Air conditioning	Petajoules	0.79	1.40	2.46	4.34	7.64	13.47	20.25	29.75
Lighting	Petajoules	1.16	2.04	3.60	6.35	11.19	18.03	27.74	40.75
Electric appliance	Petajoules	1.68	3.10	5.71	10.07	17.75	28.58	45.00	66.12
Thermal uses	Petajoules	8.02	10.37	13.20	16.57	20.54	25.35	31.12	38.16

8. Energy demand of the transportation sector

Energy use in the transportation sector is expected to increase significantly in the future as improvement in living standards increases the demand for goods that must be transported to market, and as the increasing population requires more and better quality passenger transportation. Like the industry sector, activity is projected rather than final energy to allow better comparison of different end-use technologies and is separated by freight and passenger. These are developed from the GDP growth, population growth, and the expected changes in transport modes.

8.1 Freight transportation

In 1995, the freight transportation volume was about 39.1 billion ton.km. According to the World bank [WB99], for a country such as Vietnam, the demand for freight transportation will increase more rapidly than the GDP. We assume that this trend will maintain over time but at a gradually decreasing level until 2010. Afterward, the growth rate in freight activities will be lower than the GDP. Thus, the total freight activity would increase to 343.2 billion ton.km in 2030 from 39.1 billion ton.km in 1995.

In terms of freight transportation intensity, the figure is expected to increase from 0.36 t.km/USD ppp to 0.61 in 2030. The low freight transportation intensity indicates low requirements for product exchange, i.e. most of goods are consumed locally and, as usual, transport concentrates in urban areas. The increased freight transportation intensity means that the country has been more integrated into world trade and due to improved living conditions, the transport systems become more spread, reaching rural areas. As a reference, the freight transportation intensity in 1995 was 0.8 for the USA and 0.75 for Australia [China01].

Here the ppp-normalized GDP is used because it gives a better reflection of the overall demand for goods. Details of these projections are shown in table A1.26.

Table A1.26: Projections of freight activity in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
GDP	Billion USD	20.6	28.8	40.8	57.8	81.3	114.3	156.8	211.2	
GDP GR	Percent	6.9	7.2	7.2	7.1	7.1	6.5	6.1		6.9
Elasticity		1.23	1.08	1.02	0.91	0.83	0.72	0.69		
Freight Activities	Billion ton.km	39.10	58.82	85.43	121.93	166.63	221.49	278.94	343.07	
Freight Activities GR	Percent	8.5	7.8	7.4	6.4	5.9	4.7	4.2		6.4
ppp GDP	Billion USD	109.3	144.2	183.7	234.1	296.3	375.0	463.1	561.1	
Freight Intensity	t-km/USD ppp	0.36	0.41	0.46	0.52	0.56	0.59	0.60	0.61	

Freight transportations are then broken down into four transport modes: truck, rail, air and ship. Proportion changes in the activity of each mode in the period from1995-2030 are shown in table A1.27. The activities in the air, truck and rail sub-sectors are projected to increase while ship sub-sectors decrease. These agree with the development strategy of each respective sub- transport sector [WB99].

Table A1.27: Proportion of freight transport by modes

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Truck	Percent	52.9	52.9	52.8	52.8	52.5	52.0	51.6	50.9
Rail	Percent	3.5	3.5	4.4	5.2	6.1	7.2	8.4	9.8
Air	Percent	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ship	Percent	43.6	43.6	42.8	42.0	41.3	40.8	40.0	39.2

Table A1.28 presents the freight transportation activity projections, in million-ton-km, based on the above proportions and the total freight transport activity shown in table A1.26.

Table A1.28: Activities of freight transport by modes

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Truck	Mill-ton-km	20,706	31,144	45,129	64,383	87,608	115,222	143,942	174,780
Rail	Mill-ton-km	1,370	2,061	3,771	6,352	10,243	15,929	23,471	33,775
Air	Mill-ton-km	0	0	1	2	7	22	62	171
Ship	Mill-ton-km	17,051	25,647	36,581	51,274	68,878	90,455	111,639	134,560

For illustration, the final energy demands are estimated. These are made by assuming the freight energy intensities. The overall freight energy intensity is expected to decrease slightly because of the shift to more energy efficient transport modes (rail) and the efficiency improvements of transport modes (truck, ship) (Table A1.29).

Table A1.29: Projections of final energy demand for freight transportation in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Freight Activities	Billion ton.km	39.13	58.85	85.48	122.01	166.74	221.63	279.11	343.29
Freight Energy intensity	kgoe/ton-km	0.051	0.051	0.050	0.049	0.048	0.046	0.045	0.043
Freight final energy demand	Petajoules	83.85	126.12	179.39	251.09	332.97	428.08	523.19	624.46

8.2 Passenger transportation

In 1995, passenger transportation activities consumed 972.2 KTOE in providing about 49.2 billion-passenger-km. The corresponding per capita travel activity was 681 passenger-km/person. Passenger transportation for future periods is estimated based on the assumed future per capita travel activity.

According to the [WB99], the per capita travel activity will grow at a lower rate than the GDP. Here we expect that it will grow in proportion with the GDP according to a constant elasticity of 0.75. In this manner, the per capita travel activity by 2030 would be 2960 passenger-km/person which brings the total passenger transportation to 313 billion-passenger-km. Table A1.30 provides the projections in details.

Table A1.30: Projections of passenger transportation activities in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030	95-30
Per capita GDP	USD	285	371	492	656	873	1,170	1,536	1,997	
Per capita GDP GR	percent	5.4	5.8	5.9	5.9	6.0	5.6	5.4		5.7
Elasticity		0.75	0.75	0.75	0.75	0.75	0.75	0.75		
Per capita travel activity	p-km/person	681	831	1,028	1,277	1,585	1,976	2,428	2,960	
Travel activity	Billion-p-km	49.22	64.53	85.26	112.52	147.50	193.17	247.89	312.95	

Passenger transportation activities include the following six modes: car, bus, motor-bicycle, air, rail and ship (Table A1.31). The proportion of car activity is expected to increase from 4.8% in 1995 to 7.9% in 2030 [UNIDO99]. Similarly, the share of bus activity is also expected to increase. Motorcycle activity on the other hand is assumed to still slow down even at a high level. Traffic jams and air pollution are main reasons for applying limits on the motor- bicycle industry. As a regard airway sector, a high growth rate is expected as improved living conditions will generate the demand for traveling by high quality transportation modes. Railway transport with its advantages like low costs and higher safety will continue to increase its share in the total transportation activities. Despite existing advantages in the South, particularly in the Mekong delta, the waterway proportion in total passenger transport activities is forecasted to decline in the future because of its lower growth rate relative to that of other modes.

Table A1.31: Proportion of passenger transport by modes

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Car	Percent	4.8	5.5	5.9	6.3	6.6	7.0	7.4	7.9
Bus	Percent	41.1	41.1	40.9	40.7	40.6	40.5	40.4	40.5
Motorbicycle	Percent	39.0	38.5	36.8	34.5	31.7	28.5	24.5	19.6
Air	Percent	7.8	7.1	8.1	9.7	11.7	14.0	16.8	20.2
Rail	Percent	4.3	5.0	5.6	6.3	7.2	8.1	9.1	10.3
Ship	Percent	3.0	2.9	2.7	2.4	2.2	1.9	1.7	1.5

The absolute figures by categories are presented in table A1.32.

Table A1.32: Activities of passenger transport by modes

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Car	Mill-Pass-km	2,374	3,549	5,041	7,052	9,799	13,539	18,416	24,644
Bus	Mill-Pass-km	20,211	26,507	34,843	45,830	59,957	78,182	100,114	126,608
Motorbicycle	Mill-Pass-km	19,180	24,843	31,376	38,821	46,758	55,053	60,733	61,338
Air	Mill-Pass-km	3,860	4,554	6,921	10,960	17,241	27,094	41,724	63,208
Rail	Mill-Pass-km	2,133	3,202	4,781	7,130	10,561	15,628	22,663	32,330
Ship	Mill-Pass-km	1,461	1,871	2,299	2,731	3,187	3,672	4,241	4,819

Like in the case with freight transportation, overall energy demands for passenger transportation are estimated for illustration. The energy intensity (19.8 kgoe/1000 pass-km in 1995) is expected to increase due to shifts in transportation modes with higher energy intensity, and is projected to reach 22.5 kgoe/1000 pass-km by 2030. Total final energy demands for milestone years are presented in table A1.33.

Table A1.33: Projections of final energy demand for passenger transportation in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Travel activity	Billion-p-km	49.22	64.53	85.26	112.52	147.50	193.17	247.89	312.95
Passenger energy intensity	kgoe/1000 p.km	19.8	19.5	19.9	20.4	20.8	21.4	22.0	22.5
Passenger final energy	Petajoules	40.70	52.76	71.04	95.87	128.45	173.07	228.33	294.81

9. Summary

Table A1.34 summarizes the projections of end-use demands of sectors corresponding to the BAU scenario and table A1.35 provides their growth rates over milestone years.

Table A1.34: End-use demand in future milestone years in Vietnam (1995-2030)

Enduse demand category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Industry									
Cement	Thousand tons	5828	13000	21906	34801	48356	62306	76536	90901
Chemical fertilizer	Thousand tons	100	45	800	2000	2600	3350	4197	5107
Pulp & paper	Thousand tons	216	377	638	1051	1618	2333	3242	4297
Steel	Thousand tons	450	1400	2804	4414	6791	9978	13671	18295
Other	Petajoules	159.1	221.1	313.5	419.9	548.5	713.6	928.3	1203.7
Agriculture									
Land preparation	thousand ha	1.44	2.01	2.61	3.21	3.84	4.47	4.93	5.20
Irrigation	thousand ha	1.94	2.21	2.47	2.81	3.25	3.79	4.35	5.01
Fishing	Petajoules	10.34	11.99	13.60	14.98	16.45	17.66	18.38	19.12
Agro processing	Petajoules	13.62	15.78	18.08	20.57	23.24	26.01	28.80	31.55
Commerce									
Lighting	Petajoules	1.16	2.04	3.60	6.35	11.19	18.03	27.74	40.75
Air conditioning	Petajoules	0.79	1.40	2.46	4.34	7.64	13.47	20.25	29.75
Electric appliances	Petajoules	1.68	3.10	5.71	10.07	17.75	28.58	45.00	66.12
Space & water heating	Petajoules	8.02	10.37	13.20	16.57	20.54	25.35	31.12	38.16
Resident - Urban									
Lighting	Petajoules	0.52	0.81	1.27	1.90	2.73	3.71	4.76	5.86
Cooking	Petajoules	9.43	11.62	14.84	18.86	23.86	29.75	36.22	42.83
Hot water	Petajoules	0.07	0.14	0.29	0.57	1.10	2.06	3.78	6.75
Electric appliances	Petajoules	5.62	16.28	32.64	56.52	81.21	110.31	146.12	193.95
Air conditioning	Petajoules	0.44	1.23	2.89	5.72	9.58	15.71	24.01	36.47
Resident - Rural									
Lighting- electric	Petajoules	0.28	0.49	0.65	0.85	0.97	1.03	1.07	1.05
Lighting- kerosene	Petajoules	5.87	3.81	3.25	1.85	1.06	0.52	0.26	0.24
Cooking and hot water	Petajoules	52.02	54.00	54.54	53.99	52.13	49.08	45.27	40.92
Electric appliances & A/C	Petajoules	3.21	8.72	16.52	25.87	32.49	38.87	43.02	44.58
Transport									
Freight	Billion Tkms	39.1	58.9	85.5	122.0	166.7	221.6	279.1	343.3
Passenger	Billion Pkms	49.2	64.5	85.3	112.5	147.5	193.2	247.9	312.9

Table A1.35: Growth rate of final energy demand for future milestone years (1995-2030)

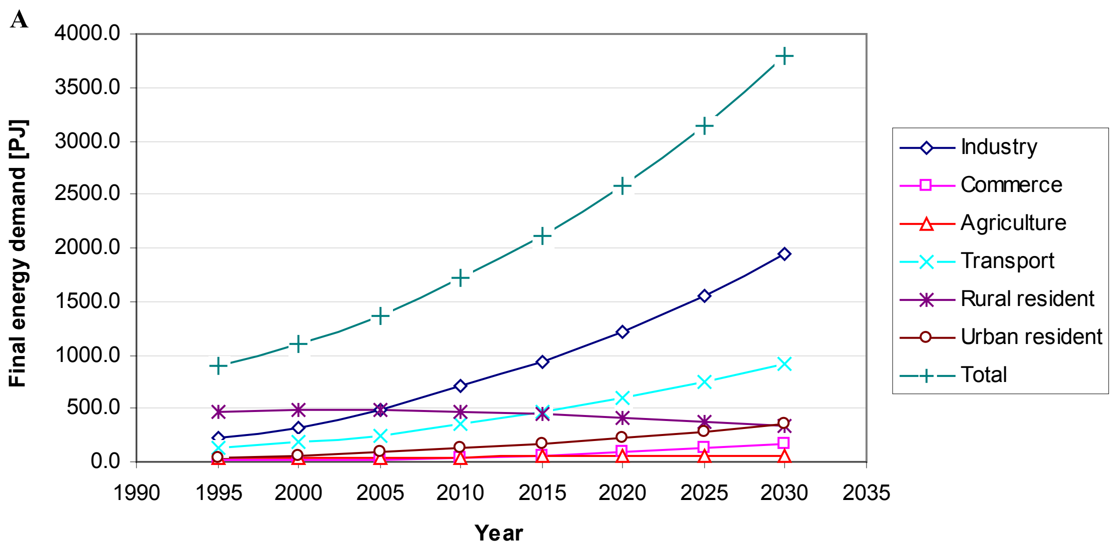
Enduse demand category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Industry									
Cement	Thousand tons	17.4	11.0	9.7	6.8	5.2	4.2	3.5	**8.2**
Chemical fertilizer	Thousand tons	-14.8	77.8	20.1	5.4	5.2	4.6	4.0	**11.9**
Pulp & paper	Thousand tons	11.8	11.1	10.5	9.0	7.6	6.8	5.8	**8.9**
Steel	Thousand tons	25.5	14.9	9.5	9.0	8.0	6.5	6.0	**11.2**
Other	Petajoules	6.8	7.2	6.0	5.5	5.4	5.4	5.3	**6.0**
Agriculture									
Land preparation	thousand ha	6.9	5.4	4.2	3.6	3.1	2.0	1.1	**3.7**
Irrigation	thousand ha	2.6	2.3	2.6	2.9	3.2	2.8	2.9	**2.8**
Fishing	Petajoules	3.0	2.5	2.0	1.9	1.4	0.8	0.8	**1.8**
Agro processing	Petajoules	3.0	2.8	2.6	2.5	2.3	2.1	1.8	**2.4**
Commerce									
Lighting	Petajoules	12.0	12.0	12.0	12.0	10.0	9.0	8.0	**10.7**
Air conditioning	Petajoules	12.0	12.0	12.0	12.0	12.0	8.5	8.0	**10.9**
Electric appliances	Petajoules	13.0	13.0	12.0	12.0	10.0	9.5	8.0	**11.1**
Space & water heating	Petajoules	5.3	4.9	4.7	4.4	4.3	4.2	4.2	**4.6**
Resident - Urban									
Lighting	Petajoules	9.2	9.2	8.5	7.5	6.3	5.1	4.2	**7.1**
Cooking	Petajoules	4.3	5.0	4.9	4.8	4.5	4.0	3.4	**4.4**
Hot water	Petajoules	14.2	15.1	14.9	13.8	13.5	12.9	12.3	**13.8**
Electric appliances	Petajoules	23.7	14.9	11.6	7.5	6.3	5.8	5.8	**10.6**
Air conditioning	Petajoules	23.0	18.7	14.6	10.8	10.4	8.9	8.7	**13.5**
Resident - Rural									
Lighting- electric	Petajoules	11.5	5.9	5.5	2.7	1.2	0.8	-0.4	**3.8**
Lighting- kerosene	Petajoules	-8.3	-3.1	-10.7	-10.5	-13.3	-13.2	-1.1	**-8.7**
Cooking and hot water	Petajoules	0.8	0.2	-0.2	-0.7	-1.2	-1.6	-2.0	**-0.7**
Electric appliances & A/C	Petajoules	22.2	13.6	9.4	4.7	3.7	2.1	0.7	**7.8**
Transport									
Freight	Billion Tkms	8.5	7.8	7.4	6.4	5.9	4.7	4.2	**6.4**
Passenger	Billion Pkms	5.6	5.7	5.7	5.6	5.5	5.1	4.8	**5.4**

For illustrative purposes, final energy demand projections for each sector are estimated (Table A1.36 & Figure A1.1A). The estimates shown for industry and transportation are based on the activity levels and energy intensities as discussed above whereas estimates for rural and urban residential are based on the assumed end-use efficiencies. These figures would not be used in the Vietnam MARKAL model developed for this study. For those sectors, the inputs into MARKAL consist of projected end-use demands plus end-use technologies. In the MARKAL model runs, the actual final energy demand will depend on the mix of end-use technologies selected by the model.

As shown in figure A1.1B, industry accounted for 24% in 1995 and would increase to 51% in 2030. In the same tendency, share of the transportation sector would rise from 14% to 24%; the commerce sector, from 1% to 4%; and urban residential sector, from 5% to 10%. In contrast, the rural residential sector would experience a significant decrease in its share. From about 50% in 1995, it reduces to just 9% in 2030. The main reason for such a decrease includes urbanization and saturation of energy demand for cooking. Similarly, the agriculture sector suffers a share reduction but at a much lower rate.

Table A1.36: Total final energy demands in Vietnam (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Industry	Petajoules	221.2	320.9	483.1	702.9	928.8	1205.6	1542.8	1941.7
Commerce	Petajoules	11.7	16.9	25.0	37.3	57.1	85.4	124.1	174.8
Agriculture	Petajoules	28.6	33.3	38.2	43.1	48.3	53.5	58.0	62.4
Transport	Petajoules	124.6	178.9	250.4	347.0	461.4	601.2	751.5	919.3
Rural resident	Petajoules	480.7	489.4	488.7	475.8	450.9	418.3	380.5	338.8
Urban resident	Petajoules	46.4	62.3	87.5	125.2	166.9	220.0	283.3	363.5
Total	**Petajoules**	**913.2**	**1101.7**	**1372.8**	**1731.2**	**2113.4**	**2583.9**	**3140.2**	**3800.6**



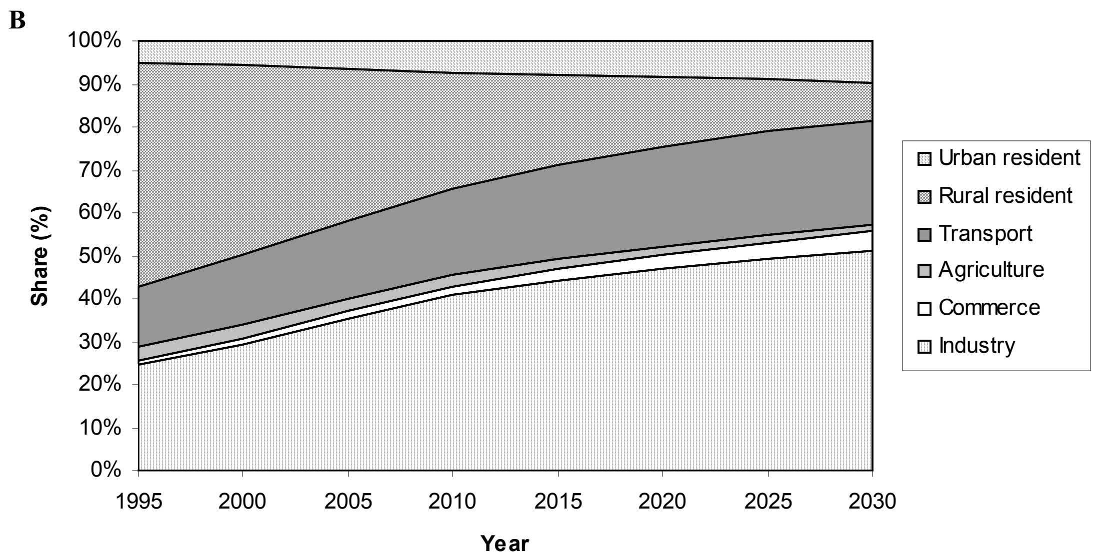


Figure A1.1: Development of final energy demand under the BAU scenario
A - in absolute values; B - in shares

Table A1.37 shows per capita energy demand growing from 12.6 GJ per person in 1995, to reach 36 GJ/person in 2030, while the energy intensity decreases to 18 MJ/USD in 2030 from 44.3 MJ/USD in 1995.

Table A1.37: Overall energy statistics (1995-2030)

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Per capita GDP	USD	285.1	371.2	492.0	656.0	873.4	1169.7	1536.1	1997.4
Per capita Energy Demand	Gj/person	12.6	14.2	16.5	19.6	22.7	26.4	30.8	36.0
Energy intensity	MJ/USD	44.3	38.2	33.6	29.9	26.0	22.6	20.0	18.0

10. Energy efficiency scenario

Also for illustrative purposes, the final energy demand corresponding to the *energy efficiency scenario (EFF)* for each sector is estimated. The estimates are obtained from the assumed market potential of energy efficiency and conservation technologies. The data shown in table A1.38 reveals that industry is the sector with the highest potential for reduction followed by the transport and rural residential sectors.

Table A1.38: Total final energy demands corresponding to the energy efficiency scenario

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Industry	Petajoules	221.2	320.9	482.1	692.0	912.0	1164.6	1461.2	1801.2
Commerce	Petajoules	11.7	16.9	24.8	36.8	55.7	82.4	119.0	166.0
Agriculture	Petajoules	28.6	33.3	38.2	43.1	48.3	53.5	58.0	62.4
Transport	Petajoules	124.6	178.9	245.1	328.8	426.9	543.6	666.9	805.6
Rural resident	Petajoules	480.7	489.4	454.2	422.6	393.8	345.7	307.5	268.3
Urban resident	Petajoules	46.4	62.2	87.0	123.5	163.6	214.3	274.3	349.9
Total	**Petajoules**	**913.1**	**1101.7**	**1331.4**	**1646.7**	**2000.2**	**2404.0**	**2886.9**	**3453.4**

Comparison of the EFF scenario to the BAU scenario is shown in table A1.39.

Table A1.39: Total final energy demand in the energy efficiency scenario contrary to that of the BAU scenario

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Industry	Percent	100	100	100	98	98	97	95	93
Commerce	Percent	100	100	99	99	98	96	96	95
Agriculture	Percent	100	100	100	100	100	100	100	100
Transport	Percent	100	100	98	95	93	90	89	88
Rural resident	Percent	100	100	93	89	87	83	81	79
Urban resident	Percent	100	100	99	99	98	97	97	96
Total	**Percent**	100	100	97	95	95	93	92	91

The overall energy statistic corresponding to this scenario is indicated in table A1.40. The per capita final energy is expected to grow from 12.6 GJ in 1995 to 32.7 by 2030, significantly lower than that of the BAU scenario. Overall energy intensity on the other hand reduces at a higher rate. By 2030, this figure is expected to be 16.4 MJ/USD contrary to 18 MJ/USD in the BAU scenario.

Table A1.40: Overall energy statistics - energy efficiency scenario

Category	Unit	1995	2000	2005	2010	2015	2020	2025	2030
Per capita GDP	USD	285.1	371.2	492.0	656.0	873.4	1169.7	1536.1	1997.4
Per capita Energy Demand	Gj/person	12.6	14.2	16.0	18.7	21.5	24.6	28.3	32.7
Energy intensity	MJ/USD	44.3	38.2	32.6	28.5	24.6	21.0	18.4	16.4

Figure A1.2 provides a comparison of the projected growth in per capita energy demand in Vietnam and the historical growth in several other developing countries. The per capita energy demand growth projected for Vietnam over the next 30 years is similar to what other countries have been able to achieve in a shorter period (15 years) [NEDO97], but this is reasonable considering Vietnam's economy structure and the lower per-capita energy starting point compared to other countries shown.

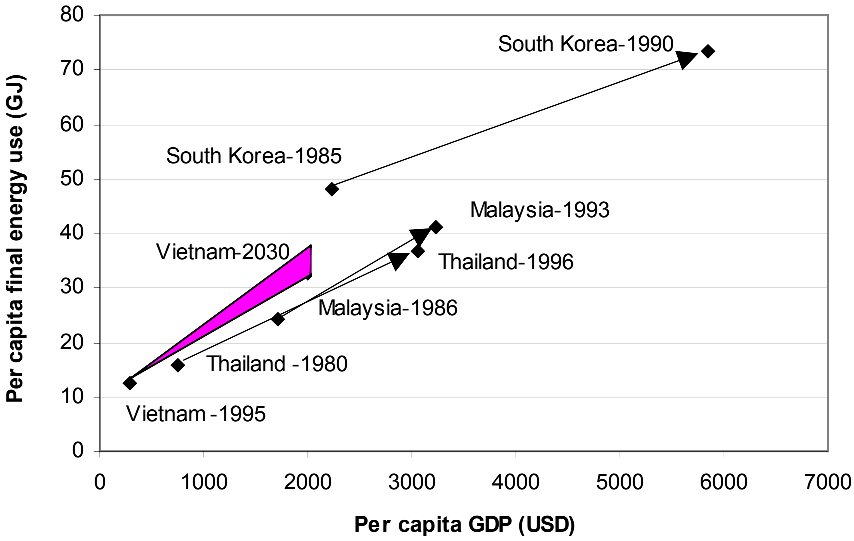


Figure A1.2: Expected evolution of per capita final energy demand (of two scenarios) in Vietnam between 1995-2030 and historical data of selected developing countries

ANNEX II

DECENTRALIZED TECHNOLOGIES FOR ISOLATED AREAS

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1. Introduction

Thermal power plants enjoy an economy of scale, i.e. they generate power in large scale and the power is then distributed largely through high-tension lines to industrial sectors and cities. On the other hand, these plants suffer a diseconomy of scale in distributing power through medium/low-tension lines in rural areas, especially in locations far away from the central grid. This high distribution cost results from (i) high line loss which increases with the distance from the grid and (ii) the low capacity utilization because of the lack of adequate demand for power, especially in the rural areas where industrial activities on a large scale are absent [ChaCha02]. From the technological and economical points of view, decentralized power plants such as solar PV or wind farms offer an alternative solution for energy requirement in such areas. However, to decide among various decentralized technologies which is most economical and suitable for a certain area, assessment of local renewable energy resources, and methodology for comparative assessment and problems concerning criteria for decentralized selection should be concerned. This section, therefore, serves for (i) identifying the proper parameters for the simulation and (ii) locating areas that can be effectively served by renewable energies.

2. Methodology

Decentralized technologies are first selected according to the technical viability, social acceptance, environmental effects and organizational features; afterward they are evaluated from an economical point of view.

2.1. Criteria for the technology selection

The technology selection is based on the following criteria [IE00b]:

Technical aspects of the technologies:

- Commercialization level
- Reliability
- Flexibility and availability
- Lifetime
- Efficiency
- Requirements for operation, maintenance and replacement
- Availability of corresponding resources
- Requirement for input supply and manpower
- Output products

Social aspects of the technologies

- Level of acceptance
- Target customer
- Job creation
- Product allocation

Environmental aspects of the technologies

- Positive and negative affects

Organizational aspects of the technologies

- Owner
- Organizational structure for project management

2.2. Method for economic evaluation

Economic viability of a technology is evaluated through its levelized cost per unit of electricity produced (LC) [KolJos02]. LC can be defined as:

$$LC = \frac{C_{pw} + M_{pw} + F_{pw} + R_{pw}}{E_{pw}} \quad \text{(A2.1)}$$

where pw is a subscript and indicates the present worth of each factor

Capital cost (C) represents initial costs for purchasing equipment and installation that should be spent before the system operation starts (year 0)

Maintenance cost (M) represents recurring costs spent every year for maintenance and operation of the system. These are escalated at rate e0 and discounted at rate d. The levelized maintenance and operation cost for a lifetime:

$$M_{pw} = \text{Annual Maintenance cost} * \left(\frac{(1+e_0)}{(d-e_0)} \right) * \left[1 - \left(\frac{(1+e_0)}{(1+d)} \right)^N \right] \quad \text{(A2.2)}$$

where N is the evaluation period in a year.

Fuel cost (F), commonly expressed as the annual fuel expenditure which is defined from the equation:

$$F_{pw} = \text{Annual Fuel cost} * \left(\frac{(1+e_f)}{(d-e_f)} \right) * \left[1 - \left(\frac{(1+e_f)}{(1+d)} \right)^N \right] \quad \text{(A2.3)}$$

where e_f is fuel cost escalation.

Replacement cost (R) represents costs spent for replacement of major components or systems which have a lifetime shorter than the evaluation period. For PV systems, replacement costs also include the replacement of batteries. The replacement costs are calculated by the equation:

$$R_{pw} = \sum_{i=1}^{v} \left[item\cos t * \left(\frac{1+e_0}{1+d} \right)^{RY} \right] \quad \text{(A2.4)}$$

where item cost is a replacement cost at point of replacement; RY is the year of replacement.

Energy output (E) represents the present worth of an annual energy output (A) received over a time period (n years) at the discount rate d

$$E_{pw} = A * \left[\frac{1-(1+d)^{-n}}{d} \right] \quad \text{(A2.5)}$$

2.3. Selection of technology

Based on criteria specified in the above section, the following technologies have been selected:

- Hydropower
- Solar PV
- Wind generator
- Diesel generator
- Gasoline generator

Advantages (+) and disadvantages (–) of the selected technologies are briefly presented in table A2.1.

Table A2.1: Advantages and disadvantages of different isolated technologies

No	Technology	Advantages	Disadvantages
1	**Small Hydropower**	+ low initial investment cost + easy operation + no pollution + localized technology + no fuel cost	– require suitable water supply – theft risk – agricultural water disturbance – distance to the load
2	**Solar PV**	+ easy operation + silent, module + no pollution + little maintenance, no fuel cost + short distance to load	– require suitable solar resource – high initial investment cost – strict requirements on battery
3	**Wind turbine**	+ reasonable initial investment cost + easy operation + little maintenance + no pollution	– strict requirements on battery – require suitable wind resource
4	**Diesel generator**	+ reasonable initial investment cost + reliability + easy installation and operation	– pollution – noise – fuel dependency, high fuel cost
5	**Gasoline generator**	+ reasonable initial investment cost + easy installation and operation + reliability + short distance to load	– pollution – noise – fuel dependency, high fuel cost

Depending on the electricity load in selected areas, more specific technologies are selected. In the case of the electricity load from a single family (energy usually used for small electrical appliances and lighting lamps working for a few hours a day), the best suitable technologies are micro hydro (MH), solar photovoltaic (SHS), wind generator (WHS), and gasoline generator (GG). In the case of a higher load, (kW range) from a public service (school, commune office, etc.) and/or a group of families, the technologies commonly applied are diesel generator, hydro-diesel hybrid, wind-diesel hybrid and solar-diesel hybrid systems.

2.4. Economic evaluation

2.4.1. General assumptions

Discount rate	10%
Fuel escalation	0%
Maintenance cost escalation	0%
Diesel price	0.28 USD/liter
Gasoline price	0.36 USD/liter
Evaluation period	20 years

The calculation assumes a uniform annual energy output and for household technologies these are assumed equal the loads.

2.4.2. Household systems

Technical and economic parameters of household systems necessary for economic evaluation are given in table A2.2 [BhuAs00], [IE00b].

Table A2.2: Parameters of household sized power technologies

System characteristics and cost items	Electric generation technologies			
	SHS	WHS	MH	GG
Capacity (W)	100	150	200	450
System total capital cost (USD)	590	270	50.4	360
Annual O&M cost (USD/yr^{-})	2.95	3.0	2.4	18
System lifetime	20 years	10 years	5 years	8000 h
Battery capacity (Ah)	100	100		
Battery depth of discharge (%)	40	40		
Investment cost (USD)	40	40		
Battery lifetime (year)	3	3		
Fuel tank investment cost (USD)				28
Fuel tank lifetime (year)				3

Here outputs of technologies are not given because they depend on some factors. For renewable energy systems such as wind home systems or solar home systems, the outputs largely depend on the availability and energy density of the resources. On the other hand, for generators, the major determining factor is operating time.

Wind home system (WHS) outputs (E, kWh) depend on wind resource, characteristics of wind turbines and distribution probability of wind speeds around the average value. The equation for the calculating outputs is:

$$E(v_m) = \sum_{v=1}^{v=25} \eta * f(v) * P(v) * 8760 \tag{A2.6}$$

where v_m is the average wind speed; *P(v)* is the turbine power at wind speed *v*; *f(v)* is Weibull probability density function for wind speed *v*, calculated for average wind speed v_m (see section 3.3.2 for more explanations), and η is system efficiency (battery, charge controller, loss in the line) (67.5%) [ByrShe98].

The wind turbine model PD 170.6 of the Research Center for Thermal Equipment and Renewable Energy (RECTERE) has been chosen as the reference technology, power curve and technical information of which is given below.

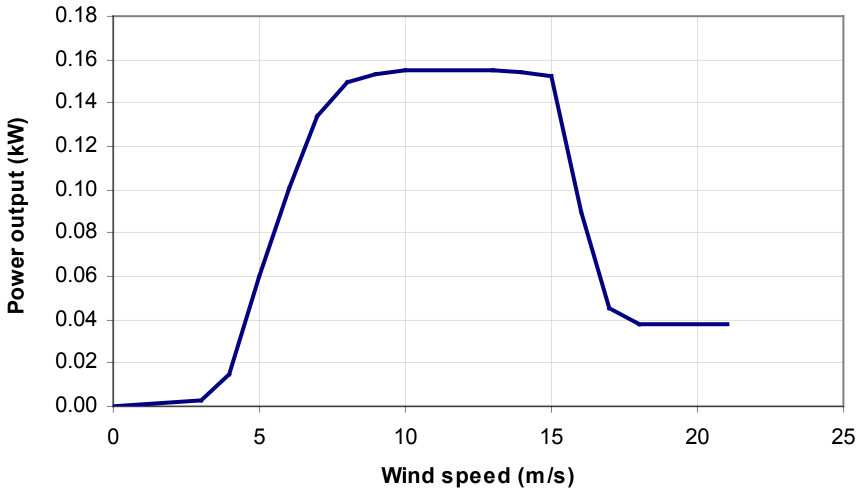

Figure A2.1: Power curve of the wind turbine PD 170.6

Table A2.3: Detailed specifications of the wind turbine PD 170.6

Indicator	**Value**
Rotor diameter	1.7 m
Swept area	2.27 m^2
Rated power	150 W
Power regulation	Pitch
Starting wind speed	3 m/s
Rated wind speed	8 m/s
Cut out wind speed	16 m/s
Generator	Synchronous
Number of blades	6 of Composit
Tower height	10 m

With the wind resource at 10 m high (see section 3.3.2), the levelized cost of electricity from wind using the wind turbine PD170.6 is calculated and it is, obviously, more competitive in coastal areas (Figure A2.2).

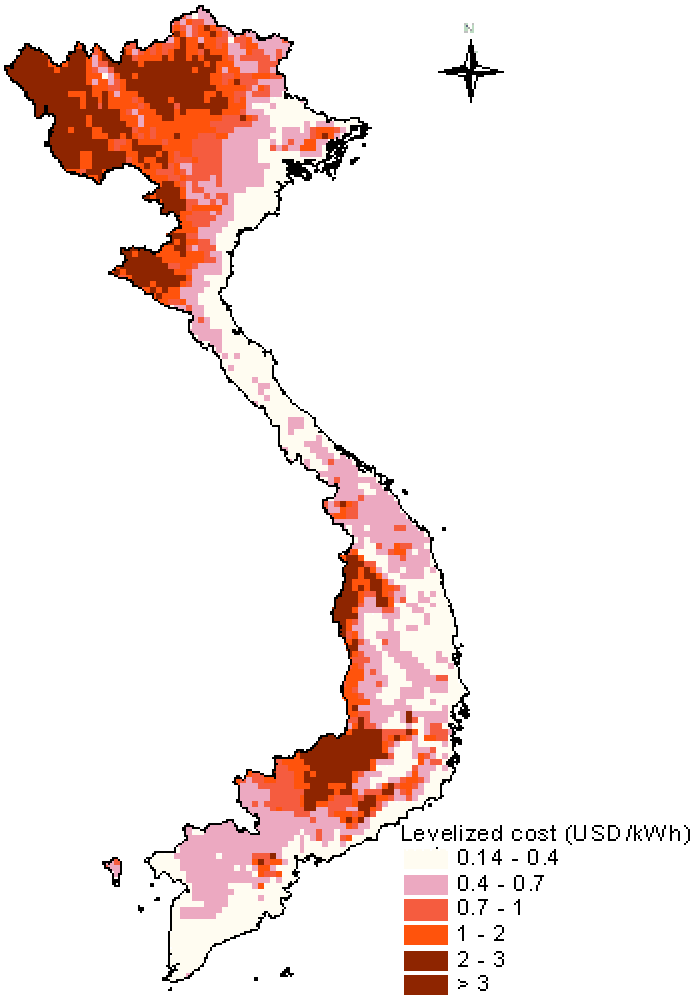

Figure A2.2: Levelized cost of electricity from wind turbine PD 170.6 at different locations in Vietnam

Micro hydropower plant outputs (E, kWh) are affected by the water supply and the time of utilization and can be defined by the equation:

$$E = N * T \tag{A2.7}$$

where N is the turbine rated capacity; T is the time of utilization per year (in hours).

Most micro turbines are of the “run of river” type, their availability to generate power is, therefore, limited during stream flooding periods and during dry seasons. In practice, the plant factor for micro hydropower plants in Vietnam ranges from 0.1-0.15. Thus, the levelized costs are between 0.06 and 0.09 USD/kWh.

Solar home system outputs (E, kWh) are estimated by the following equation [Elha02]:

$$E = \eta * W_p * Q * 365 \tag{A2.8}$$

where: η is system efficiency (67.5%); W_p is peak capacity of the PV module; Q is the annual daily average solar irradiation kWh/m^2.day; 365 days per year.

Based on these parameters, levelized costs corresponding to various solar isolations in Vietnam are estimated (Figure A2.3).

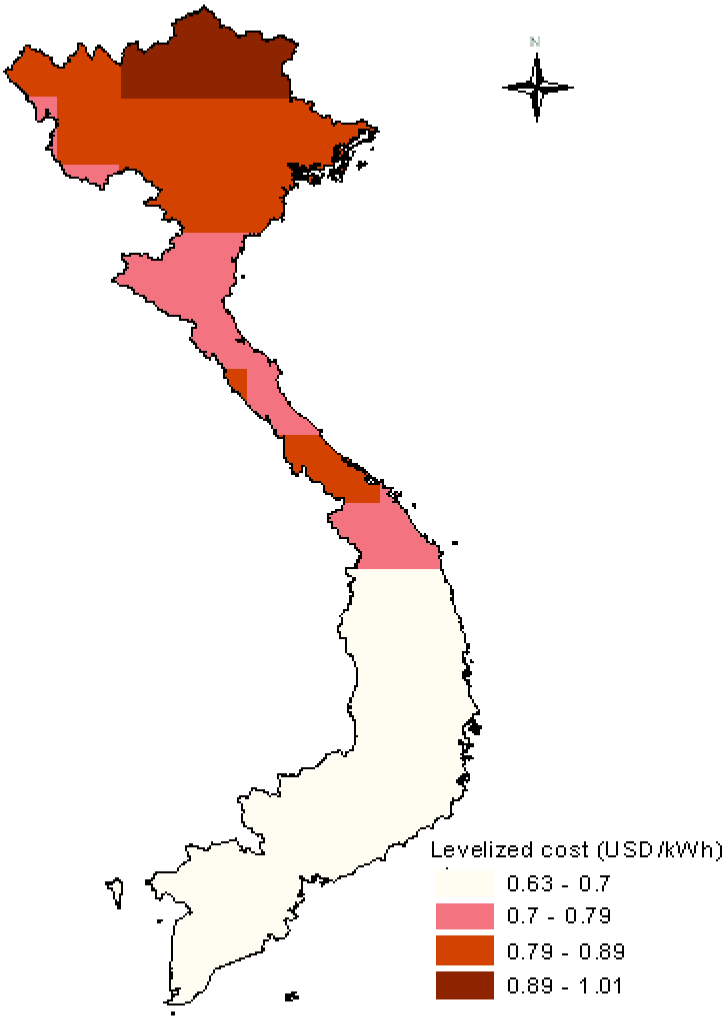

Figure A2.3: Levelized costs of electricity from solar home system in Vietnam

Gasoline generator suitable for household use is the model EM650-450W of Honda. The gasoline generator is assumed to operate at a standard capacity for four hours per day and consume 0.43 litters of fuel per kWh. The corresponding levelized cost therefore will be 0.42 USD/kWh.

2.4.3. Commune systems

Electricity load in commune systems consists of household and institutional demands, which require a higher quality of energy services. Therefore, in case renewable energy technologies are used, they must be coupled with diesel generators to improve reliability. Overall, four hybrid systems are available: diesel generator, wind-diesel generator, solar-diesel generator and hydro-diesel generator. Obviously, service costs are decided by the availability of local renewable energy resources and the coincidence between the resources and the demand. For this purpose, an arbitrary load profile for a village in rural areas has been developed (Figure A2.4).

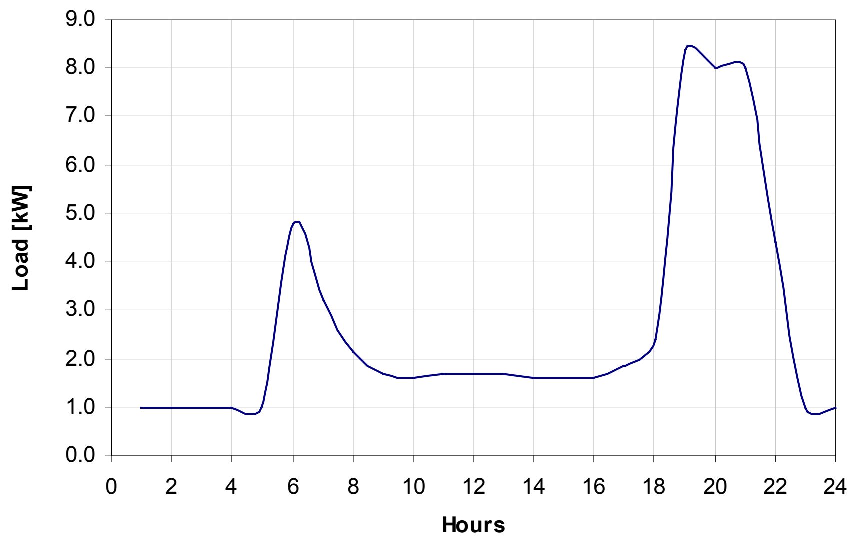

Figure A2.4: Typical load profile for a village in Vietnam (adapted from [Tran02])

On the other hand, renewable energy resources for a latitude 8 and longitude 105 were obtained from NASA as reference resource data (Figure A2.5). The average wind speed (at 10 m high) and the average daily solar irradiation at this location are 4.7 m/s and 5.24 kWh/m^2.day, respectively.

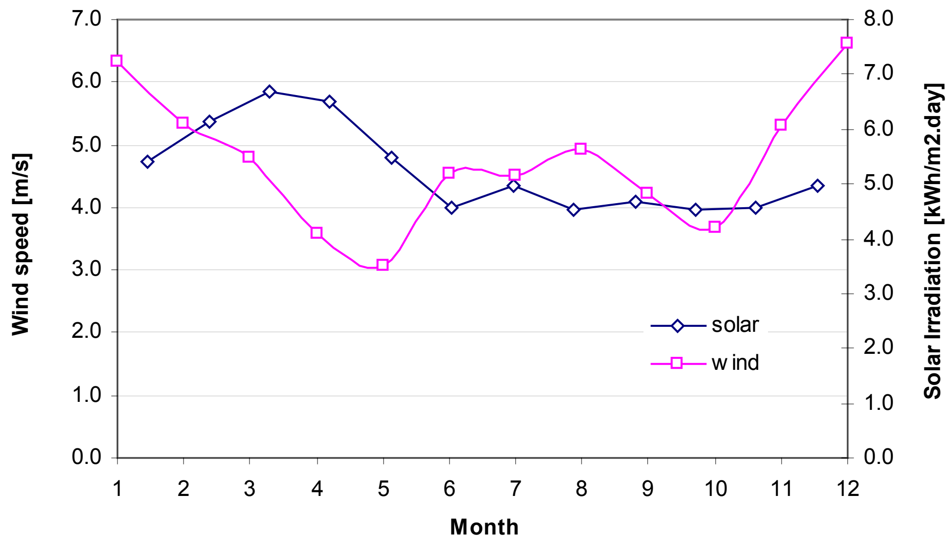

Figure A2.5: Wind and solar resource for one location in Vietnam

Sizing of hybrid systems is then achieved by using the HOMER, an optimization model for renewable energies developed by the US National Renewable Energy Laboratory (NREL) [HOMER]. This model identifies the least cost system that meets the electricity load by performing hourly simulations from thousands of potential power systems. Therefore, in addition to the detailed load profiles and the information on renewable energy resources, it is necessary to provide a sufficient range of technologies with their size and cost for the simulation model.

Diesel generators: cost of diesel generator depends on their sizes. With capacities from 5 kW to 45 kW, the cost can be represented by the cost curve $3650 + $ 166/kW [EVN99].

Fuel use is modeled in the HOMER by a linear fuel curve characterized by a slope and an intercept at no load. For a capacity range of 5 kW to 45 kW, the slope and the intercept are respectively 0.33 l/h/kW and 0.05 l/h/kW [EVN99].

Parameters needed for the simulation of a diesel generator by the HOMER model are listed in table A2.4.

Table A2.4: Diesel generator technical and cost assumptions

Parameters	Unit	Values
Fixed capital cost	USD	3650
Increment capital cost	USD/kW_{rated}	166
Fixed O&M	USD/hour	0.15
Incremental O&M cost	$USD/hr/kW_{rated}$	0.01
Operational lifetime	Hours	25,000
Minimum load ratio		0
Fuel curve intercept coefficient	$l/hr/kW_{rated}$	0.05
Fuel curve slope	$l/hr/kW_{output}$	0.33
Fuel price	USD/l	0.28
Annual interest rate	%	10

A solar-diesel generator is simulated in the HOMER model based on technical and economic assumptions of diesel generator (Table A2.4) as well as the cost assumptions for PV and other components (Table A2.5 and 6).

Table A2.5: Photovoltaic array - technical and cost assumptions

Parameters	Unit	Value
Capital cost	USD/kW	5000
O&M cost	USD/kW/year	10
Derating factor	%	90
Lifetime	Years	20
Tracking system	Horizontal axis, monthly adjustment	

Table A2.6: Technical and cost assumptions for other components of a solar-diesel hybrid system

Parameters	Unit	Value
Battery (Exide E120-23)		
Capital cost	USD/kWh	100
O&M cost	USD/year/kWh	2.5
Cycle life	Full cycles	500
Float life	Years	10
Maximum charge rate	A/Ahr unused	1
Nominal capacity	KWh	8.25
Maximum capacity	KWh	9.204
Capacity ratio		0.543
Rate constant		0.3
Minimum state of charge	%	30
Initial state of charge	%	100
Round trip efficiency	%	65
Inverter		
Capital cost	USD/kW_{rated}	1000
Lifetime	Years	10
Efficiency	%	90
Relative rectifier capacity	%	75
Rectifier efficiency	%	85
System evaluation		
Annual interest rate	%	10
Project lifetime	Years	20

A wind-diesel generator is simulated in the HOMER model based on technical and economic parameters of the wind turbine Whisper-3000 (Table A2.7) and technical and economic parameter of diesel generator (Table A2.4).

Table A2.7: Technical and economic parameters of wind turbine - Generic 3kW

Parameters	Unit	Value
Capacity	KW	3
Starting wind speed	m/s	4
Rated wind speed	m/s	13
Cut-off wind speed	m/s	17
Capital cost	USD	5630
O&M cost	USD/year	78
Life time	Years	20

A hydro-diesel generator is sized manually because the HOMER does not cover hydropower. Considering the climate condition which is characterized by two seasons (raining and dry), the reservoir of hydropower plants (usually small for small hydro plants) and the requirement that the capacity of the hydropower plants should be dimensioned in a way that it is able to cover the load during raining seasons (usually to last for 9 months). Selected capacity of both generator and hydro power plants should therefore be 10 kW.

Assuming then that 30% of the energy per year is covered by a diesel generator and the fuel consumption is accordingly proportionate, the following parameters for hydro-diesel generators have been obtained (Table A2.8).

Table A2.8: Technical and economic parameters of a hydro-diesel hybrid system

Parameters	**Unit**	**Value**
Diesel generator - 10 kW		
Capital cost	USD	5310
Fixed O&M	USD/hour	0.15
Fuel consumption	Litter	1872
Hours of operation	Hours/year	2628
Fuel price	USD/l	0.28
Hydro power plant - 10 kW		
Capital cost	USD	6000
Fixed O&M	USD/year	180
Minor repair	USD/5 years	900
Major repair	USD/10 years	1800
Lifetime	Years	20

The optimal sizes of technologies that meet the given electricity load under the given conditions of renewable energy resources simulated by the HOMER are presented in table A2.9. The levelized costs are also provided to enable a direct comparison between selected technologies.

Table A2.9: Detailed dimension of the commune sized energy technologies and their levelized costs

Items	**Diesel**	**Solar - Diesel**	**Wind - Diesel**	**Hydro - Diesel**
System size	10 kW	2 kW solar + 8 kW diesel	3 kW wind + 8 kW diesel	10 kW diesel + 10 kW hydro
Battery (kWh)		12	12	
Inverter (kW)		2	2	
Fuel consumption (litter)	11968	9445	9158	1872
Levelized costs (USD/kWh)	0.334	0.32	0.294	0.155

3. Conclusions

a. Family sized systems

An evaluation of the cost of electricity from 4 selected energy systems at household scales indicates that hydropower is the most cost effective system, ranging from 0.06 and 0.09 USD/kWh. However, as most micro generators are of the “run of river” type, electricity can be generated only during raining seasons. Thus, it appears unfair to compare energy services from hydropower with others where the objective of the latter is to provide energy service all year round. Therefore, comparison is recommended only when the water resource is stable all the year round.

At levelized costs mostly from 0.14 USD to 0.7 USD/kWh, the locally made small wind turbines appear to be the second most economical solution for providing electricity services to remote families. Generators offer the next least cost system, 0.42 USD/kWh. Gasoline generators do not have a high investment cost but their annual fuel cost prevents it from providing electricity with cost effectiveness. For application of this technology, the availability of gasoline needs to be considered however.

Levelized costs of PV ranged from 0.63 to 1.01 USD/kWh and represent the most expensive system because initial investment costs are too high.

Levelized costs of electricity from the above four options are displayed in figure A2.6. It is clear that LCC per kWh is sensitive to local resource conditions such as wind speed, solar irradiation and geographical topography. This figure, if combined with figure A2.2 and 3, could give a hint to select a suitable technology for a specific location.

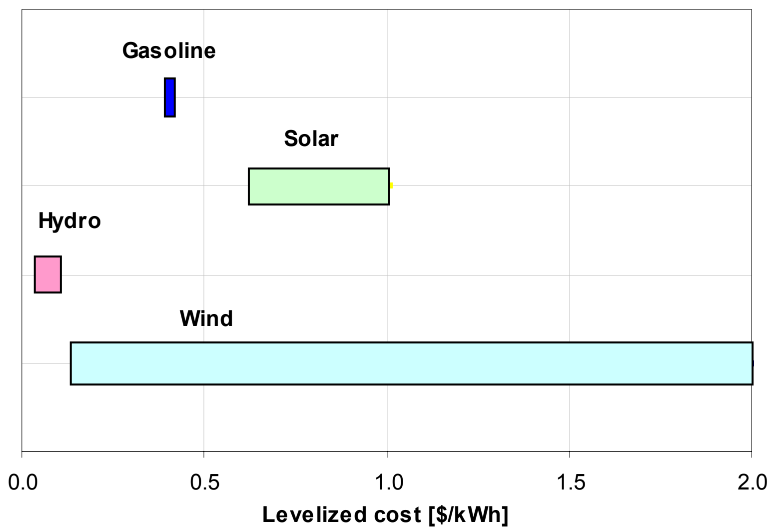

Figure A2.6: Levelized costs of electricity of household sized technologies in Vietnam

b. Commune sized systems

Unlike the household systems, commune systems require energy services with higher quality. Therefore, renewable energy technologies have been combined with diesel gensets to ensure cost effectiveness and reliability.

The levelized costs of electricity depend on local renewable energy resources and load patterns. Hydro-diesel, following by wind-diesel hybrid systems, appears to be the most cost efficient system. The solar-diesel system, despite the relatively high initial capital, is still more competitive in terms of levelized costs per kWh than the mere diesel generator (Figure A2.7).

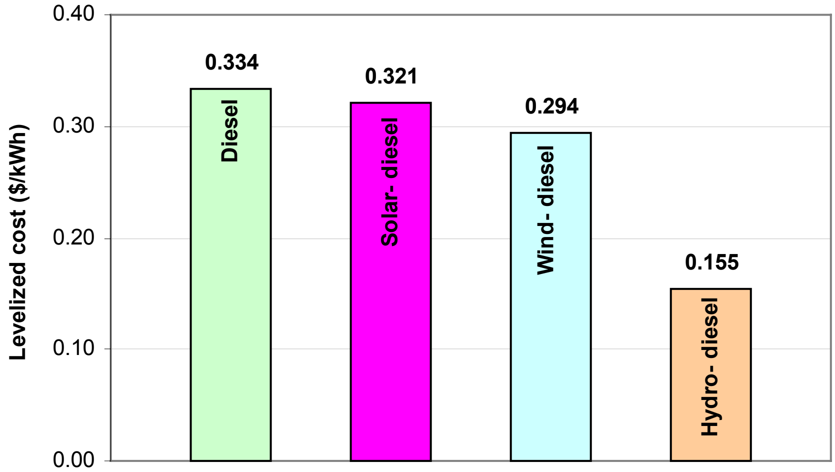

Figure A2.7: Levelized cost of electricity of commune sized technologies in Vietnam

A sensitivity analysis corresponding to a wide range of renewable energy resources in Vietnam are also carried out (Figure A2.8). The resource range for solar energy is 3.4 kWh/m^2.day to 5.24 kWh/m^2.day, for wind energy is 4m/s to 7/s.

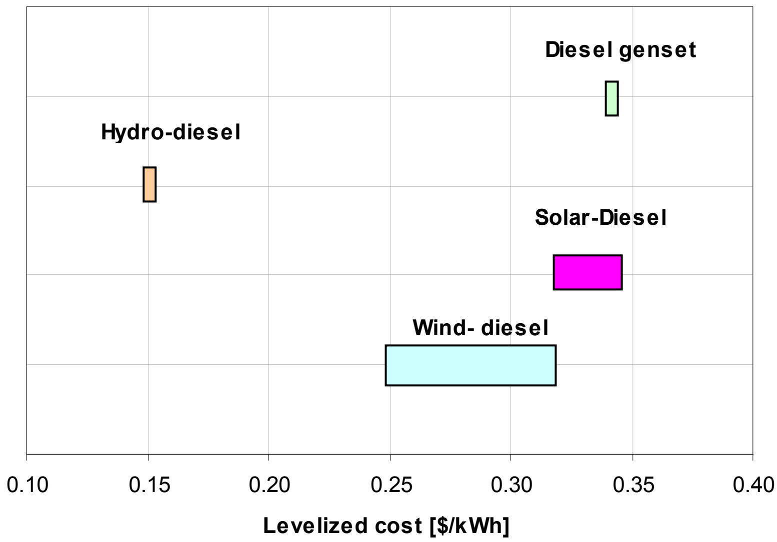

Figure A2. 8: Range of levelized cost for electricity for commune sized technologies in Vietnam

ANNEX III

NET CALORIFIC VALUES FOR FUELS

Table A3.1: Net calorific value for fuels

Fuel	Units	Calorific Value
Crude oil	Petajoules/Million tons	42.62
Coal	Petajoules/Million tons	25.12
Domestic coal	Petajoules/Million tons	23.44
Gasoline	Petajoules/Million tons	43.96
Jet fuel	Petajoules/Million tons	43.12
Kerosene	Petajoules/Million tons	43.12
Diesel oil	Petajoules/Million tons	42.70
Fuel oil	Petajoules/Million tons	41.44
LPG	Petajoules/Million tons	45.21
Natural gas	Petajoules/Billion Cu.m.	37.13
Agriculture residue	Petajoules/Million tons	12.50
Fuel wood	Petajoules/Million tons	14.65
Dung	Petajoules/Million tons	14.10
Biogas	Petajoules/Billion Cu.m	22.50

ANNEX IV

EMISSION FACTORS

Table A4.1: CO_2 emission factors for fuels

Fuel	Units	CO_2 emission factor
Crude oil	Thousand tons/Petajoule	72.60
Coal	Thousand tons/Petajoule	96.30
Domestic coal	Thousand tons/Petajoule	96.30
Gasoline	Thousand tons/Petajoule	68.61
Jet fuel	Thousand tons/Petajoule	70.79
Kerosene	Thousand tons/Petajoule	70.79
Diesel oil	Thousand tons/Petajoule	72.60
Fuel oil	Thousand tons/Petajoule	76.59
LPG	Thousand tons/Petajoule	63.10
Natural gas	Thousand tons/Petajoule	55.82

Table A4.2: CH_4 (uncontrolled) emission factors (in Kt/PJ)

			Unit	Coal	Natural gas	Oil	Wood Wood waste	Charcoal	Other biomass and wastes
Energy industry			Kt/PJ	0.001	0.001	0.003	0.03	0.2	0.03
Manufacturing & construction			Kt/PJ	0.01	0.005	0.002	0.03	0.2	0.03
Transport	*Aviation*		Kt/PJ			0.0005			
	Road		Kt/PJ		0.05	gaso (0.02); diese(0.005)			
	Railways		Kt/PJ	0.01		0.005			
	Navigation		Kt/PJ	0.01		0.005			
Other sectors	*Commercial/institutional*		Kt/PJ	0.01	0.005	0.01	0.3	0.2	0.3
	Residential		Kt/PJ	0.3	0.005	0.01	0.3	0.2	0.3
	Agriculture/ Forestry/ Fishing	Stationary	Kt/PJ	0.3	0.005	0.01	0.3	0.2	0.3
		Mobile	Kt/PJ		0.005	0.005			

Table A4.3: N_2O (uncontrolled) emission factors (in Kt/PJ)

			Unit	Coal	Natural gas	Oil	Wood Wood waste	Charcoal	Other biomass and wastes
Energy industry			Kt/PJ	0.0014	0.0001	0.0006	0.004	0.004	0.004
Manufacturing & construction			Kt/PJ	0.0014	0.0001	0.0006	0.004	0.004	0.004
Transport	*Aviation*		Kt/PJ			0.002			
	Road		Kt/PJ		0.0001	gaso (0.0006); diese (0.0006)			
	Railways		Kt/PJ	0.0014		0.0006			
	Navigation		Kt/PJ	0.0014		0.0006			
Other sectors	*Commercial/institutional*		Kt/PJ	0.0014	0.0001	0.0006	0.004	0.001	0.004
	Residential		Kt/PJ	0.0014	0.0001	0.0006	0.004	0.001	0.004
	Agriculture/	Stationary	Kt/PJ	0.0014	0.0001	0.0006	0.004	0.001	0.004
	Forestry/	Mobile	Kt/PJ		0.0001	0.0006			
	Fishing								

ANNEX V

DETAILED RESULTS OF THE BAU–BASE SCENARIO

Table A5.1: Primary energy consumption (PJ)

Fuel type	1995	2000	2005	2010	2015	2020	2025	2030
Coal	110.6	175.9	301.6	448.9	651.3	1104.9	1955.7	2972.5
Natural gas	7	50.9	154.9	409.4	640.6	678.3	678.3	678.3
Oil	205.6	344.4	383.9	508.7	671.8	930.6	1138.3	1357.8
Hydro	119.6	138.6	186.3	186.6	186.9	281.0	338.8	504.9
Geothermal	0.0	0.0	7.4	7.4	22.2	29.6	29.6	29.6
Wind	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.9
Solar	0.0	0.0	0.1	0.1	0.3	0.7	1.8	4.5
Import of electricity	0.0	0.0	0.0	4.9	21.1	56.7	64.8	72.9
Biomass	597.1	626.1	640.9	649.7	635.6	601.4	545.1	473.2
Animal Dung	0.26	0.44	0.69	1.12	1.79	2.85	4.55	7.32
Sum	**1040.3**	**1336.3**	**1675.8**	**2216.8**	**2831.7**	**3686.2**	**4757.3**	**6101.9**

Table A5.2: Energy import (PJ)

Fuel type	1995	2000	2005	2010	2015	2020	2025	2030
Jet fuel	10.5	12.4	1.9	7.5	17.7	15.7	51.5	104.2
Diesel	80.3	121.4	48.0	81.2	122.5	33.6	141.9	271.7
Fuel oil	46.4	128.9	96.9	117.7	151.6	127.7	191.2	228.3
Gasoline	55.2	73.9	0.0	0.0	0.0	0.0	0.0	0.0
Coal	0.0	0.0	0.0	0.0	9.4	427.6	1265.3	2280.9
Kerosene	10.8	7.8	0.0	0.0	0.0	0.0	0.0	0.0
LPG	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	0	0	0	5	21	57	65	73
Sum	**205.6**	**344.4**	**146.8**	**211.3**	**322.4**	**661.3**	**1714.8**	**2958.0**

Table A5.3: Energy export (PJ)

Fuel type	1995	2000	2005	2010	2015	2020	2025	2030
Coal	85.2	96.1	120.2	118.5	0	0	0	0
Crude Oil	320.4	690.8	508.2	602.1	532.7	0	0	0
Sum	**405.6**	**786.9**	**628.4**	**720.6**	**532.7**	**0.0**	**0.0**	**0.0**

Table A5.4: Final energy demand (PJ)

Fuel type	1995	2000	2005	2010	2015	2020	2025	2030
Agriculture								
Electricity	2.26	2.63	3.00	3.50	4.04	4.65	5.29	6.04
Coal	1.05	1.21	1.39	1.58	1.79	2.00	2.22	2.43
Biomass	12.59	14.58	16.70	19.00	21.47	24.04	26.61	29.15
Diesel	8.02	9.52	11.02	12.35	13.75	14.99	15.79	16.47
Fuel oil	0.32	0.37	0.42	0.46	0.51	0.55	0.57	0.59
Gasoline	3.69	4.37	5.06	5.66	6.32	6.88	7.24	7.55
Kerosene	0.71	0.68	0.61	0.52	0.44	0.38	0.30	0.24
Total agriculture	*28.64*	*33.36*	*38.20*	*43.07*	*48.32*	*53.49*	*58.02*	*62.47*
Commerce								
Electricity	3.64	6.54	11.78	20.76	36.58	60.08	92.98	136.62
LPG	0.73	1.66	2.89	4.45	6.57	9.47	13.31	18.36
Fuel oil	3.63	4.23	4.93	5.72	6.47	7.15	7.71	8.16
Kerosene	1.92	2.22	2.49	2.76	2.99	3.16	3.26	3.30
Coal	1.74	2.27	2.90	3.63	4.50	5.56	6.83	8.35
Total commerce	*11.65*	*16.92*	*24.98*	*37.33*	*57.12*	*85.43*	*124.10*	*174.79*
Industry								
Electricity	16.63	33.35	61.81	111.25	189.90	303.39	474.12	696.16
LPG	0.26	0.43	0.70	1.03	1.48	2.12	3.04	4.33
Natural gas	0.00	0.75	33.52	60.62	84.34	96.05	114.24	153.37
Diesel	1.46	3.09	5.83	9.90	16.01	23.98	35.89	53.73
Fuel oil	26.43	45.63	73.11	104.79	144.95	186.55	235.86	294.47
Kerosene	0.23	0.41	0.73	1.18	1.84	2.76	4.13	5.89
Biomass	113.19	133.71	155.44	177.22	183.66	180.15	155.72	120.54
Coal	63.23	101.85	152.90	237.73	311.58	449.04	570.18	671.11
Total industry	*221.43*	*319.22*	*484.04*	*703.72*	*933.76*	*1244.04*	*1593.18*	*1999.60*
Resident								
Electricity	17.79	38.67	68.31	110.10	152.32	200.77	254.56	322.53
LPG	1.17	6.27	13.31	18.27	25.08	34.45	47.33	62.71
Kerosene	7.34	4.10	2.79	1.26	0.30	0.00	0.00	0.00
Biogas	0.26	0.44	0.69	1.12	1.79	2.85	4.55	7.32
Biomass	471.37	477.80	453.91	436.79	407.28	368.89	326.43	285.82
Coal	20.74	23.76	29.15	34.61	37.65	38.72	37.00	23.67
Total resident	*518.67*	*551.04*	*568.16*	*602.15*	*624.42*	*645.68*	*669.87*	*702.05*
Transport								
Diesel	62.60	94.75	135.63	189.94	251.11	323.22	397.99	477.68
Fuel oil	3.76	6.45	10.23	15.79	23.03	32.45	42.66	54.37
Gasoline	48.39	65.29	84.41	108.40	137.07	168.28	194.97	217.52
Jet fuel	9.90	11.68	17.42	27.05	41.82	64.61	98.40	148.03
Coal	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total transport	*124.88*	*178.17*	*247.69*	*341.18*	*453.03*	*588.56*	*734.02*	*897.60*
SUM	**905.27**	**1098.71**	**1363.07**	**1727.45**	**2116.65**	**2617.20**	**3179.19**	**3836.51**

Table A5.5: Fuel wise energy consumption (PJ)

Fuel type	1995	2000	2005	2010	2015	2020	2025	2030
Coal	**110.6**	**175.9**	**301.7**	**448.9**	**651.3**	**1104.9**	**1955.7**	**2972.5**
Power	23.57	46.83	115.31	171.33	295.80	609.59	1339.46	2266.90
Agriculture	1.05	1.21	1.39	1.58	1.79	2.00	2.22	2.43
Commerce	1.74	2.27	2.90	3.63	4.50	5.56	6.83	8.35
Industry	63.23	101.85	152.90	237.73	311.58	449.04	570.18	671.11
Resident	20.74	23.76	29.15	34.61	37.65	38.72	37.00	23.67
Transportation	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural gas	**7.00**	**42.04**	**148.84**	**384.50**	**595.18**	**638.12**	**619.77**	**597.02**
Power	7.00	41.29	115.32	323.88	510.84	542.07	505.53	443.65
Industry	0.00	0.75	33.52	60.62	84.34	96.05	114.24	153.37
Diesel	**73.71**	**108.99**	**157.14**	**219.10**	**293.45**	**387.15**	**489.34**	**611.78**
Power	1.63	1.63	4.66	6.91	12.58	24.96	39.67	63.90
Agriculture	8.02	9.52	11.02	12.35	13.75	14.99	15.79	16.47
Industry	1.46	3.09	5.83	9.90	16.01	23.98	35.89	53.73
Transportation	62.60	94.75	135.63	189.94	251.11	323.22	397.99	477.68
Fuel oil	**43.81**	**121.61**	**136.14**	**168.03**	**214.67**	**262.70**	**322.58**	**357.59**
Power	9.67	64.93	47.45	41.27	39.71	36.00	35.78	0.00
Agriculture	0.32	0.37	0.42	0.46	0.51	0.55	0.57	0.59
Commerce	3.63	4.23	4.93	5.72	6.47	7.15	7.71	8.16
Industry	26.43	45.63	73.11	104.79	144.95	186.55	235.86	294.47
Transportation	3.76	6.45	10.23	15.79	23.03	32.45	42.66	54.37
LPG	**2.16**	**8.36**	**16.90**	**23.75**	**33.13**	**46.04**	**63.68**	**85.40**
Commerce	0.73	1.66	2.89	4.45	6.57	9.47	13.31	18.36
Industry	0.26	0.43	0.70	1.03	1.48	2.12	3.04	4.33
Resident	1.17	6.27	13.31	18.27	25.08	34.45	47.33	62.71
Kerosene	**10.20**	**7.41**	**6.62**	**5.72**	**5.57**	**6.30**	**7.69**	**9.43**
Agriculture	0.71	0.68	0.61	0.52	0.44	0.38	0.30	0.24
Commerce	1.92	2.22	2.49	2.76	2.99	3.16	3.26	3.30
Industry	0.23	0.41	0.73	1.18	1.84	2.76	4.13	5.89
Resident	7.34	4.10	2.79	1.26	0.30	0.00	0.00	0.00
Gasoline	**52.08**	**69.66**	**89.47**	**114.06**	**143.39**	**175.16**	**202.21**	**225.07**
Agriculture	3.69	4.37	5.06	5.66	6.32	6.88	7.24	7.55
Transportation	48.39	65.29	84.41	108.40	137.07	168.28	194.97	217.52
Jet fuel	**9.90**	**11.68**	**17.42**	**27.05**	**41.82**	**64.61**	**98.40**	**148.03**
Transportation	9.90	11.68	17.42	27.05	41.82	64.61	98.40	148.03

Table A5.6: Electric generation (PJ)

Fuel type	1995	2000	2005	2010	2015	2020	2025	2030
Coal	6.60	13.12	39.14	60.42	109.22	231.61	508.91	861.29
Natural gas	3.08	18.16	50.73	142.49	224.74	238.48	222.41	195.18
Oil	4.21	24.63	18.07	16.64	18.30	20.40	24.93	19.97
Hydro	38.15	44.14	59.30	59.29	59.29	89.31	107.71	160.76
Renewable	0.13	0.20	6.26	7.04	14.25	18.62	21.80	22.87
Sum	**52.17**	**100.25**	**173.50**	**285.88**	**425.80**	**598.42**	**885.76**	**1260.07**

Table A5.7: Electric generation shares according to fuel types

Fuel type	1995	2000	2005	2010	2015	2020	2025	2030
Coal	12.7%	13.1%	22.6%	21.1%	25.7%	38.7%	57.5%	68.4%
Natural gas	5.9%	18.1%	29.2%	49.8%	52.8%	39.9%	25.1%	15.5%
Oil	8.1%	24.6%	10.4%	5.8%	4.3%	3.4%	2.8%	1.6%
Hydro	73.1%	44.0%	34.2%	20.7%	13.9%	14.9%	12.2%	12.8%
Renewable	0.2%	0.2%	3.6%	2.5%	3.3%	3.1%	2.5%	1.8%

Table A5.8: Electric capacity (GW)

Fuel type	1995	2000	2005	2010	2015	2020	2025	2030
Coal	0.65	0.65	1.75	2.65	4.68	9.79	21.52	36.41
Natural gas	0.23	0.77	2.15	6.02	9.58	10.36	9.98	9.55
Oil	0.65	1.46	1.35	1.12	1.17	1.25	1.47	1.06
Hydro	2.85	3.30	4.43	4.43	4.43	6.67	8.10	12.07
Renewable	0.03	0.04	0.37	0.42	0.78	1.01	1.18	1.27
Sum	**4.4**	**6.2**	**10.1**	**14.6**	**20.6**	**29.1**	**42.3**	**60.4**

Table A5.9: Investment cost in electric generation capacity (Mill USD)

Fuel type	1995-00	2000-05	2005-10	2010-15	2015-20	2020-25	2025-30	2030-35
Coal	-	-	1,980	1,620	4,036	9,990	21,104	26,817
Natural gas	281	679	1,721	4,849	4,441	1,265	200	1,182
Oil	-	1,248	35	35	129	179	280	459
Hydro	-	1,004	2,554	8	6	3,966	3,111	8,869
Renewable	-	13	427	95	912	632	725	630
Sum	**281.3**	**2943.4**	**6716.7**	**6607.6**	**9524.2**	**16030.6**	**25420.6**	**37957.0**

Table A5.10: Renewable energy capacity (GW)

Fuel type	1995	2000	2005	2010	2015	2020	2025	2030
Biomass	0	0	0.22	0.25	0.4	0.5	0.65	0.70
Geothermal	0	0	0.1	0.1	0.3	0.4	0.4	0.4
Small hydro	0.03	0.04	0.05	0.07	0.08	0.1	0.11	0.13
PV	0	0	0	0	0	0	0	0
Wind	0	0	0	0	0	0.01	0.02	0.04
Sum	**0.03**	**0.04**	**0.37**	**0.42**	**0.78**	**1.01**	**1.18**	**1.27**

Table A5.11: Emission (Thousand tons)

Emission type	1995	2000	2005	2010	2015	2020	2025	2030
CO_2	**25030**	**43541**	**64883**	**101709**	**145336**	**210174**	**306279**	**418707**
Solid	10646	16943	29049	43228	62722	106404	188333	286248
Liquid	13857	23756	27629	36511	48116	67294	81688	96775
Gas	527	2842	8206	21970	34498	36476	36257	35685
CH_4	**0.53**	**1.02**	**2.33**	**4.2**	**6.16**	**7.45**	**8.98**	**10.20**
N_20	**0.39**	**0.67**	**1.07**	**1.58**	**2.26**	**3.6**	**6.1**	**9.07**

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DATA SOURCES FOR TECHNOLOGIES IN VIETNAM

Technical and economics information of various technologies (conversion, process, demand technologies) in Vietnam has been referred and collected mainly from the following sources.

Conversion technologies

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In addition to that, data have been also collected through personal surveys, personal meetings with relevant people and reference to relevant websites. For renewable energy technologies, sources of data are mentioned individually in chapter III.

Erklärung

Die vorliegende Dissertation mit dem Titel

"Long term optimization of energy supply and demand in Vietnam with special reference to the potential of renewable energy"

ist von mir ohne fremde Hilfe angefertigt worden. Es sind keine anderen als die angegeben Quellen und Hilfsmittel verwendet werden. Alle Stellen, die wörtlich oder sinngemäß aus Veröffentlichungen entnommen sind, sind als solche kenntlich gemacht worden.

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