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Greenhouse gas mitigation potential of biomass energy technologies in Vietnam using the long range energy alternative planning system model

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Abstract

The greenhouse gas (GHG) mitigation potentials of number of selected Biomass Energy Technologies (BETs) have been assessed in Vietnam. These include Biomass Integrated Gasification Combined Cycle (BIGCC) based on wood and bagasse, direct combustion plants based on wood, co-firing power plants and Stirling engine based on wood and cooking stoves. Using the Long-range Energy Alternative Planning (LEAP) model, different scenarios were considered, namely the base case with no mitigation options, replacement of kerosene and liquefied petroleum gas (LPG) by biogas stove, substitution of gasoline by ethanol in transport sector, replacement of coal by wood as fuel in industrial boilers, electricity generation with biomass energy technologies and an integrated scenario including all the options together. Substitution of coal stoves by biogas stove has positive abatement cost, as the cost of wood in Vietnam is higher than coal. Replacement of kerosene and LPG cookstoves by biomass stove also has a positive abatement cost. Replacement of gasoline by ethanol can be realized after a few years, as at present the cost of ethanol is more than the cost of gasoline. The replacement of coal by biomass in industrial boiler is also not an attractive option as wood is more expensive than coal in Vietnam. The substitution of fossil fuel fired plants by packages of BETs has a negative abatement cost. This option, if implemented, would result in mitigation of 10.83 million tonnes (Mt) of CO_2 in 2010.

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1. Introduction

The conference of parties (COP) held in Kyoto, Japan, in December 1997 recognized the need to urgently address the issue of climate change and established GHG emission reduction targets for industrialized countries. Also, the developing countries are expected to identify GHG emission mitigation options compatible with national development. Utilization of biomass for energy offers one of the important options to reduce GHG emissions. Many new biomass energy technologies are now in the different stages of development, demonstration and commercialization. Some of the promising biomass energy technologies include biomass integrated gasification combined cycle, direct combustion of biomass for steam engine, Stirling engines, co-firing and improved cooking stoves.

Biomass is one of the most important energy sources in Vietnam. In Vietnam traditional fuels accounted for 37.8% of the total energy consumption in 1997 [1]. Fuel wood is the main component of the biomass fuels. Its share in the traditional energy supply is about 84% [2]. Vietnam is an agriculture-dominated country. About 80% of the population resides in the rural area and most of them are farmers. The potential of agricultural residues is enormous in this country and the increasing population is expected to lead to more crop as well as residue production. Also, due to price increase of fossil fuel, the pressure on high utilization of agricultural residues would increase. The country also has a large potential for generation of biogas from animal waste. The major domestic animals in Vietnam are buffalos, cows, pigs, chicken and ducks. Bhattacharya et al. [2], estimated the potential of biogas production from animal wastes in Vietnam to be 11.28 million m^3 of biogas or 85 PJ.

It has been reported that Vietnam has lost about 30% of its forest cover in the last 30 years. Energy plantation in the deforested land can potentially serve to produce large amount of biomass for energy. Also, large quantities of agricultural residues are currently left unused; the surplus residues can significantly contribute to biomass energy potential in Vietnam. The authors assume that future growth in biomass energy consumption considered in this paper can come from new plantations and surplus residues/wastes without causing any significant impact on soil erosion and water quality.

In view of the potentials of BET and the need to formulate energy policies and programs taking into account the multitude of options and critical constraints associated with complexity and interdependence of the energy systems. These call for an integrated approach to solve the energy problem. Such an approach considers the energy supply and demand options along with the available energy technologies, fuel and energy saving practices.

LEAP is a computerized framework for the evaluation of national/regional energy planning policies [3]. The system is designed to assist energy planners and decision-makers to identify and quantify the future pattern of energy consumption and the problems associated with this pattern of energy use, and also the likely impact of the different policies. This system also tracks down the long-term energy demand and supply situation in a given country and has been used by several researchers for analyzing measures to mitigate global warming [4,5,6].

This paper presents the GHG mitigation potential of biomass energy technologies in Vietnam using the LEAP model for a number of greenhouse gas abatement scenarios.

2. Methodology

2.1. The LEAP model

LEAP is structured as a series of integrated programs in four main program groups namely, Energy Scenarios, Aggregation, Environmental Database (EDB) and Fuel Chains [3]. Fig. 1 shows the schematic structure of LEAP. The Energy Scenarios group consists of several closely linked programs: Demand, Transformation, Biomass, Environment and Evaluation programs. These are the main tools used to perform the integrated energy–environment planning exercise for a single area. The Aggregation program is a tool used to display multi-area results from analyses carried out in different areas. EDB can either be used as a stand-alone reference tool or linked to the rest of LEAP to automatically calculate emissions and other environmental impacts of energy scenarios. The fuel chain is used to compare total energy and environmental impacts of specific fuel and technology choices per unit of energy of service delivered.

The demand program uses the end-use driven approach. The data is assembled in a hierarchial format based on four levels; sector level (residential, industry, transport etc.), sub-sector levels such as rural or urban, further end-use (lighting, cooking etc.) and finally end-uses according to devices (charcoal cooking stoves, biomass cooking stoves etc.) or according to fuel use (diesel, biomass etc.). Fig. 2 shows the hierarchial levels in the residential sector. Similarly the hierarchial levels for the industry, transport, agriculture and service sector have been developed. This program calculates the energy demand of each sector and thereby the total energy demands of the area in consideration. The transformation program consists of the modules, consisting of different processes responsible for the conversion of the primary energy to final energy such as electricity and gasoline. The program estimates the primary resources, imports and exports to the total energy demand as calculated by the demand program. The environmental program helps in quantitatively estimating the environmental emissions and impacts associated with an energy scenario. These emissions are estimated using the emission coefficients contained in the LEAP Environmental Database. The evaluation program is to compare the different scenarios. The program determines the environmental consequences as a result of implementing energy policy. Appendix 1 presents the input data and assumptions to the LEAP program.

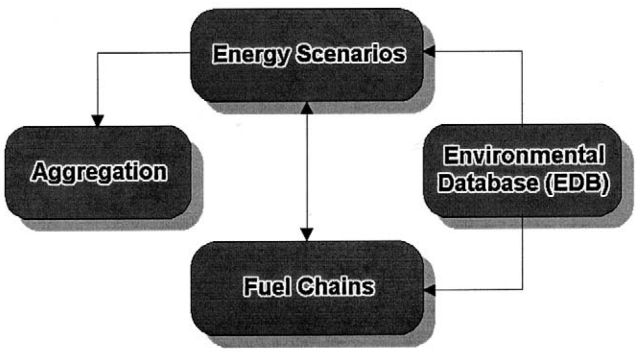

Fig. 1. A schematic showing structure of LEAP.

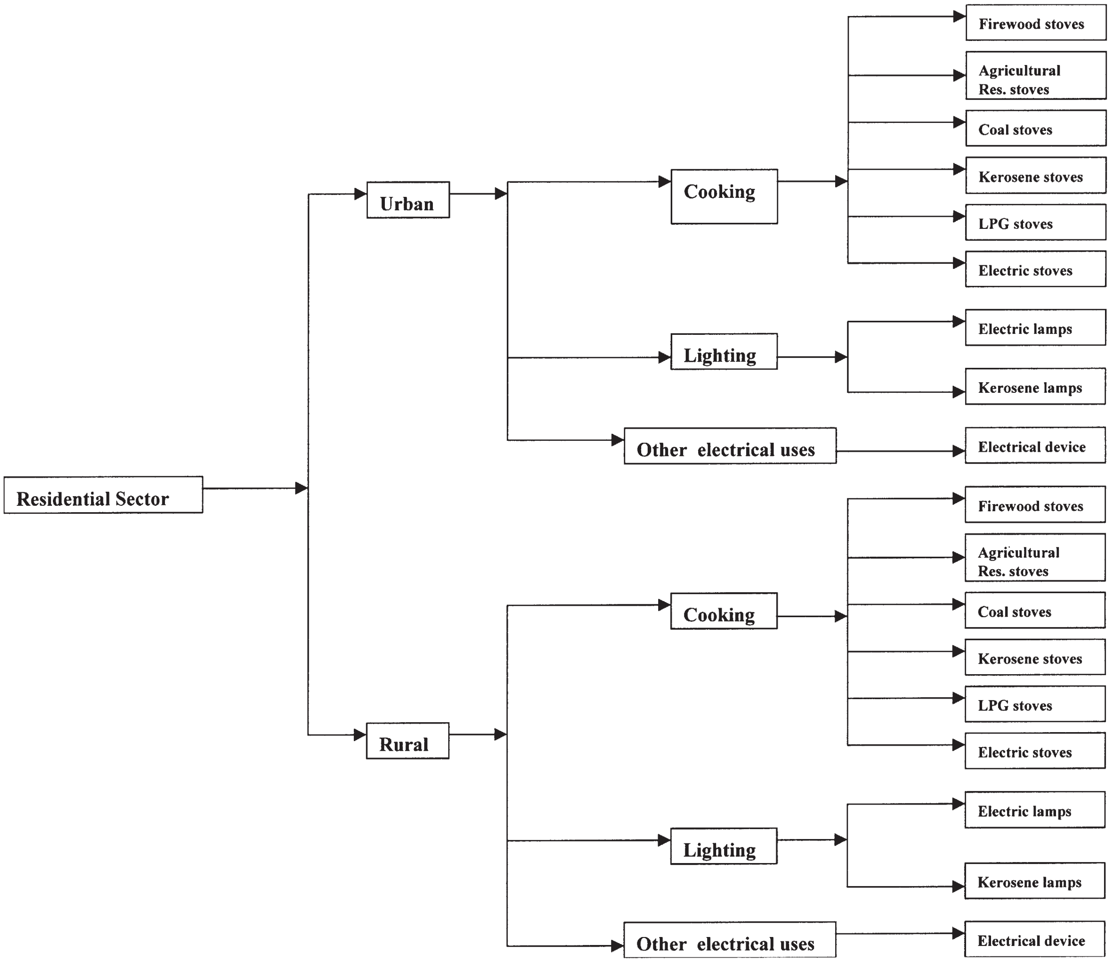

Fig. 2. Energy demand tree for residential sector.

2.2. Description of the different scenarios considered

In this study the scenarios considered were the following; the base case with no mitigation options considered, replacement of coal stoves by biomass stoves, replacement of kerosene and LPG stoves by biogas stoves, substitution of gasoline by ethanol in road vehicles, replacement of coal by wood as fuel in industrial boilers, electricity generation with biomass energy technologies and integrated scenario. The integrated scenario gives the picture of the cumulative effect of the different mitigation options in Vietnam.

2.2.1. Base case

The base case has been prepared by entering the data as a scenario with no mitigation options. It is an extension of the present trend of the energy consumption in Vietnam. The energy consumption in five different sectors has been considered. These are residential, industrial, transportation, service sector and agricultural sector. These sectors have been further divided under hierarchial level as required by LEAP. The base case energy consumption data for the different end-uses has been taken from the study of the Ministry of Science, Technology and Environment (MOSTE) of Vietnam [7]. The projection of the future demand is based on the Asia Least Cost Greenhouse Gas Abatement Strategy (ALGAS) studies (1994–1998). This was a regional project under United Nations Development Programme (UNDP)/Global Environment Facility (GEF) funded by Asian Development Bank (ADB). The main objectives of the study were to assess the present level of GHG emissions, review the options to reduce GHG emissions and identify technologies, which could be cost-effective in terms of reducing GHG. The study covers eleven asian countries which includes Bangladesh, China, Democratic People’s Republic of Korea, India, Indonesia, Mongolia, Myanmar, Pakistan, Philippines, Republic of Korea, Thailand, and Vietnam.

Table 1 shows the base case final energy demand of the different sectors from 1995 to 2020. The total final energy demand is expected to grow at 5.9% per annum. It can be seen that in the base year 1995 residential sector was the main consumer of energy consuming 47% of the energy, followed by industry. But it is projected that the industry sector would be largest energy consumer in 2020; the growth of energy demand in the industry sector will be 8.9% per annum. The transport sector is expected to grow at the rate of 6.7% per annum. The agricultural sector is expected to be the smallest consumer of energy in 2020. The growth rate of the energy consumption in the residential sector is low at 2%; this is because the population is expected to grow at a low rate of 1.5% per annum.

Table 2 shows the demand of different fuels from 1995 to 2020 in the different energy consuming sectors. It can be seen that by 2020 the highest demand would be for the diesel/gas oil growing at 8.5% per annum. The main consumer of diesel/gas oil in Vietnam is the industrial sector for use in boilers and furnaces. Hence it is expected that the use in these energy-consuming devices would increase substantially. The biomass fuels, firewood and rice husk, are mainly used in the residential sector for cooking. The decrease in the demand of these fuels shows that the use of fossil fuel based cooking systems would increase.

The demand of biomass fuels has a negative growth rate of about 2% per annum from 1995 to 2020. The growth rate of other fuels are gasoline: 6.3%; kerosene: 5.6%; residual fuel oil/gas oil: 6.3%; coal: 5.5%; and jet fuel: 6.3%.

In this study, the residential sector has been divided in rural and urban sub-sectors. The sub-

Table 1
Final energy demand in the different sectors of Vietnam in the base case [Peta Joule (PJ)]

Sectors	1995	2000	2005	2010	2015	2020
Residential	257.94	275.39	301.40	334.24	377.87	421.49
Industry	144.62	232.32	426.64	630.71	925.36	1220.02
Agriculture	16.86	20.35	26.34	29.33	33.77	38.20
Transport	111.17	167.79	253.61	341.00	450.68	560.37
Service	13.87	18.88	25.02	34.84	40.99	47.14
Total	544	715	1033	1370	1829	2287

Source: Calculated from this study by LEAP model

Table 2
Base case demand of different fuels in the different sectors from 1995 to 2020 (PJ)

Fuels	1995	2000	2005	2010	2015	2020
Electricity	43.81	67.04	142.20	234.32	338.82	443.33
Gasoline	58.32	90.5	133.17	174.08	220.58	267.08
Kerosene	15.27	19.32	24.90	36.20	48.03	59.87
Diesel/gas oil	112.56	174.51	297.46	441.36	649.32	857.29
Residual/fuel oil	19.92	29.30	45.40	57.35	74.87	92.39
LPG/bottled gas	0.13	0.97	3.68	10.16	19.65	29.14
Coal anthracite	100.52	149.01	207.25	258.97	321.27	383.57
Firewood	151.94	140.91	132.76	109.90	101.36	92.82
Bagasse	0.66	0.61	0.57	0.48	0.44	0.40
Rice husk	32.24	29.90	28.17	23.32	21.51	19.70
Jet fuel	9.09	12.66	17.46	24.00	32.83	41.66
Total	544	715	1033	1370	1829	2287

Source: Calculated from this study by LEAP model

sectors has been further divided into end uses and different devices of energy consumption. End–uses which have been considered are cooking, lighting and other electrical use for both rural and urban areas. Energy use for air conditioning and water heating has been considered only in urban sub-sectors. In this study, the stoves considered, uses coal, firewood, agricultural residues, kerosene, LPG and electrical energy for both rural and urban sub-sectors. For lighting purposes in the urban and rural sectors, the devices that have been considered are electrical lamps and kerosene lamps. In the residential sector 59% of the energy demand is expected to come from urban sub-sector in 2020. The pattern of energy use in the two sub-sectors is somewhat different. In the rural households energy is mainly used for lighting, cooking and other electrical use. In the urban sector the energy is used in cooking, lighting, air conditioning and hot water heating and in other electrical use.

In Vietnam the fuels used for cooking are traditional fuels like firewood and agricultural residues, coal, kerosene, LPG and electricity. Table 17 (Appendix 1) shows the energy consumption for cooking in urban and rural sub-sectors respectively for the period 1995-2020. Data available from MOSTE (Vietnam) gives the aggregate consumption of traditional fuel. It doesn’t specify the separate consumption of firewood and agricultural residues. The amount of firewood and agricultural residues consumption in the residential sector in the year 1991 by end-use technologies was 2.5 and 5.8 Tg per year respectively [2]. Using this consumption data and the calorific value of firewood and agricultural residues, the percentage contribution of firewood and agricultural residues in traditional fuel has been calculated.

The calorific values of firewood were assumed to be 17.32 MJ/kg [3]. The contribution of the charcoal from biomass has been neglected, for simplicity, as its consumption was only 2% of the energy from biomass in 1991. In 1991 the energy provided by bagasse and rice husk/other residues was 1.05 and 76 PJ respectively [2]. The agricultural residues in the present study have been assumed to mainly consist of sugar cane bagasse and rice husk. The weighted average calorific value of the agricultural residues is assumed to be 16.70 MJ/kg based on the assumption that percentage contribution of rice husk is 98% and that of bagasse is 2%. This percentage contribution is derived from their energy contribution in 1991. The calorific values of bagasse and rice husk are assumed as 8.36 and 16.87 MJ/kg [3] respectively.

The electrical energy consumption for air-conditioning (AC) and hot water supply has been assumed to be only in the urban sub-sector as there is no separate data available for consumption in urban and rural sub-sectors. Table 17 (Appendix 1) gives the energy consumption in lighting, other electrical uses, air-conditioning and hot water for urban and rural households. Table 3 shows the energy consumption in the residential sector.

Also, in the urban areas the highest percentage of energy is consumed for cooking. The energy demand for cooking is expected to increase at 3.6% per annum. The maximum growth rate of 7.33% per annum in the energy demand is seen in air conditioning and hot water requirements; this is because of the increased standard of living. About 66% of the energy use in the urban sub-sector is expected in cooking, and 21% in air conditioning and hot water in the year 2020.

The different types of fuels that are used in residential sector of Vietnam include kerosene, LPG, coal, firewood, agricultural residues and electricity. Table 4 shows the demand of different fuels in the residential sector.

Biomass is the main fuel used in the residential sector. It contributed 72% of the fuel demand in 1995 and is expected to contribute 27% in 2020. It would be mostly replaced by coal. The contribution of coal increases from 17 to 27% in the study period. The demand of biomass is decreasing because the population would be increasing in the urban areas. Also efficient fossil fuel based stoves would be penetrating the market. The demand for LPG is expected to increase at a rate of 14.6% per annum. An oil refinery coming into use in Vietnam in 2005, would lead to increased availability of LPG.

Table 5 shows the industrial energy consumption in terms of different fuels. In the industry sector, energy consumption in six different industries has been considered. These are Food Industry, Textile-garments, Chemicals, Metallurgy and Engineering, Building Materials and Others. The energy consumption of all the industries have been combined and put into three end-uses. The three end-uses are thermal use, mechanical use and electrical use. The thermal uses in the industries are mainly in the boilers and furnaces. The fuel used is coal and residual fuel oil

Table 3
Final energy demand in the residential sector (PJ)

	1995	2000	2005	2010	2015	2020
Rural						
Lighting	0.06	0.05	0.05	0.05	0.05	0.05
Cooking	191.56	186.99	193.24	187.12	179.91	172.70
Urban						
Cooking	46.8	67.57	75.81	98.12	131.65	165.19
Lighting	2.15	3.37	4.00	5.42	7.15	8.88
Other electrical use	5.71	8.50	10.70	14.36	18.39	22.43
AC and hot water	11.66	8.91	17.61	29.17	40.71	52.25
Total	258	275	301	334	378	421

Source: Calculated from this study by LEAP model

Table 4
Demand of different fuels in the residential sector (PJ)

Fuels	1995	2000	2005	2010	2015	2020
Electricity	14.97	21.84	42.99	66.65	86.75	106.85
Kerosene	15.27	19.32	24.90	36.20	48.03	59.87
LPG	0.13	0.97	3.68	10.16	19.65	29.14
Coal	42.73	61.84	68.33	87.54	100.13	112.72
Firewood	151.94	140.91	132.76	109.9	101.36	92.82
Bagasse	0.66	0.61	0.57	0.48	0.44	0.40
Rice husk	32.24	29.90	28.17	23.32	21.51	19.70
Total	258	275	301	334	378	421

Source: Calculated from this study by LEAP model

Table 5
Demand of different fuels in industry sector (PJ)

	1995	2000	2005	2010	2015	2020
Thermal use						
Residual oil	12.81	19.70	32.55	39.84	52.84	65.46
Coal	49.82	76.71	125.71	153.5	200.72	247.94
Mechanical use						
Equipment	61.87	101.98	184.51	289.38	443.94	598.49
Electrical energy use						
Electrical equipment	20.12	33.94	83.87	147.99	228.06	308.13
Total	145	232	427	631	925	1220

Source: Calculated from this study by LEAP model

and for mechanical use it is diesel. The electrical uses consist of all the uses of electricity in the industries.

The total demand of energy in the industrial sector is projected to increase at a rate of 6.9%. The percentage share of diesel as fuel varies from 40 to 50% in the study period. The percentage contribution of coal is projected to decrease from 34% in 1995 to 20% in 2020. The electricity demand is expected to increase at an average of 9.2% per annum with its percentage share increasing from 13 to 26% during the study period.

The transportation sector is one of the largest energy consuming sectors in Vietnam. In 1995 it consumed approximately 21% of the final energy demand and it is projected that this would rise to 23% in 2020. The main mode of passenger transport is by road. The energy consumption in the passenger transport by road is expected to increase at 5.3% per annum. This is the result of population growth and also less development of the other modes of passenger transport. The freight transport is mainly through road and water. Energy consumption in the freight transport through water and road is expected to grow at the rate of 5.7% and 3.4% respectively. This would be because of the development of the waterways as it is the cheaper option. Table 6 shows the energy demand for the different modes of transport.

Gasoline and diesel are the major fuels required in the transport sector. The use of road vehicles, especially two wheel vehicles (motorcycles, scooters etc.) and cars, would lead to increase in the demand of gasoline. Coal is mainly used in the locomotives. The requirement of coal would decrease to zero by the year 2005. This would mean that the railway engines would be diesel based and all the steam engines would be phased out. The requirement of jet fuel also shows an increase over the study period. The increase in the use of fuel oil/residual oil is not significant.

The energy use in the agricultural sector is mainly for water pumping and irrigation; the main fuel used in the sector is diesel. Diesel is used for driving the machinery and also for small-scale power generation. The energy demand in the agricultural sector is expected to increase at 2.5% per annum. This energy demand would be mainly driven by the increased use of diesel for mechanical use as its percentage share in 1995 was 59% and in 2020 would be 57%. The electrical energy is mainly used for pumping water; the demand for this is expected to increase at 2.9% per annum. In the agricultural sector, energy is used for mechanical, thermal and electrical uses. The mechanical uses mostly include the use of diesel driven machinery and small-scale electricity generation. Thermal uses include mainly consumption of fuel oil and coal and electrical energy is used mainly in irrigation pumping. The transport sector is one of the main energy consuming sectors in Vietnam. It has been divided into two sub-sectors, passenger and transport. The sub-sectors have been divided in end-uses as roads, railway, water and air.

The energy in the service sector is mainly used for non-space heating purposes rather than for space heating and air conditioning, the fuel mainly used being coal. The use of coal is expected to increase at 3.3% per annum while the demand of electricity is expected to increase at 4.8% per annum. The percentage share of coal in 2020 is expected to be 48% of the total energy demand in the service sector. The service sector has been divided into two sub-sectors. These sub-sectors are; space heating and air conditioning and non-space heating and air conditioning. The fuels consumed for space heating and air conditioning include coal, residential fuel oil and

Table 6
Energy demand in the different modes of transport (PJ)

	1995	2000	2005	2010	2015	2020
Passenger						
Railway	0.90	1.11	1.34	1.54	1.92	2.31
Road	47.60	75.52	119.65	160.31	217.00	273.68
Air	9.09	12.66	17.46	24.00	32.83	41.66
Water	0.84	1.17	1.61	2.21	3.02	3.84
Freight						
Railway	1.23	1.59	2.17	2.87	4.37	5.87
Road	27.41	41.06	61.02	79.79	87.41	95.04
Water	21.47	30.84	44.9	62.32	92.76	123.19
Bunker	2.64	3.84	5.47	7.96	11.37	14.78
Total	111	168	254	341	451	560

Source: Calculated from this study by LEAP model

electricity. The data for fuel consumption in space heating and air conditioning is not available and has been assumed to be zero.

As the final demand of energy in Vietnam is expected to increase, the primary supply would also be increasing. The primary energy supply is expected to increase at an annual growth rate of 5.8 % increasing 4.1 times during 1995–2020 levels. Table 7 shows the primary energy supply for Vietnam.

The supply of petroleum products would increase significantly at an annual growth rate of 7.6%. This would be because of the demand for petroleum fuels in the industrial sectors and in transportation sector. The supply of petroleum products in 2020 would be almost 6.3 times the base year. The share of petroleum products in the total energy supply would be constantly increasing.

The supply of coal would increase about three times in 2020 from 1995 level. This would be mainly due to the increase in the demand in industries and in power generation. But the percentage of primary supply for coal would decrease from 29.2% in 1995 to 22.8% in 2020. The average growth rate of coal supply as estimated in this study is 4.5%.

The other important fuel whose supply is to increase substantially is the natural gas. The percentage contribution of natural gas in the total primary energy supply is expected to increase from 1.3% in 1995 to 7.7% in 2020. This increase would be mainly driven by its increased demand in the power sector. Gas based power plants would be installed by year 2020.

It can be seen that hydro and geothermal power supply would be increasing at an average annual rate of 8%. The share of hydropower is expected to take a big leap. It is expected to increase from 6.8% in 1995 to 14.0% in 2020.

The electricity generation is expected to increase from 14.32 TWh in 1995 to 144.88 TWh in 2020. Table 8 shows the power generation by different plants in the milestone years.

The two main power-producing plants to be installed in 2020 would be hydro and pulverized coal power plants along with natural gas based power plants. The percentage share of hydro and coal power plants would be 47% and 14% respectively. The hydropower generation is projected to grow at 7.5% per annum and coal power plants at 7.6% per annum.

The primary supply of natural gas as fuel grows at a rate of 11.1% per annum. In 2020, natural

Table 7
Primary energy supply in Vietnam (PJ)

Fuels	1995	2000	2005	2010	2015	2020
Petroleum products	219.66	341.33	543.24	770.55	1076.1	1374.53
Coal/coke	196.92	181.22	284.14	409.02	501.59	594.07
Natural Gas	8.68	55.02	119.42	152.65	169.22	304.93
Hydro/geothermal/nuclear	46.12	50.04	96.99	167.46	308.36	314.89
Electricity	0	0	0	8.90	0	39.03
Non-wood biomass	0.69	0.64	0.61	0.50	0.46	0.42
Wood Fuel	159.94	148.33	139.75	115.68	106.69	97.70
Other	43.03	44.13	47.42	49.16	56.08	63.25
Total	675	821	1232	1674	2218	2789

Source: Calculated from this study by LEAP model

Table 8
Electricity generation by the different plants from 1995-2020 (TWh)

Types of plants	1995	2000	2005	2010	2015	2020
Pulverized coal ST	3.33	1.72	6.62	14.36	17.23	20.80
Import base	0	0	0	2.47	0	10.84
Hydro base	10.25	11.12	21.17	35.28	66.38	68.06
Geothermal base	0	0	0.15	0.79	0.87	0.78
New natural gas—STIG	0	2.89	4.26	5.44	6.03	5.38
Diesel oil—PP	0.74	0.46	0.54	0.69	0.76	0.68
Natural gas CC–GT	0	4.60	12.05	15.40	17.08	36.22
Oil steam boiler	0	0.33	0.75	0.96	1.07	0.95
Oil fired—GT	0	0.79	0.92	1.18	1.31	1.17
Total	14	22	46	77	111	145

Source: Calculated from this study by LEAP model, ST—steam turbine, STIG—steam injected gas turbine, PP—power plant, CC-GT—combined cycle gas turbine, GT—gas turbine

gas based power plants would be producing 41.6 TWh of electricity. This substantial increase is because of the commissioning of 5400 MW of natural gas based combined cycle plants in the period 2015–2020.

Hydro, natural gas and coal are the main fuels, which would be used for power generation. These fuels together contribute to 95% of the total fuel required. Hydropower would be the largest contributor. The consumption of natural gas and hydro is expected to increase at 7.1% and 7.5% annually. The requirement for coal would be increasing at 7.6% but its contribution in 2020 would be 23.4%.

The overall energy demand and supply in Vietnam shows that the economic growth would result in the increased use of fossil fuel, though hydropower would also be installed but the significant portion of fuel requirement would be fulfilled by fossil fuels. This would result in the increased release of GHGs. Replacing fossil fuels by biomass can control the release of GHGs. Keeping this in view the different scenarios have been considered in the present study. The GHG mitigation achieved from the different scenarios is shown in detail.

2.3. Scenario 1—replacement of coal stoves by biomass stoves

In this scenario, the mitigation option considered is the replacement of coal-fired cooking stoves by the biomass-fired cooking stoves. The biomass stoves include wood and rice husk fired stoves. As the emission factor for the combustion of biomass is less than that of coal, the replacement leads to substantial mitigation of greenhouse gases. The replacement is considered in both rural and urban households. The penetration rate assumed in this study for the replacement of coal stoves by biomass stoves is shown in Table 9.

The penetration rate of the stoves has been assumed higher in the urban sub-sector as compared to that in the rural sub-sector because of the easy access and also the flexible attitude and the purchasing power of the urban households as compared to that of the rural households. Also, the

Table 9
Assumed penetration rate for different described scenarios in Vietnam

	2000	2005	2010	2020
Replacement of coal stoves by biomass stoves				
Rural households (%)	0	10	15	20
Urban households (%)	0	15	20	30
Replacement of kerosene and LPG stoves by biogas based stoves				
Rural households (%)	0	10	15	20
Substitution of gasoline by ethanol				
Penetration rate (%)	0	0	2	10
Replacement of coal by biomass as fuel in industrial boilers				
Penetration rate	5	10	15	20

awareness of the urban people toward the environment is expected to be more as compared to that of the rural ones.

2.3.1. Scenario 2—substitution of kerosene and LPG stoves by biogas stoves

In this scenario, the mitigation option considered is the replacement of kerosene and LPG stoves by the biogas-based cookstoves. This replacement is considered only in the rural households. The assumed penetration rate for the replacement of kerosene and LPG stoves in the rural areas by the biogas stoves is shown in Table 9.

2.3.2. Scenario 3—substitution of gasoline by ethanol

The scenario considers the substitution of gasoline by ethanol; this would require the development of ethanol feedstock, conversion and fuel distribution infrastructure. It has been assumed that the substitution of gasoline by ethanol will reach 2% by the year 2010. The substitution of gasoline by ethanol is projected to increase by 1.4% per year from 2000 to 2020 in the USA [8]; a similar growth in gasoline substitution in Vietnam after 2010 is assumed in this study. Table 9 shows the assumed penetration rate of gasoline substitution by ethanol during the study period.

2.3.3. Scenario 4—substitution of coal by wood as fuel in industrial boilers

In Vietnam, most of the industrial boilers use coal as fuel. The combustion of coal emits greenhouse gases. Replacing coal by wood as fuel can control this. At present, 5% of the boilers use biomass as fuel. In this scenario, it has been assumed that the same boilers would be used for both coal and wood. Based on the available potential of wood fuel, the assumed level of the substitution of coal by wood is shown in Table 9 for the years 2005, 2010 and 2020 respectively.

2.3.4. Scenario 5—electricity generation with biomass energy technologies

This scenario includes the substitution of some of the candidate fossil fuel plants by biomass-based plants. The biomass energy technologies which have been considered are BIGCC based on wood, direct combustion steam turbine based on wood, direct combustion steam turbine based on rice husk, co-generation in the sugar mills using bagasse, Stirling engine based on wood and co-firing wood with coal. The penetration is constrained with the present development status of the technologies, electricity generation planning of the country, its infrastructure, availability of the fuel and level of awareness.

The growth rate of different technologies has been assumed based on extensive literature review. The growth rates of BIGCC, direct combustion steam turbine plants and Stirling engine after year 2005 have been assumed to be 20%, 20% and 30% respectively. It is also assumed that the installed capacity of the biomass-based plants on the above technologies in the year 2005 would be 30, 30 and 0.1 MW respectively. The growth rate of Stirling engines is assumed higher based on the fact that these are decentralized units of very low capacity and can be mass-produced. Table 10 shows the capacity penetration of the different BETs in different years.

The capacity of BETs based on the penetration rate is not enough to replace any candidate fossil fuel power plant individually. In this scenario, a package of BETs has been considered to replace a candidate fossil fuel fired plant. Table 11 gives the package of BETs assumed to replace the fosssil fuel fired power plants in the different years. In LEAP, the capacity of the BETs has been entered for the years 2000, 2005, 2020, 2015 and 2020. The efficiency and the capacity factor entered are the weighted values so that the selected package of BETs is treated as equivalent to a single power plant.

2.3.5. Scenario 6—integrated scenario

In this scenario all of the above mentioned scenarios have been considered together. This scenario would give the cumulative effect of the different mitigation option in Vietnam.

3. Results and discussion

Using the LEAP model a number of greenhouse gas abatement scenarios have been considered. All the costs are in 1995 US$, Table 22 (Appendix 1).

3.1. Scenario 1—replacement of coal by biomass stoves

The biomass stoves include firewood and rice husk fired stoves. The penetration of the biomass stoves has been considered from 2005 onwards. Table 12 gives the comparison of the biomass and coal requirement in the base case and the scenario 1.

The replacement of coal stoves by biomass stoves would result in the reduction of greenhouse gases emission from the whole energy system, as the emission from biomass stoves is less than that of coal stoves. Table 13 shows the comparison of the emissions in CO_2 equivalent from the whole energy system between the present scenario and the base case.

The emission reduction between the base case and scenario 1 increases at a rate of 5.2%. The average emission reduction per year is 1093.34 kt. The cost of emission reduction in this scenario increases over the years. The percentage of stove using rice husk are significantly less than those using wood. The cost of wood for the base year is $38.6/Mg while for coal is $27.17/Mg. The abatement cost increases over the study period because the difference in the cost of coal and wood increases. The levelized cost of emission reduction is $49.78/Mg of CO_2 reduced.

Table 10
Penetration of the different biomass energy technologies in different years in Vietnam

Technology	Growth rates %	Capacities (MW)															
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
BIGCC	20	30.00	36.00	43.20	51.84	62.21	74.65	89.58	107.50	128.99	154.79	185.75	222.90	267.48	320.98	385.18	462.21
ST- Direct	20	30.00	36.00	43.20	51.84	62.21	74.65	89.58	107.50	128.99	154.79	185.75	222.90	267.48	320.98	385.18	462.21
Stirling	30	0.10	0.13	0.17	0.22	0.29	0.37	0.48	0.63	0.82	1.06	1.38	1.79	2.33	3.03	3.94	5.12

Table 11
Power generation by different BETs replacing fossil fuel power plants in different years

	Fossil fuel plants planned	Plant to be replaced	BIGCC wood fired (MW) (units x cap.)	DC wood fired (MW) (units x cap.)	Rice husk fired plant (MW) (units x cap.)	Bagasse based cogen (MW) (units x cap.)	Coal fired power plant With co-firing (MW) (units x cap.)	Total (MW)
2007	1 x 300 MW North Coal ST plant	1 x 300 MW North Coal ST plant	1 x 29	1 x 25	20 x 2.5	10 x 10	1 x 100	
		Total (MW)	29	25	50	100	100	305.7
2008	4 x 300 MW North Coal ST plant	1 x 300 MW North Coal ST plant	1 x 56	1 x 50	8 x 12.5	10 x 10	3 x 300	
		Total (MW)	56	50	100	100	900	1208.2
2015	1 x 300 MW North Coal ST plant	1 x 300 MW North Coal ST plant	1 x 132 1 x 56	2 x 50	1 x 12.5			
		Total (MW)	188	100	12.5			300.5
2016	3 x 300 MW South Combined Cycle (CC), Nat. Gas	2 x 300 MW South CC, Nat. Gas	1 x 132 1 x 56 1 x 29	6 x 50	7 x 12.5		1 x 300	
		Total (MW)	217	300	87.5		300	904.5
2017	4 x 300 MW South CC, Nat. Gas	3 x 300 MW South CC, Nat. Gas	2 x 132	8 x 50 1 x 25	9 x 12.5	10 x 10	1 x 300	
		Total (MW)	264	425	112.5	100	300	1201.5
2018	4 x 300 MW South CC, Nat. Gas	3 x 300 MW South CC, Nat. Gas	2 x 132 1 x 56	10 x 50 1 x 25	5 x 12.5		1 x 300	
		Total (MW)	320	525	62.5		300	1207.5
2019	7 x 300 MW South CC, Nat. Gas	3 x 300 MW South CC, Nat. Gas	2 x 132 2 x 56	10 x 50 1 x 25			4 x 300	
		Total (MW)	376	525			1200	2101
2020	4 x 500 MW South Coal ST	2 x 500 MW South Coal ST	3 x 132 1 x 56	50 x 11			2 x 500	
		Total (MW)	452	550			1000	2002

Table 12
Comparison of the fuel demand in the base case and different scenarios (PJ)

Fuels	2005		2010		2015		2020	
	Base case	New scenario	Base case	New scenario	Base case	New scenario	Base case	New scenario
Scenario 1								
Coal	68.33	60.25	87.54	72.65	100.13	78.29	112.72	83.92
Firewood	132.76	139.40	109.90	122.14	101.36	119.31	92.82	116.49
Rice husk	28.17	30.18	23.32	26.45	21.51	25.84	19.70	25.22
Scenario 2								
Kerosene	24.90	24.16	36.20	34.62	48.03	45.93	59.87	57.23
LPG	3.68	3.66	10.16	10.08	19.65	19.49	29.14	28.90
Biogas	0	0.75	0	1.65	0	2.26	0	2.87
Scenario 3								
Gasoline	133.17	133.17	174.08	171.57	220.58	208.88	267.08	246.18
Ethanol	0	0	0	2.50	0	11.70	0	20.89
Scenario 4								
Coal	127.71	113.14	153.50	130.47	200.72	164.41	247.94	198.35
Firewood	0	12.57	0	23.02	0	36.31	0	49.59

Source: Calculated from this study by LEAP model

Table 13
Comparison of the CO_2 equivalent emissions from the whole energy system between the abatement scenario and the base case (Mt)

	2005	2010	2015	2020
Base	106.88	123.73	158.22	177.26
Scenario 1	106.13	122.36	156.19	174.58
Scenario 2	106.83	123.62	158.06	177.06
Scenario 3	106.88	123.60	157.59	176.14
Scenario 4	105.63	121.53	154.73	172.50

Source: Calculated from this study by LEAP model

3.2. Scenario 2—replacement of kerosene and LPG stoves by biogas stoves

This scenario considers the replacement of kerosene and LPG stoves by biogas stoves; the replacement has been considered from 2005 onwards. Table 12 gives the comparison of kerosene, LPG and biogas requirements in the base case and the scenario 2.

In this scenario, the primary energy supply shows that the growth rate of the supply of petroleum products decreases from 7.61% per annum in the base case to 5.78% per annum in the present scenario. This decrease is because of the decreased demand of kerosene and LPG. On the other side, the supply for non-wood biomass is expected to increase at the rate of 6.78% per annum while in the base case it had a negative growth rate of 1.97% per annum. The increase is because of the increase in the use of biogas.

The replacement of kerosene and LPG stoves by biogas stoves would result in the reduction of greenhouse gases emission from the whole energy system as the emission from the biogas stove is less compared with the kerosene and LPG stoves. Table 13 shows a comparison of the emissions of CO_2 equivalent from the entire energy system between the present scenario and the base case.

The detailed analysis of the emissions reduction shows that the abatement mainly takes place in the residential sector. The emission reduction increases at the rate of 5.5% calculated based on each year reduction. The average emission reduction per year is 84.48 kt over the study period. In this scenario, the abatement cost is high. With a new refinery coming up in Vietnam by 2005, which would make LPG and kerosene cheaper; the abatement cost is expected to increase. The levelized cost of emission reduction is \$94/Mg of CO_2 reduced.

3.3. Scenario 3—substitution of gasoline by ethanol in the transportation sector

This scenario considers the substitution of gasoline by ethanol in the passenger vehicles. The penetration of ethanol as fuel has been considered from 2010 onwards. Table 12 gives the comparison of gasoline and ethanol requirements in the base case and the scenario 3. The ethanol trend shows that the demand increases rapidly after 2010 as its penetration increases from 2 to 10% in the year 2015.

The primary energy supply shows that the supply of the petroleum products has decreased. The growth rate in the base case was 7.61% per annum but in the present scenario it has come down to 5.66% per annum. This decrease has come because of the decreased demand of gasoline in the transportation sector. On the other side the supply for the non-wood biomass is expected to increase at the rate of 15.33% while in base case it had a negative growth rate of 1.97% per annum. The increase is because of the increase in the demand of ethanol.

The substitution of gasoline by ethanol would result in the reduction of the greenhouse gases emission from the whole energy system, as the emission of ethanol combustion is less than that of gasoline. Table 13 shows the comparison of the emissions of CO_2 equivalent from the whole energy system between scenario 3 and the base case.

In this scenario when compared with base case, the average emission reduction per year is 270.19 kt. The cost of emission reduction is decreasing over the years. The abatement cost is positive because ethanol is more expensive than gasoline, but over the years it is expected that the price of ethanol will decrease. The levelized cost of emission reduction is \$39.68/ Mg CO_2 reduced.

3.4. Scenario 4—substitution of coal by firewood in the industrial boilers

This scenario considers the substitution of coal by firewood in the industrial boilers. The penetration of firewood as fuel in place of coal has been considered from 2005 onwards. Table 12 gives the comparison of coal and wood requirements in the base case and the scenario 4.

The primary energy supply in scenario 4 shows a decreasing trend in coal supply. The growth rate in the base case was 4.52% per annum but in the present scenario it has come down to 4.49% per annum. This decrease has come about because of the decreased demand of coal in the industrial sector. On the other side the supply for the wood is expected to increase at the rate of 0.04%

per annum while in base case it had a negative growth rate of 1.95% per annum. The increase is because of the increase in the demand of wood in industrial boilers.

The substitution of coal by wood would results in the reduction of the greenhouse gas emissions from the whole energy system, as the emission during the combustion of wood is less than that of coal. Also, the reduced requirement of coal would result in less emission during coal extraction and mining. Table 13 shows the comparison of the emission in CO_2 equivalents from the whole energy system between the scenario 4 and the base case.

The emission reduction in this scenario compared with the base case increases at the rate of 5.64 %. The average emission reduction per year is 1855.28 kt. The cost per unit of emission is increasing over the years, as the price of wood increases over the years as compared to coal. The abatement cost increases at the rate of 3.37% per annum. The levelized cost of emission reduction is \$39.68/Mg CO_2 reduced.

3.5. Scenario 5—electricity generation with biomass energy technologies

In this scenario, the biomass energy technologies have been considered for the substitution of fossil fuel power plants. Table 14 gives the power generation of the different plants in the scenario 5. The biomass energy technologies starts penetrating from the year 2007 when a candidate power plant is replaced by a package of BETs. This package of BETs includes BIGCC plant, bagasse-based co-generation, co-firing plants, Stirling engines based on wood, direct combustion plants

Table 14
Electricity generation by different plants in the base case and scenario 5 (TWh)

Types of plants	2010		2015		2020	
	Base	Scenario 5	Base	Scenario 5	Base	Scenario 5
Pulverized coal ST	14.36	8.49	17.23	9.41	20.80	8.34
Import base	2.47	2.48	0	0	10.84	10.81
Hydro base	35.28	35.40	66.38	66.61	68.06	68.06
Geothermal base	0.79	0.79	0.87	0.87	0.78	0.78
New natural gas—STIG	5.44	5.46	6.03	6.05	5.38	5.38
Diesel oil—PP	0.69	0.69	0.76	0.76	0.68	0.68
BIGCC	0	0.32	0	1.13	0	6.96
Bagasse—cogen	0	0.75	0	0.83	0	1.10
Co-firing	0	3.73	0	4.13	0	15.00
Stirling engine—wood	0	0.02	0	0.03	0	0.04
DC-wood based	0	0.28	0	0.72	0	9.14
DC- rice husk base	0	0.56	0	0.67	0	1.55
Natural gas CC-GT	15.40	15.46	17.08	17.13	36.22	15.18
Oil steam boiler	0.96	0.97	1.07	1.07	0.95	0.95
Oil fired—GT	1.18	1.18	1.31	1.31	1.17	1.16
Total	77	77	111	111	145	145

Source: Calculated from this study by LEAP model, Cogen—co-generation, DC—direct combustion based on wood and rice husk. It can be seen that the percentage of power generation by the pulverized coal power fired power plants decreased by 40, 45 and 60% in the years 2010, 2015 and 2020 respectively.

The annual growth rate of BIGCC based on wood, direct combustion plants based on wood and co-firing plants are 13, 15 and 5.7% respectively. The electricity generation by rice husk-based direct combustion plants and the bagasse-based co-generation plants increases by 4.2 and 1.5% respectively. The use of these biomass energy technologies would increase the demand of wood, rice husk, bagasse and hence will affect the primary energy supplies.

In the base case, the primary supplies of biomass fuels would decrease but in this scenario the supply increases from 2010 onwards as the BETs are installed in the period 2005 onwards. The scenario is not constrained by the availability of the biomass fuels. In the case of Vietnam, the potential of wood fuel is 641 PJ [9], rice husk and bagasse is estimated to be 130.30 and 20.23 PJ respectively [2]. Thus, the requirement of the fuel can be meet by the potential available.

The detailed analysis of the emission reduction shows that the abatement mainly takes place in the energy conversion process. Table 15 shows the comparison of the emissions of CO_2 equivalent in the power sector of this scenario and the base case. Comparison between the emission reduction between this scenario and the base case shows that, the emission reduction increases at the rate of 5.42% per annum. The average emission reduction per year is 4932.39 kt.

In this scenario the abatement cost is −\$45.40/Mg CO_2 reduced in 2010 then it increases to −\$6.08/Mg CO_2 reduced and finally decreases drastically to −\$1865/Mg CO_2 reduced in the year 2020. The trend is like this because BETs would come in operation by year 2007 and the year 2010, 1500 MW power plants will be running on biomass fuel, replacing the coal-fired power plants. Out of the 1500 MW, 1000 MW plants would be co-firing power plants and the rest would be BIGCC and direct combustion plants. The co-fired plants have negative abatement cost when coal fired power plants are modified. The direct combustion plants based on bagasse and rice husk also have negative abatement cost. In the period 2015-2020, 7400 MW plants are installed with 3100 MW would be co-fired by 2020. These co-firing plants would be replacing the natural gas based combine cycle plants. The abatement cost would be greatly influenced by these co-fired plants. The direct combustion of biomass-based plants also contributes significantly adding to more negative abatement cost.

3.6. Integrated scenario

In this scenario, all of the scenarios considered as mitigation options would be considered together. The most important aspect of this scenario would be the percentage contribution of each mitigation option in reducing greenhouse gases.

Table 15
Comparison of CO_2 equivalent emission from the whole energy systems between the abatement scenario 5 and the base case (Mt)

	2010	2015	2020
Base	24.02	27.88	37.46
Scenario 5	19.46	21.57	20.37

*Source: C*alculated from this study by LEAP model

In this scenario, analysis of the primary energy supply suggests that demand for petroleum products would be increasing over the study period along with coal and hydropower. There is a substantial decrease in the supply of natural gas from 2015 to 2020. This is because the natural gas based combined cycle plants as planned in the base case would be replaced by BET package. As a result, the demand for natural gas would reduce substantially. Analysis of the supply of wood indicates that demand increases in year 2010 because BETs would be coming up in the period 2005 to 2010. Also the demand has increased partially by the replacement of the coal in the industrial boilers and coal stoves by wood stoves. Similarly, the requirements for rice husk and bagasse have also increased.

Since the estimate of the potential fuels is available only for 2010 [7], it would be appropriate to compare the different options in 2010. Table 16 shows the abatement cost of the different options along with the potential emission reduction in the milestone year 2010.

It can be inferred that substitution of the fossil fuel fired power plant is the least cost option. All the other options are considered costly having positive values. Replacement of coal stoves by biomass stoves is the next lucrative option. The potential of biomass resources would play an important role in implementing the biomass energy technologies of fossil fuel plants. The other option of substitution of gasoline by ethanol can become viable if the technology of producing ethanol improves and the cost of ethanol production decreases. The other option of replacement of coal is not viable as the cost of coal is less than wood in Vietnam. This option can become viable if the environmental cost is taken into account. If the taxes are included in the price of coal as it produces GHGs than wood on combustion, the above-considered options might become cost effective.

4. Conclusions

The greenhouse gas mitigation potentials of different biomass energy technologies have been assessed in Vietnam. The selected biomass energy technologies considered for mitigation of greenhouse gases includes BIGCC based on wood and bagasse, direct combustion plants based on wood, co-firing power plants, Stirling engines and cooking stoves. Different options were con-

Table 16
Different options for emission mitigation for year 2010

	Option 1	Option 2	Option 3	Option 4	Option 5
Emission mitigation potential (million kg)	1363.40	113.57	131.63	2185.10	10,830
Cost/emission reduction ($/ Mg CO_2 reduced)	48.80	114.89	59.79	49.81	−45.59

Option 1—replacement of coal stoves by biomass
Option 2—replacement of LPG and kerosene stoves by biogas stoves
Option 3—replacement of gasoline by ethanol in cars
Option 4—replacement of coal by wood in industrial boilers
Option 5—substitution of fossil fuel power plants by package of BETs

sidered for mitigation of these greenhouse gases, which include substitution of coal stoves by biomass stoves, substitution of LPG and kerosene by biogas stoves, replacement of gasoline by ethanol in the transportation sector and the use of wood in place of coal in the industrial boilers. In the supply side, the substitution of fossil fuel based power plants by package of BETs was considered.

In the case of scenario 1, where the coal stoves are substituted by biomas cooking stoves, the abatement cost (\$/Mg of CO_2 reduced) is positive and increases over the study period. This is because the cost of wood is more than coal in the case of Vietnam. In scenario 2, replacement of LPG and kerosene is also unattractive as the abatement cost is again positive. In 2005, a new oil refinery would be established in Vietnam, this is expected to make kerosene and LPG cheaper so that the abatement cost is expected to increase further.

In scenario 3, replacement of gasoline by ethanol can be realized in a few more years. At present, the cost of ethanol is more than gasoline; this results in a positive abatement cost. The cost of ethanol is expected to decrease in the future which would result in the decrease of abatement cost. Scenario 4 considers the substitution of coal by biomass in the industrial boilers. In this option, the abatement cost is significantly affected by the resource cost. As stated, wood in Vietnam is more expensive than coal, which make this option unattractive.

In scenario 5, the substitution of fossil fuel power plants by packages of biomass energy technologies is the most attractive option among the abatement scenarios. The first BET package will be deployed in 2007 to substitute a coal power plant. The abatement cost is negative, but it increased until 2010. This option if implemented, would result in mitigation of 10.83 Mt CO_2 in Vietnam.

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Appendix 1

Input data and assumptions

Detailed in Tables 17–19.

Input data for demand program.
Cost data and assumptions in energy demand sector. The non-fuel costs of energy consuming devices were entered in the energy demand module. The evaluation program later uses these costs as part of its cost–benefit calculations. The cost of any device can be entered. However, for studying the different scenarios, only the cost of the branches where energy intensities changes has been entered. In this study, since total energy consumed by the devices has been entered, the number of devices is not required. To find the total non-fuel cost, the cost of the device per unit

Table 17
Energy consumption in households (PJ)

	1994	1995	2000	2005	2010	2020
Urban households—cooking						
LPG	0.00	0.00	0.00	0.00	0.00	0.00
Firewood	16.30	19.20	23.24	21.04	18.48	19.19
Bagasss	0.07	0.08	0.10	0.09	0.08	0.08
Rice husk	3.46	4.07	4.93	4.46	3.92	4.07
Agricultural residues	3.53	4.16	5.03	4.56	4.00	4.16
Traditional fuel	19.83	23.36	28.27	25.59	22.48	23.34
Electricity	1.23	2.02	3.91	7.89	11.60	19.03
Kerosene	3.69	5.03	9.02	14.36	22.67	42.65
Coal	13.65	15.57	24.48	24.51	34.59	61.46
Urban households—lighting						
Electricity	1.29	1.62	2.43	3.93	5.33	8.73
Kerosene	0.43	0.48	0.88	0.00	0.00	0.00
Urban households—air-conditioning and hot water						
LPG	0	0.12	0.22	0.73	2.45	6.89
Kerosene	0	6.47	2.60	1.05	0.00	0.00
Electricity	0	4.86	5.93	15.52	26.21	44.44
Urban households—other electrical uses						
Electricity	4.63	5.61	8.35	10.51	14.10	22.03
Rural households—cooking						
LPG	0.00	0.00	0.03	0.77	2.48	5.95
Firewood	130.33	130.06	115.18	109.38	89.48	71.99
Bagasss	0.56	0.56	0.50	0.47	0.39	0.31
Rice husk	27.66	27.60	24.44	23.21	18.99	15.28
Agricultural res.	28.22	28.16	24.94	23.68	19.38	15.59
Traditional fuel	158.55	158.22	140.12	133.06	108.85	87.58
Electricity	0.36	0.58	0.81	4.33	8.19	10.69
Kerosene	1.60	2.98	6.46	9.04	12.89	16.16
Coal	19.53	26.40	36.26	42.62	51.41	49.27
Rural households—lighting						
Electricity	1.54	2.08	2.68	3.90	4.83	4.43
Kerosene	4.23	4.07	2.63	1.06	0.00	0.00
Rural households—other electrical uses						
Electricity	0	0	0	0	0	0

Table 18
Energy consumption in industrial sector, agricultural sector and service sector (PJ)

	1994	1995	2000	2005	2010	2020
Industrial sector—thermal use						
Coal	36.75	48.94	75.35	123.49	150.78	243.56
Residual fuel oil	9.51	12.59	19.35	31.97	39.14	64.30
Industrial sector—mechanical use						
Diesel	48.30	60.78	100.17	181.25	284.27	587.90
Industrial sector—electrical use						
Electricity	14.73	19.76	33.34	82.38	145.37	302.68
Agricultural sector—thermal use						
Fuel-oil	1.09	1.18	1.35	1.65	1.75	2.16
Coal	0.15	0.17	0.19	0.23	0.25	0.30
Agricultural sector—mechanical use						
Diesel	8.72	9.78	11.83	15.15	16.71	21.56
Agricultural sector—electrical use						
Electricity	4.87	5.44	6.61	8.84	10.11	13.50
Service sector— uses except space heating & air conditioning						
Coal	6.12	7.29	9.80	12.74	17.37	22.19
Residual fuel oil	2.69	3.21	4.31	5.61	7.64	9.76
Electricity	2.69	3.13	4.44	6.23	9.22	14.35

energy consumed has been calculated. When comparing the different scenarios the LEAP calculates the total non-fuel cost required for the devices.

Assumptions made regarding cooking stoves costs in the study are as follows; the capital cost of kerosene, LPG and biogas stoves are \$42, \$60 and \$16 respectively, lifetime assumed to be 3,5 and 7 years respectively. The biomass stoves have been assumed to be \$0.9075. The cost of coal stoves has been assumed to be the same as that of biomass stoves. The biomass stoves refer to both the stoves using firewood and agricultural residues as fuel. The lifetime of the biomass stoves and coal stoves has been assumed to be 3 years [10]. The efficiencies of the biomass and coal stoves have been assumed to be same as kerosene stoves.

One of the mitigation scenarios consider is related to the substitution of the gasoline vehicle by ethanol vehicle. The capital costs of the vehicles in terms of the dollars per unit of fuel consumed have been calculated. The calculation gives the cost for gasoline and ethanol vehicles as \$0.487/MJrequired and \$0.495/MJrequired respectively. Table 20 shows the technical and economic details of gasoline and ethanol vehicle.

Table 19
Energy consumption in transportation sector for passenger transport by roadways (PJ)

	1994	1995	2000	2005	2010	2020
Passenger transport by roadways						
Gasoline	29.50	38.92	62.23	94.13	123.03	205.22
Diesel	6.22	7.84	11.96	23.40	34.45	63.62
Passenger transport by railways						
Coal	0.16	0.16	0.12	0.00	0.00	0.00
Diesel	0.62	0.73	0.97	1.32	1.51	2.27
Passenger transport by waterways						
Diesel	0.74	0.82	1.15	1.58	2.17	3.77
Passenger transport by airways						
Jet Fuel	8.02	8.93	12.43	17.15	23.58	40.92
Freight transport by roadways						
Gasoline	13.73	18.37	26.68	36.68	47.97	57.14
Diesel	5.59	8.55	13.66	23.26	30.41	36.22
Freight transport by railways						
Coal	0.24	0.23	0.17	0.00	0.00	0.00
Diesel	0.90	0.98	1.39	2.13	2.82	5.77
Freight transport by waterways						
Diesel	19.11	21.09	30.30	44.11	61.22	121.01
Freight transport by bunker						
Fuel oil	2.31	2.60	3.77	5.37	7.82	14.52

Table 20
Technical and economic details of gasoline and ethanol vehicle

	Inv. cost ($/skm/yr)	Variable O&M cost ($/skm)	Unit size (kW)	Technical availability (%)	Plant life (yr)	Ethanol input (MJ/skm)	Capital cost ($/MJ required)
Gasoline car	0.306	0.0049	40	99	15	0.64	0.487
Ethanol car	0.272	0.0049	45	99	15	0.56	0.495

Source: [14], $/skm/yr—dollars/seat km/yr

Input data for transformation program.

The transformation modules, which have been formed, are transmission and distribution modules, electricity and generation module, crude oil production, gas production, and oil refining and coal production.

In the transmission and distribution module, the losses occurring in the transportation, transmission or distribution is described. Each process is simply defined as fuel with accompanying percentage loss fraction. The fuels whose transportation, transmission of distribution have been considered are electricity, natural gas, kerosene, diesel, residual/fuel oil, LPG bottled gas, crude oil, bagasse, anthracite coal, rice husk, firewood and ethanol. The loss of the biomass fuels in transportation has been assumed to be higher than that of fossil fuels, assumed at 5%. The cost of transportation includes the annualized capital cost and the operation and maintenance cost of the system of transportation. The transportation cost for diesel, gasoline, kerosene and residual oil are considered through the pipeline.

The electricity generation module is used to define the electricity generation planning. The plant characteristic data has been entered which includes plant capacity, the energy produced for base year, the efficiency of the plant and the maximum capacity factor of the plants. In the case of Vietnam, expansion planning for fossil based power plants has been done till the year 2003. The expansion scheduled generated by the output of the Integrated Resource Planning (IRP) model, [11], has been fed to the LEAP model as the input. The cost entered for the different biomass energy technologies plants are the weighted average cost. The cost figures of fossil fuel plants have also been entered as the weighted average cost. The capital costs of the different power plant obtained through literature review are given in Table 21.

The gas production module deals with the production of natural gas and is related to the extraction of the gas. In Vietnam, the production of natural gas is done both offshore and onshore. The analysis of the gas production has shown that most of the production takes place offshore. There is no export and import of natural gas from Vietnam. The output of the gas wells has been taken from the energy balance report of Vietnam [12]. The efficiency of 100% and a capacity factor of 80% [13] have been assumed for the wells for all the years. The capital cost has been entered for the offshore extraction, cost annualized at a discount rate of 12% and a lifetime of 20 years.

The crude oil production module deals with the crude oil production in Vietnam. In Vietnam, the production of crude oil is done both offshore and onshore. The output of the crude oil wells has been taken from the energy balance report of IOE, Vietnam. The efficiency of 100 and 90% [13] capacity factor has been assumed for the wells for all the years. The oil refinery in Vietnam will be coming into use in 2005. So the crude oil is mostly exported in these years.

The oil-refining module is related to the crude oil refining in Vietnam. At present, Vietnam does not have a refinery; the refinery is coming into use in 2005 and presently all the petroleum products are imported. The capacity of the refinery has been calculated using the refining output data from the energy balance table of Vietnam. The efficiency and the capacity factor of the refinery have been assumed to be 95 and 80% [13] respectively. LEAP requires that the output of the fuel should be entered. The outputs of the fuel, which have been considered, are gasoline, kerosene, diesel/gas oil, residual fuel oil, LPG/bottled gas, air fuel and petro-products.

The coal production mode deals with coal production. In Vietnam different kinds of coal are produced, these include anthracite, bituminous, etc. Coal production has been entered as the sum of the coal produced by different kinds of mines. The output of the coalmines has been taken from the energy balance report of Vietnam [12]. The efficiency of 100% and a capacity factor of 80% [13] have been assumed for the open cast mines for all the years.

Input data for environment, evaluation programs and general data and assumptions.

The environment program requires the input of the fuel compositions. In this study, the in-built fuel composition has been used. Thus, no fuel composition has been entered. The other requirement is the input of the environmental cost. This has been not considered in this study as very less work has been done in the area of environmental cost for developing countries and such data are difficult to get.

Table 21
Calculation for the cost

Plants	Capacity (MW)	Efficiency (%)	No. of units of each technology which is coming in the planning horizon 2006-2020	Capital cost ($/kW)	Fixed O & M cost ($/kW/annum)	Variable O & M cost (cents/kWh)	References
BIGCC/BIG—GT	29.0	42.00[a]	2	2437.4		0.230	[15]
	56.0	36.01[b]	7	1804.4		0.170	[15]
	132.0	39.70[b]	11	1557.9		0.150	[15]
			Weighted average cost	1635.5		0.200	
Direct combustion wood	25.0	29.80[b]	4	2045.3		0.184	[16]
	50.0	30.00[b]	48	1552.2		0.140	[10]
			Weighted average cost	1571.9		0.100	
Direct combustion rice husk	2.5	16.70[a]	20	1898.9		0.182	[17]
	12.5	28.80[a]	30	2045.3		0.196	[18]
			Weighted average cost	2028.1		0.200	
Bagasse based cogen	10.7		30	1157.6		0.110	[19]
			Weighted average cost	1157.6		0.110	
Co-firing (10%)	100.0		1	19.3		0	[20]
	300.0		12	19.3		0	[20]
			Weighted average cost	19.3		0	
Pul. coal ST (until 1995)	110.0		4	1020.0	22.80	0.500	[12]
	55.0		2		40.00	0.620	
	25.0		4		31.80	0.620	
			Weighted average cost		27.09	0.500	
Diesel oil—power plant	35.0		2	1285.0	6.00	0.910	
	35.0		2		9.48	0.910	
			Weighted average cost		7.74	0.900	
Nat. gas CC-GT	300.0		11	600.0	11.80	200.0	[12]

[a] Lower heating value.
[b] Higher heating value. The capacity factor of the biomass power plant was 70%.

Table 22
General assumptions in the model

Variables	Values
Real discount rate	4%
Escalation rate	5%
Monetary value	US dollar
Base year for prices	1995
Study period	25 years (1995–2020)

The global warming potential has been considered the same as in the database, no global warming potential has been considered externally.

The input for the evaluation program is the resource cost. It also requires the import and the export cost of the different fuels. Wherever local prices were not available, international prices have been used. If the variation of price resources is not available a fixed escalation rate has been assumed.

In the section of general data and assumptions, the reporting years have been specified for which data would be entered and also the years for which the reporting of the results would be done. The data entry year starts from 1995 and goes up to year 2020 at an interval of 5 years. Table 22 gives the general assumption data. There is provision in LEAP to define the new fuels. In this study two fuels have been defined. These include rice husk and air fuel, which is the jet fuel. The standard unit has been chosen to be PJ.

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