Analysis of Long-Term Energy Pathways for Vietnam by Using Energy Scenarios

Tien Minh Do and Deepak Sharma

Abstract— *This paper aims to exploring alternative energy pathways for Vietnam by using various energy scenarios. The paper develops and analyses three energy scenarios for Vietnam that are both exploratory and quantitative. The Base Scenario or Business As Usual reflects the current situation of Vietnam's energy sector with low economic development, low level of commitments to climate-friendly-energy production and few technological breakthroughs. Two other scenarios, namely the Moderate and Advanced scenarios, represent contexts where clean energy and energy efficiency play a greater role in addressing challenges faced by the energy sector, such as dependency on imported energy, low energy efficiency and environmental pollution caused by energy activities. Future energy consumption, composition of electricity generation, energy diversity and green gas emissions are analysed for each scenario through 2050. New and renewable energy, Energy savings, and industry and transportation activities are identified as promising opportunities for achieving alternative energy pathways in Vietnam. The paper concludes with a set of policy implications revealed from the energy scenarios analysis for Vietnam.*

Keywords— **Energy scenarios and energy demand.**

1. INTRODUCTION

Since introducing market-oriented economic reforms in 1986, Vietnam has made an appreciable socio-economic progress. For example, over the period 1986-2007, the GDP of Vietnam has grown at approximately 7 per cent per year which is the highest growth rate in the ASEAN region. In this growth, the country's energy sector has played a vital role, including a contribution of approximately one third of the nation's foreign earnings. This role is likely to increase in significance in the years to come especially if one takes note of the fact that over the period 2005-2025, the country's economy is expected to grow at an annual rate of 7%, requiring 8.6% annual increase in energy requirements in the same period [1]. The provision of such energy supplies is, however, likely to be a challenging task because of the emerging concerns about security of energy supply, environment and the social and political impacts of energy development.

In order to deal with these challenges, it is important for Vietnam to develop effective long-term energy policies and appropriate institutional mechanism for implementing such policies that would to guide for the development of the energy sector. The development of such policies in turn requires systematic information base that connects current choices and uncertainties with their potential implications for the future. Therefore, there is a need for Vietnam to examine alternative energy pathways under condition of uncertain and changing energy context. Alternative pathways are increasingly important if Vietnam is to balance its energy needs with other economic, social and environmental interests, especially with growing economy and population. For this purpose, scenario analysis is a suitable method because it could help in gaining insight into forces that would shape the country's energy sector evolution over the long-term period 2000-2050. For example it will help answer following questions: What options in terms of energy resources would be available for Vietnam to meet its long-term energy requirements? How the diversity of the energy mix could replace the existing fossil-dominated one? What options would be appropriate to reduce energy import dependency? How advanced technologies could affect the development of the country's energy system? What options would be useful to reduce the negative impacts of energy activities on the environment?

This paper develops and evaluates three energy scenarios – the Base and two alternative scenarios - to examine a range of possible future energy pathways for Vietnam. The Base scenario reflects the current situation of Vietnam's energy sector with low economic development, low level of commitments to climate-friendly-energy production and modest technological breakthroughs. The alternative scenarios, namely Moderate and Advanced, represent contexts where clean energy and energy efficiency play a grater role in addressing challenges faced by the energy sector, such as dependency on imported energy, low energy efficiency and environmental pollution caused by energy activities. These scenarios are quantitatively modelled in this paper, using an energy optimisation model (MARKAL Model) to examine future energy consumption, fuel mix, generation mix and CO_2 emissions associated with each scenario through the year 2050. The paper concludes by

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indicating critical issues and policy implications for sustainable development of the Vietnam's energy sector.

2. METHODOLOGY

The methodology used in this paper involves a scenarios-based approach and energy model for analysing the evolution of the Vietnam's energy system. In energy research, scenarios are most commonly used to characterizes an envelope of expected future conditions or quantify savings potentials from policy, technology, or behavioural changes. Scenarios have gained prominence with the fields of climate change and energy efficiency. Scenarios are distinct from forecasts in that they investigate a range of possible outcomes resulting from uncertainty. In contrast, forecasts aim to identify the most likely pathway and estimate uncertainties. As a result, forecasting models are most effective under condition when information availability is extensive and understanding of governing dynamics is high. However, when system is less well defined and interrelationships among factors are less stable and predictable, energy forecasts usually fails to characterize process of change. A recent review of energy forecast in USA over the last 50 years indicated that historical forecasts have routinely failed to represent actual conditions by underestimating uncertainties and overestimating consumption [2].

Recently, there have been considerable discussions and analyses on Vietnam's energy scenarios however, this study is unique in developing and analysing energy scenarios for Vietnam. The existing energy studies have focused on limited number of factors that could affect future development of the energy system. In these studies, those factors are separately treated without consideration of their linkages in a comprehensive picture. For example, the study carried-out by the Institute of Energy Vietnam concentrated on examining impacts of energy imports on electricity prices only [3]. The other study on National Energy Master Plan, carried-out by JICA focused on optimizing energy supply, taking into account of economic growth and changes in energy prices but neglecting the environmental impacts [1]. The lack of investigation of the interactions among energy, economic and environmental factors has made the results of these studies limited in application. This study, in contrast, employs a comprehensive approach which involves developing and quantitatively analysing a number of scenarios, using energy modelling techniques. The scenarios stories provide a set of alternative contexts for examining different ways that the future might unfold by taking all energy, economic and environmental issues into consideration. Energy modelling evaluates the systematic changes and impacts resulting from each scenario on Vietnam's energy system over the period 2000-2050. The energy optimisation model, the MARKAL model is used to examine impacts of energy options. This is a linear programming based optimisation model. The back-bone of this model is a Reference Energy System (RES), which represents the complex network of energy flows, starting from resource extraction (such as, coal mining and gas extraction) to transformation (for example, refinery and power plants) to end-use (such as, industry and households) [4]. The MARKAL model minimises the total discounted cost of the energy system over the entire planning horizon, subject to a set of pre-specified constraints. The model simulates the competition among fuels and technologies and chooses the most cost efficient mix of fuels and technologies to satisfy various exogenously determined energy demands, subject to compliance with CO2 emission limits and targets for energy saving and share of renewable energy in generation mix.

3. SCENARIO DEVELOPMENT

A scenario development process generally involves developing a set of alternative storylines around a set of assumptions. These assumptions are developed by taking into account various drivers that envision how the future might unfold. The scenarios are then modelled quantitatively to examine their impacts on energy, economy and the environment. In fact, the methods used for constructing scenarios vary, depending on the questions under analysis.

In this research, energy scenarios for Vietnam are constructed, following three steps. First, five key variables which are important from the policy viewpoint and which could influence the future development of the energy systems and policies in Vietnam are identified. Second, alternative scenarios are constructed by developing logically consistent set of assumptions about these variables as a set of policy constraints. Finally, the scenarios are modelled quantitatively using MARKAL model (the energy optimisation model) to assess their impacts on the energy sector. The energy scenario development process for Vietnam is presented in detail below.

Identification of key variables

Five key variables are selected in this paper for the purpose of energy policy analysis for Vietnam. This selection is based on their potentials to deal with challenges faced by Vietnam's energy sector.

Energy diversity. Diversity of the energy supply mix is likely to be one of the most important issues for Vietnam, especially in the context of rapidly increased energy demand for the country's socio-economic development and vulnerable energy supply sources. It has become an issue of strategic policy direction in the broader context of energy supply security - as specified in the National Energy Policy [8]. At present, the primary mix in the country lacks diversity. It is dominated by two types of fossil fuels, namely coal and petroleum products, constituting of more than 70 percent of total primary energy demand. In the year 2005, for instance, coal and petroleum products accounted for 30 and 44 percent, respectively, in the total primary energy demand [1]. The scenarios in this research assume that diversifying the energy supply mix, away from these two energy sources, would become vital in order to reduce the risk associated with overwhelming dependence on few energy sources. For example, over reliance on coal, which although is an indigenous energy resource, could cause a big problem, particularly if a global reduction of CO2 emissions become imperative in the future. And significant dependence on oil could constitute a high risk because its supply is highly vulnerable due to geo-political conflicts in the oil exporting regions. The diversification of fuels would be even more important for electricity generation where coal and oil currently account for nearly 25% of total generation mix. These two fuels are also major source of CO2 emissions. In 2005, for example, CO2 emissions generated by coal and oil fired plants accounted for 30 percent of total CO2 emitted by the country [9]. Fuel diversification, in the scenarios in this paper, is not confined just to fossil fuels, such as coal and oil, but would also include new and renewable energy sources through their use in power generation (PV, wind, biomass, geo-thermal and nuclear), household application (biogas and solar water heating) and transportation (CNG, ethanol and methanol). This would offer more options for energy use and allow a competition among fuels and technologies in order to determine an optimizing energy solution for the country.

Energy import dependency. The urgency of reducing the dependency on imported fuels, such as petroleum products at present, and coal in the near future, is another important factor that is likely to shape the future energy pathways of Vietnam. Oil products have remained a major component of energy demand in the country, mainly because of its use in the transport sector. In 2005, for example, oil products accounted for 54% of total commercial energy demand. Vietnam has limited indigenous oil reserves that are expected to run out in the next ten years [10]. Vietnam is, therefore likely become a net oil importer within a decade. In addition, the country could be exposed to supply and price volatility Therefore, reducing dependency on imported oil is vital for Vietnam. Several measures are currently being considered by the Vietnamese government to reduce oil import dependency. These include introduction of new transport fuels (such as CNG, ethanol and methanol) and increase of fuel economy for vehicles.

For the coal supply, it is expected that Vietnam will have to import coal for power generation also. In the next 10 year Vietnam will have to import 10 million tons of coal for power generation [11]. This will lead to increase in electricity price because price of domestic coal that at present is still regulated by Government is lower than world coal prices. The question of how much the electricity price will be affected by coal import has been answered by a current study carried-out by the Institute of Energy, Vietnam but how to reduce coal import dependency in the future still remains unclear [12]. So, it is necessary to examine what options, for example, nuclear, renewable, highly efficient technologies or electricity import could be used to reduce dependence on imported coal.

Advanced technologies. Technology in general, and energy technologies in particular, play an important role in improving energy efficiency and hence enhance energy security and reduce negative impacts on the environment caused by energy activities. At present, due to most relatively antiquated technologies employed in both, the conversion and end-use sectors, energy efficiency in Vietnam is rather low. For example, in 2005 the country's primary energy intensity was 0.23 KgOE/USD while those of ASEAN and OECD were 0.2 and 0.18 KgOE/USD, respectively [13]. As a result, significant amounts of energy resources are being wasted and more damage is being caused to the environment. It is, therefore, worth examining how advanced technologies, for example power generation technologies (IGCC, PV and wind) and end-use technologies, such as transport (Hybrid, Hydrogen and Bio-fuel) and metal processing (Direct Reduction of Iron in steel production) technologies could contribute to enhancing energy security and reducing GHG emissions.

Social, political and economic factors. This is an issue of energy choices. The energy choice reflects predominantly personal decisions made through market or collective decisions by the government and the public at large. The attitudes of the government and public opinion on questions, such as energy supply security and environmental impacts, will significantly influence the development of future energy systems. Personal choices that reflect value, environment and lifestyles will also be influential and will be reflected in patterns of energy consumption. For example, how the society becomes environmentally conscious and begins to accept more efficient and environmentally friendly appliances, such as solar water heater and hybrid vehicles, would influence the evolution of the energy system, including the introduction of the new and renewable energy technologies in power generation to reduce fossil fuels consumption and CO2 emissions. In addition, other factors, such as growth of GDP and population, rural electrification and urbanization will also impact the patterns of energy consumption. All these factors will play role in defining energy scenarios for Vietnam.

CO2 emissions. Climate change caused by CO2 emissions that are mostly generated from energy activities has become a major global issue. Vietnam is currently one of the lowest per capita emitters of CO2 emissions. For example, in 2005, the country's CO2 emissions per capita were 0.97 tons - approximately to 23% of the world average. However, with the economic growth target for the next decades, the CO2 emissions are expected to grow rapidly as Vietnam industrializes and the economy utilizes more carbon intensive fuels substituting traditional fuels such as biomass and agriculture residues. On moderate, the CO2 emissions are projected to increase at annual rate of 8.5% and could reach 410 million tons by 2025. Major polluters are energy, industry and transport sectors accounting for more than 85% of total CO2 emissions [1]. Thus, there is a high need for examining impacts of energy activities on environment, especially in the context of emerging issue on global warming caused by GHG emissions. This issue will be taken into serious consideration to examine the possible ways of reducing CO2 emissions to protect environment while maintaining economic growth rate for Vietnam.

Energy scenarios for Vietnam

Three scenarios are developed around five key variables which are important from policy viewpoint and which have potential to shape the future development of the Vietnam energy system as discussed above. The level at which these variable may influence, from low to moderate and high defines these scenarios (see Fig. 1) Accordingly, these scenarios are labelled Base, Moderate and Advanced scenario. For the quantitatively modelling purpose, these scenarios are described in more details below.

Base Scenarios*:* The Base Scenario reflects a situation in which the levels of commitments to climate-friendly-energy production, economic development and technological breakthroughs are low. The scenario represents a continuation of the current trends in economic and energy policies without any major change taking place. This scenario is characterised by no restriction on fossil fuels use in power generation and industries, no specific commitment to promote new and renewable energy sources, including solar, wind, geo-thermal and bio-fuels and no limit on CO_2 emissions. The scenario also will not include any attempt at promoting energy efficiency and conservation. Some key features of the Base scenario are noted in table 1 below.

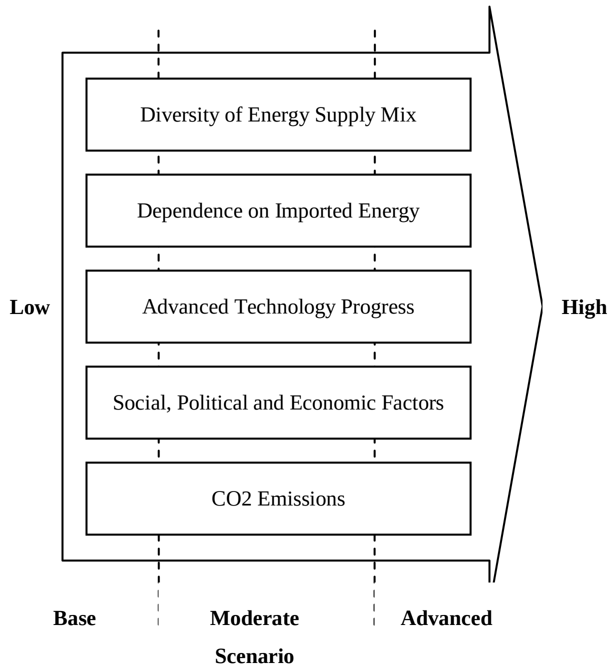

Fig. 1. Key scenario variables.

Table 1. Key Features of the Base Scenario

1. Socio-economic indicators[1]	2000-2005	2006-2010	2011-2020	2021-2030	2031-2040	2041-2050	2006-2050
1.1 GDP growth rate (%)	7.5	6.2	7.0	7.0	6.5	5.0	6.3
• Industry	9.4	8.0	8.5	8.5	7.0	6.0	7.6
• Agriculture	2.8	3.5	3.0	2.5	2.0	2.0	2.5
• Service	8.4	5.5	6.5	6.0	6.5	3.4	5.6
1.2 Population growth rate (%)	1.4	1.2	1.1	1.0	0.9	0.7	1.0
2. Energy indicators[2]							
2.1 Energy Resources	• No restriction on fossil fuel use in electricity generation and industries • No specific commitment on renewable energy development • No attempt on promoting alternative fuels in transport sector • No immediate concern towards reducing oil dependency						
2.2 Electricity Generation	• No restriction on coal-based generation plants • No specific policies to promote renewable-based generation						
2.3 End-use							
2.3.1 Industry	• Technologies for cement and steel production remain at present state • No specific policies to promote energy efficiency in this sector						
2.3.2 Residential and Commercial	• No promotion on solar water heaters and electrical saving lamps						
2.3.3 Transport	• No specific policies to promote alternative fuels and technologies in the transport sector						
3. Environmental Indicator	• No restriction on CO2 carbon emissions						

[1] The GDP and population growth scenarios are taken from the 6th Master Plan for Power Development [11].
[2] Energy indicators and their features are adapted from National Energy Policy [8].

Moderate Scenarios: The Moderate Scenario represents the situation where there is a moderate level of commitments to climate-friendly-energy production, economic development and technological breakthroughs. The scenario is constructed to reflect a future in which there would be a moderate level of urgency to promote energy diversity, energy efficiency and renewable energy, reduce fossil fuel consumption and limit CO_2 emissions. This could result from several possibilities, such as emerging issue of security of energy supply for economic development and pressure from international community (for examples, Kyoto Protocol and Bali Agreements) and public opinion on environmental protection due to new scientific evidences on climate change and pollution from energy activities. This scenario expects some initiatives to be taken to shift from the current state of high carbon intensive fuels to the mix with higher share of new and renewable energy. Also there would be a moderate level of advanced and energy efficient technologies employed in both conversion and end-use sectors. Some key features of the Moderate scenario are shown in table 2 below.

Table 2. Key Features of the Moderate Scenario

1. Socio-economic indicators[3]	2000-2005	2006-2010	2011-2020	2021-2030	2031-2040	2041-2050	2006-2050
1.1 GDP growth rate (%)	7.5	7.6	7.2	7.0	6.5	5.0	6.5
• Industry	9.4	10.0	8.2	7.5	6.5	5.1	7.2
• Agriculture	2.8	3.0	3.0	2.5	2.0	1.8	2.4
• Service	8.4	7.2	7.3	7.3	7.1	5.2	6.8
1.2 Population	1.4	1.2	1.1	1.0	0.9	0.7	1.0
2. Energy indicators							
2.1 Energy Resources	• Moderate use of renewable energy (see 2.2 Electricity generation for assumption of share of renewable energy in generation mix). • Moderate promotion on alternative fuels in transport sector (see 2.3.3 Transport for assumption of share of bio-fuels and CNG in total fuels consumed by road transport vehicles) • Specific policies towards reducing fossil fuels use. From 2010 onwards, 5% of total fossil fuels in this scenario would be saved[4].						
2.2 Electricity Generation	• Share of renewable energy in total electricity generation would be 5% from 2015 onwards[5].						
2.3 End-use							
2.3.1 Industry	• Share of cement and steel produced by new technologies, such as Dry method for cement production and DRI and EAF for steel production would be increased to reduce energy consumption and CO2 emissions[6]						
2.3.2 Residential and Commercial	• New technologies for water heating and lighting, such as solar water heaters and fluorescent lamps, are encouraged to use to reduce energy consumption in these sectors[7]						
2.3.3 Transport	• Alternative fuels and technologies, such as, bio-fuels and CNG are used in the transport sector to reduce oil dependency and CO2 emissions. This scenario assumes that bio-fuels and CNG would account for 5% of total fuel consumed by road transport vehicles [8].						
3. Environmental Indicator	• CO2 carbon emissions would be limited at the 1990 Kyoto level[9].						

[3] Same as 3
[4] This figure is made up with reference to target set for energy savings in the National Energy Policy [9].
[5] This figure is made up with reference to target set for share of renewable energy in generation mix in the National Renewable Energy Master Plan up to 2015 with vision to 2025. Renewable energy here refers to small hydro, wind, solar and bio-mass. It does not include large hydroelectric generation [14].
[6] Adapted from Energy Saving and Efficiency Program [15].
[7] Same as 8
[8] Expert's estimation adapted from other study carried-out by Institute of Energy, Vietnam [3].
[9] Kyoto Protocol, Annex 1[16] – At this stage of development, Vietnam is not in the list of countries that are required to limit CO2 emissions in the Kyoto Protocol. However, according to socio-economic development plan, Vietnam will become industrial country in 2020. Therefore, this study assumes that by that time, Vietnam also has to comply with Kyoto protocol.

Advanced Scenario: The Advanced Scenario reflects the situation where levels of commitments to climate-friendly-energy production, and economic development and technological breakthrough are at high. The scenario is developed to represent a future in which there would be a higher level of urgency to increase diversity of energy supply mix, reduce dependency on energy import, to promote the use of advanced technologies and to lower CO2 emissions even further than the Moderate scenario. The scenario assumes that under the international pressure resulted from international commitments, for example Kyoto Protocol and Bali Agreements, and strong public opinions driven by change in people's consciousness towards environment-tally-friendly energy, the government would support to shift the fossil fuel mix towards cleaner fuels, such as renewable energy and bio-fuels. Also, there would be more restrictions on high energy intensive technologies, for example old coal-fired plants and coal-based metal production technologies, to improve energy efficiency and reduce CO2 emissions. Key features of this scenario are summarized in table 3 below.

Table 3: Key Features of the Advanced Scenario

1. Socio-economic indicators[10]	2000-2005	2006-2010	2011-2020	2021-2030	2031-2040	2041-2050	2006-2050
1.1 GDP growth rate (%)	7.51	8.5	8.5	8.0	7.0	6.3	7.6
• Industry	9.44	11.0	10.0	8.5	7.0	6.0	8.2
• Agriculture	2.75	3.5	3.0	2.5	2.0	2.0	2.5
• Service	8.35	8.0	8.4	8.3	7.5	6.9	7.8
1.2 Population growth rate (%)	1.37	1.2	1.1	1.0	0.9	0.7	1.0
2. Energy indicators							
2.1 Energy Resources	• Greater use of renewable energy compared to the Moderate scenario. (see 2.2 Electricity generation for assumption of share of renewable energy in generation mix). • Higher promotion on alternative fuels in transport sector (see 2.3.3 Transport for assumption of share of bio-fuels and CNG in total fuels consumed by road transport vehicles) • Specific policies towards reducing fossil fuels use. From 2010 onwards, 10% of total fossil fuels in this scenario would be saved[11].						
2.2 Electricity Generation	• Share of renewable energy in total electricity generation would be 10% from 2015 onwards[12].						
2.3 End-use							
2.3.1 Industry	• Share of cement and steel produced by new technologies, such as Dry method for cement production and DRI and EAF for steel production would be increased to reduce energy consumption and CO2 emissions[13]						
2.3.2 Residential and Commercial	• New technologies for water heating and lighting, such as solar water heaters and fluorescent lamps, are encouraged to use to reduce energy consumption in these sectors[14]						
2.3.3 Transport	• Alternative fuels and technologies such as bio-fuels and CNG are used in the transport sector to reduce oil dependency and CO2 emissions. This scenario assumes that bio-fuels and CNG would account for 10% of total fuel consumed by road transport vehicle [15].						
3. Environmental Indicator	• CO2 carbon emissions would be limited at the 1990 Kyoto level[16].						

[10] Same as 3
11 Same as 6
12 Same as 7
13 Same as 8
14 Same as 8
15 Same as 10
16 Same as 11

4. MODEL SET-UP

In order to quantitatively model the scenarios, a model was set up and run in the Windows-based interface of the MARKAL model, known as ANSWER V5 (Version 5) developed by ABARE (2002). The ANSWER interface provides a user friendly platform to handle and analyse the scenarios effectively.

As first step, a Reference Energy System (RES) for Vietnam was established. The RES includes primary energy resources, conversion and process technologies, demand technologies and end-use demand sectors. Energy is extracted at the primary resources level (for example, by mining or import), then undergoes transformation through conversion and process technologies (such as refineries and power plants) and delivered to the demand technologies (such as, furnace and heater), which finally satisfy end-use services (steel outputs and heating area) as demanded by various economic sectors. Each component in RES is characterised by certain parameters for which data need to be input. They include, for example, technical parameters (residual capacity, efficiency, life, availability), cost parameters (investment cost per unit, fixed cost and variable cost), and emissions characteristics, etc. Also, various policy constraints (for example, constraints on CO2 emissions, maximum growth rate that need to be allowed for technologies such as, share of renewable energy in power generation and bio-fuel in transportation) are specified as required by the scenarios. The database for the alternative scenarios (Moderate and Advanced) uses the general database structure of the Base scenario, with some modifications to reflect constraints.

The Window-based interface, ANSWER V5, translate input data and policy constraints into a linear programming (LP) problem with an objective function and constraints comprising a number of variables. To solve the optimisation problem, the interface uses the solver, GAMS (General Algebraic Modelling System), developed by Alexander Meeraus and Anthony Brooke of the World Bank [17].

The model was first run for the Base scenario and two other alternative scenarios which are Moderate without constraints (MODNO) and Advanced without constraints (ADVNO). The results from two scenarios (MODNO) and (ADVNO) are used to calculate fossil fuel savings for the Moderate (MOD) and Advanced (ADV) scenario. Then the model is run for two alternative scenarios MOD and ADV with constraints on the share of renewable energy in power generation, fossil fuel savings and CO2 emissions limits. The model provides solutions for all time periods (for example, 2000, 2010, 2020, 2030, 2040 and 2050) simultaneously. The model run solves the LP problem – to determine the combination of technologies and fuels that represent the most cost effective means of satisfying the specified levels of energy services.

5. DATA CONSIDERATION

The energy sector model employed in this paper is a bottom-up approach. It requires various data on end-use services, energy resources and technologies (e.g., costs, efficiency, capacity factor). The data on end-use service demand is forecasted based on GDP growth and energy-economy elasticity for each scenario. Three scenarios of GDP growth are taken from the Sixth Master Plan for Power Sector Development, which was developed by the Institute of Energy, Vietnam in 2007 [11]. The energy demand for Vietnam in the future period 2005-2050 is projected from the country's historical data on sectoral energy-economy elasticity and energy intensity provided by Institute of Energy, Vietnam, IEA data [13] and the target set for energy efficiency in the National Energy Policy [8]. The energy resources data, in particular data on coal, oil and gas reserves as well as their annual exploitation potentials are obtained from the study on National Energy Master Plan [1]. For the technology specific data, such as costs, efficiency, capacity factor etc., both domestic and international sources are used. For example: Data on electricity load curve and plan for retired power plants or growth of different types of road transport vehicles such as Bio-diesel and CNG trucks could be found in internal sources like Institute of Energy, Vietnam and Vietnam Registration Office; Data on efficiency and costs of new technologies such as wind and solar power generation plants are taken from external sources like IEA and European countries. The data source for establishing constraint on CO2 emissions limits is IEA website where there is an Annex 1 of the Kyoto Protocol that sets the CO2 emissions limits [16].

6. RESULTS AND DISCUSSIONS

This section presents the results, indicating the energy impacts of the three scenarios. The energy impacts are quantified in this research in terms of primary and final energy requirements, electricity generation fuel mix, plant capacity requirements and CO2 emissions for Vietnam over the period 2000-2050. These estimates are obtained from the application of MARKAL model as presented in section 5 and under a set of assumption as described in section 4 of this paper.

Primary and Final Energy Requirements

The primary and final energy requirements for the Base, Moderate and Advanced scenarios are summarised in the Table 4. The results show that Vietnam is on the path of increasing energy consumption into the foreseeable future in all three scenarios. For example, during the period 2000-2050, annual growth rates of the primary energy requirements for the Base, Moderate and Advanced scenarios are 5.6, 5.5 and 6.3 per cent while those of the final energy consumption are 5.1, 5.3 and 6.1 per cent, respectively. The increased energy demand is driven by population growth and economic activities. Especially, in the first half of the planning horizon the energy demand increases sharply with annual growth rates of 7.6%, 7.8% and 8.7% for the Base, Moderate and Advanced scenarios, respectively due to the Government policy on promoting industrialisation, which is characterized by high energy intensive technologies and change in people's lifestyle, as a result of improvement in income and access to modern energy, for example rural electrification program.

Table 4: Primary and final energy requirements

	Base year 2000	Base scenario 2025	MOD scenario 2025	ADV scenario 2025	Base scenario 2050	MOD scenario 2050	ADV scenario 2050
Primary energy requirement							
Total commercial primary energy (MTOE)	24.6	153.0	161.4	199.5	370.8	362.1	524.0
Average annual growth rate (2000-2050) %		7.6	7.8	8.7	5.6	5.5	6.3
Energy Intensity (TOE/1000USD)	0.79	0.92	0.89	0.89	0.52	0.47	0.44
Energy-economy elasticity		1.3	1.2	1.2	1.2	1.1	1.0
Final energy requirements							
Total final energy (MTOE)	17.6	97.3	107.2	135.0	215.1	236.6	345.5
Average annual growth rate % (2000-2050)		7.1	7.5	8.5	5.1	5.3	6.1

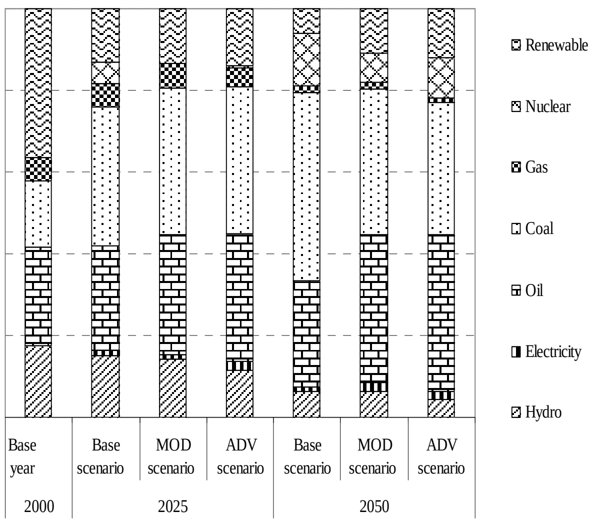

Fig. 2: Primary energy mix.

Despite of the increased share of renewable energy for power generation (from 4% in Base scenario, to 10% in Moderate scenario, and 15% in Advanced scenario), oil and coal still account for more than 60% of total primary energy requirements in all three scenarios (see Fig. 2). This suggests that the energy supply system of Vietnam is expected to be heavily dependent on fossil fuels. It is interesting to note that while oil demand increases rapidly for all three scenarios, demand for coal increases in the Base scenario only and decreases in both, Moderate and Advanced scenarios. This could be explained by the increased demand for oil products from industry and transport sectors. And at the same time, under pressure on reducing CO2 emissions in the Moderate and Advanced scenarios to the level of 1990 Kyoto protocol, a large share of coal is replaced by renewable and nuclear energy in power generation, leading to reduction of the share of coal in total primary energy mix. The results also foreshadow the increasing significance of nuclear power in ensuring the security of energy supply and environmental protection. It is indicated by the fact that in the second half of the planning period, nuclear energy is introduced in all three scenarios with its share ranging from 12.8%, 7.1% and 9.8% for the BASE, Moderate and Advanced scenario respectively to meet energy demand for high economic growth and to reduce CO2 emissions from use of fossil fuels.

The end-use energy demand in agriculture, commercial, industry, residential and transport sector is expected to increase steadily over the next decades in all scenarios. The composition of energy demand reveals that the industry makes up 24% of energy consumption in the base year 2000 and continues to increase in absolute and relative terms for all three scenarios through 2050, followed by transport sectors and residential (see Fig. 3). These are the three biggest energy consumers, accounting for more than 90% of final energy consumption. However, while the share of final energy consumed by transport sector increases in all scenarios through the planning horizon the share of residential sector tends to move in the opposite direction in the same period.

The absolute and relative size of industry and transport sectors' energy consumption brings to light the dominant role these sectors play in defining Vietnam's overall energy pathways. Even under conditions of active sector reform, the overall potential for the country's energy savings is constrained by several critical factors, for example, lack of investment capital to replace high energy intensive technologies with the energy efficient ones, increasing per capita driving activity, growing population and other forms of non-road transportation such as shipping and air travel. It is surprising to note that even under the conditions of 10% and 15% reduction of fossil fuels set for the Moderate and Advanced scenarios, respectively or competition allowed for selecting advanced technologies, such as DRI and EAF in steel production or bio-fuels and CNG in road transport, the energy demand of these two sectors continues to increase. This points to the critical importance of policies for these two sectors for managing level of absolute energy consumption in the face of continued trends of industrialisation and increasing population and driving activity.

Finally, there is a significant potential for improvement of energy efficiency and reduction of CO2 emissions through fossil fuels savings and the utilisation of new and renewable energy. It is indicated by the fact that by applying constraints on fossil fuels in two alternative scenarios, the energy intensity in the year 2050 decreases from 0.52 in the Base scenario to 0.47

and 0.44 in Moderate and Advanced scenarios, respectively. As a result, energy-economy elasticity also decreases from 1.2 in the Base scenario to 1.1 in Moderate and 1.0 in advanced scenario at the same time.

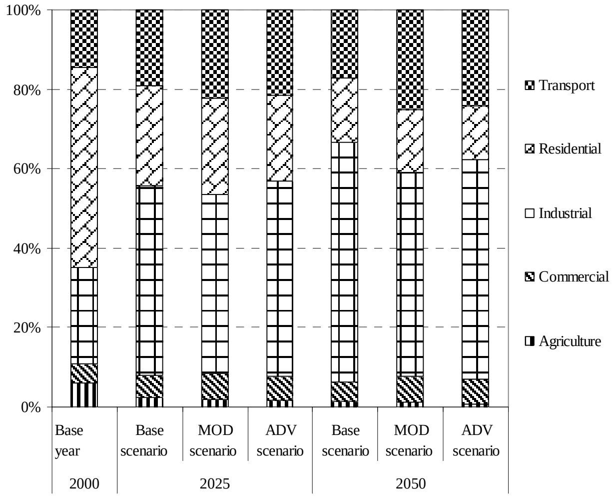

Fig. 3: Share of final energy requirements by sector

Electricity generation

Electricity generation is expected to grow at a high rate to meet the increasing demand, driven by population growth and economic activities. During the planning period 2000-2050, the annual growth rates of electricity generation in the Base, Moderate and Advanced scenarios are 7.3, 6.9 and 7.6%, respectively (see Table 5). These growth rates in the first half of the planning horizon (2000-2025) are even higher, at 10.6, 10.6 and 11.5% for the Base, Moderate and Advanced scenarios, correspondingly. The industry sector, especially manufacturing which is identified as a key contributor to industrialisation is primarily responsible for increased electricity demand. In addition, residential sector is also a major electricity consumer because of the improvement in people's income and access to national electricity network.

The generation mix changes in all scenarios over the period 2000-2050. Coal, hydro and gas account for more than 60% of electricity generation mix in all three scenarios (see Fig. 4). During the planning horizon, the shares of gas and hydro decrease due to their limited reserves while the share of coal, which is supported by plenty of domestic coal reserve and new coal-based generation technologies with high efficiency and low CO2 emissions, is expected to increase. However, to meet the targets set for CO2 emissions and reduction of fossil fuel use, the share of coal in total generation mix decreases in the advanced scenario. Nuclear and renewable energy are substituted for coal, accounting for 16.4% and 13.8% of total generation mix in the year 2050. The increase of nuclear and renewable energy, both in absolute and relative terms in power generation means that these fuels have an important role to play in ensuring the security of energy supply, through a diversification of fuel mix and in making energy activities more friendly to the environment. Therefore, to support to development of the Vietnam's electricity system in this direction, it is necessary to have long-term policies, for example, policy on promoting investment in electricity infrastructure, especially power generation and policy on electricity pricing to make electricity produced from renewable energy competitive with the conventional fuels.

Table 5: Electricity generation

	Base year 2000	Base scenario 2025	MOD scenario 2025	ADV scenario 2025	Base scenario 2050	MOD scenario 2050	ADV scenario 2050
Electricity capacity (GW)	6.9	63.9	66.4	80.6	169.6	143.3	203.0
Electricity capacity growth (%)		9.3	9.5	10.3	6.6	6.2	7.0
Electricity generation (TWh)	27.6	343.1	344.1	422.1	937.6	776.6	1067.6
Electricity generation growth (%)		10.6	10.6	11.5	7.3	6.9	7.6

Table 6: CO2 emissions by sector

	Base year 2000	Base scenario 2025	Moderate scenario 2025	Advanced scenario 2025	Base scenario 2050	Moderate scenario 2050	Advanced scenario 2050
Total emissions (Mill. tons)	38.0	346.9	396.5	498.4	994.5	922.0	1293.1
Change compared to 2000 (time)		9.1	10.4	13.1	26.2	24.3	34.0

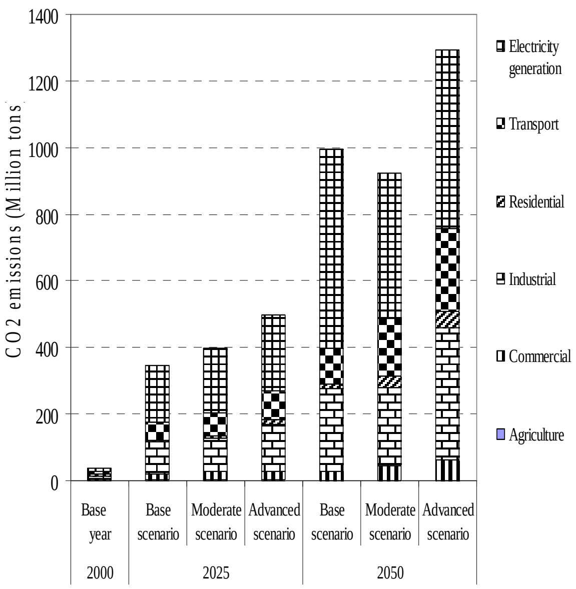

Fig. 5. CO2 emissions by sector

The energy-related CO2 emissions are projected to increase in all three scenarios, in both the absolute and relative terms, as a result of increased energy consumption driven by population growth and economic activity. Fig. 5 shows the magnitude and composition of CO2 emissions by sector in the Base year (2000) and for each scenario in the years 2025 and 2050. The total emissions in the Base year (2000) were 38.02 millions tons. This value is expected to increase by 9 and 26 times in the years 2025 and 2050, respectively, for the Base scenario. In the two alternative scenarios, (Moderate and Advanced), higher CO2 emission increases are envisaged. Specifically, CO2 emissions in the Moderate scenario are projected to increase by 10 and 25 times by the years 2025 and 2050, and in the Advanced scenario by 13 and 34 times. Compared to the Base and Moderate scenarios, the Advanced scenario which is characterized by the highest economic growth rates produces the biggest quantities of CO2 emissions (see Fig. 5).

The major contributions to CO2 emissions include power generation, followed by industry and transportation sectors in all three scenarios (see Fig. 6). Collectively, these sectors account for more than 90% of total CO2 emissions. However, while the share of CO2 emissions emitted by these sectors increases in the BASE scenario with 49 and 60% in 2025 and 2050, respectively, this figure remains unchanged during the planning period for the Moderate and Advanced scenarios as a result of applying measures to improve energy efficiency and limit CO2 emissions. The results suggest that these sectors need greater attention if the government is to mitigate the rate of increase of CO2 emissions.

An important step in this direction is to study and adopt regulations to reduce the CO2 emissions by road vehicles. The regulations also create incentives for improving transportation technologies and encouraging wise ways of using transport facilities, for example replacing fossil fuel-based cars with the bio-fuel powered ones or individual cars with public transport facilities.

The results of scenario analysis also suggest that there is a high potential for CO2 emissions reduction. These measures include diversification of fuel mix in power generation to incorporate a greater share of new and renewable energy and enhancement of energy savings. For example, without mitigation measures, the Advanced scenario would produce a biggest quantities of CO2 emissions. However, by increasing shares of renewable and nuclear energy to 14% and 16% ,respectively and reducing fossil fuel use by 15% through energy efficiency and savings, the CO2 emissions of this scenario are kept at the 1990 levels of the Kyoto Protocol. Finally, industry sector which account for more than 25% of total CO2 emissions also has high potential for green-house gas reduction.

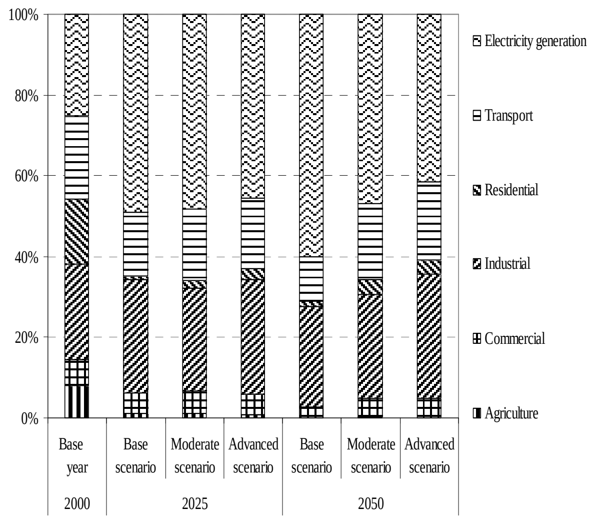

Fig. 6. Share of CO2 emissions by sector (%).

7. OPPOTUNITIES AND POLICY IMPLICATIONS

This section aims to provide a deeper discussion on the above results of scenarios analysis through which some opportunities and policy implications for better development of the Vietnam's energy system could be identified.

a) Energy diversity versus fossil fuel dependence.

Vietnam is on a fossil fuel pathway. The results of scenario analysis show that the country is on the way of increasing fossil fuel dependence. Currently, fossil fuels comprise more than 70% of primary energy demand [18]. Expectations of population growth and increasing economic activities, especially industry and transportation would take Vietnam down a pathway towards even greater reliance on fossil fuels. Energy diversity plays role in supply security, energy planning and environment. In Vietnam, increasing energy diversity is also linked to decreasing relative fossil fuel dependence. With the large fraction of the country primary energy consumption attributed to coal and oil, energy consumption will only become more diverse if a greater proportion of energy consumption is made up of non-fossil fuels. The scenario analysis results show that the key dynamic of increasing energy diversity is to reduce coal and oil dependence through energy savings, new and renewable energy activities. Electricity generation and transportation with their direct association to coal and oil consumption are critical sites for diversity activities. Residential and commercial sectors also have a role to play in increasing share of renewable energy consumption through application of solar energy in heating and cooking. In summary, an integrated approach combining technology, policy and individual choices is needed to enhance energy diversity for Vietnam in the coming decades.

b) Lack of adequate policies makes the diversity of Vietnam's future electric power sector highly uncertain.

In the first half of the planning horizon, electricity generated from coal, gas and hydro account for more than 80% of total generation mix. However, due to limited gas and hydro reserves and high need for reduction of CO_2 emissions, the shares of renewable and nuclear are expected to increase dramatically in the second half of the period. In addition, new coal-fired power plants with high efficiency and low CO_2 emissions, such as IGCC and Carbon capture are projected to have important position in development of Vietnam's future power system. Vietnam has realised the vital role of energy diversity in power generation and this issue was taken into consideration when making the Sixth Master Plan for Power Development in which all potential sources, such as fossil fuels, renewable and nuclear are mobilised for electricity production [11]. However, how to realise this plan is still remained as a critical issue and wise policies are needed to remove bottle-necks for power infrastructure development. Some of the critical policies are policy on power sector reform, especially development of the market for electricity generation and policy on electricity pricing to attract more investment in this area through fair competition among players [19]. A reasonable electricity pricing could make the new and renewable energy become competitive with the conventional sources and hence promote energy diversity in power generation.

c) More attention should be paid to demand side management

Among end-use sectors, industry and transportation are two biggest energy consumers and CO_2 emitters. These two sectors account for 70% of the country's final energy consumption and 40% CO_2 emissions. The industry and transport sector bear responsibility for the country's oil dependence and local air quality. Steel production, car and truck are the most energy intensive technologies, meaning that small change in this area could have significant impacts on both energy security and environment. Policies on encouragement of energy efficient technologies, promotion of alternative fuels and decrease of driving activity offer large opportunities for reducing future energy consumption, decreasing pollution and increasing energy diversity. The magnitude, impacts and risks of activities in industry and transport sectors and fossil fuel consumption provide hearty justification for assertive policy in these areas and planning at the sectoral and national levels. In addition, the residential and commercial sectors have an important role to play. These two sectors account for only around 20% of total final energy consumption but are ranked as second biggest electricity consumer [11]. In the future, the electricity consumed by these sectors is expected to increase due to improvement in residential income and change in their lifestyle. From environmental point of views, these are two significant indirect CO_2 emissions emitters because power generation accounts for largest share of CO_2 emissions. These sectors also offer a great opportunity for energy diversification through application of off-grid generation technologies and solar-based heating and cooking equipment.

d) A master plan for renewable energy development can provide a road map for the future.

The results of scenario analysis indicate important role of renewable energy in contribution to security of energy supply and reducing CO_2 emissions. For Vietnam to pursue energy diversity pathways and catalyse a supportive investment environment, the country needs to assert its commitment to renewable energy and transparently articulate the way it will encourage these activities. Recently, Vietnam has developed a Master plan for renewable energy development - an important step in this direction. The plan provides ideal flagship energy policy for beginning the process of creating a national renewable energy framework and vision for future policy and planning. However, some important issues which are critical for future development of the renewable energy, for example, the form of incentives, purchasing contracts, standardisation of interconnections and utility cooperation were not addressed in this plan [14].

e) Energy savings can play an important role in the Vietnam's clean energy pathway and reduction of dependency on imported energy.

Energy savings, in both demand side and supply side offer important opportunities for decreasing fossil fuel dependence, offsetting pollution and increasing energy security. Energy savings involve both energy efficiency and decreasing energy consumption as both technologies and social choices have a role to play in Vietnam's energy pathway. Energy saving and energy efficiency are the most secure and least environmentally disruptive forms of energy supply. The Government of Vietnam has set the targets for energy savings of 3 to 5% in the period 2006-2010 and 5 to 8% for the period 2011-2015 [15]. However, with technological progress and community involvement, potential for energy savings is still very high. Therefore, increasing ability of individual and state planners to consider energy savings both from technologies and social choices is important to realizing alternative energy pathways.

8. CONCLUSIONS

Ensuring security of energy supply for social-economic development and at the same time minimizing negative impacts caused by energy activities on natural environment are challenging task for Vietnam in the next decades. In order to find potential energy pathways that could meet the country's energy needs in a balanced manner, three energy scenarios characterised by specific conditions, representing possible future of the energy system that might unfold are examined, using the linear programming based energy optimisation model - the MARKAL model. The scenarios presented here do not try to predict what the future will be or even what should be like. Rather they open the doorway to possibilities. The results of scenario analysis demonstrate that plausible alternative energy pathways do exist and the questions of what forces would shape the future development of the Vietnam's energy system and how the country will move forwards in the next 50 years are also responded. Some important conclusions which could be drawn from this scenario analysis are: (i) Diversity of energy supply sources and energy savings are the possible energy pathways for Vietnam to overcome dependency on energy import and fossil fuels and to reduce environmental pollutions; (ii) It is critical for Vietnam to make adequate long-term energy policies to enhance security of energy supply and to protect environment; and (iii) Trade-off among energy, socio-economic and environment factors must be made in making energy policies to ensure sustainable and affordable development of the Vietnam's energy system. This task is outside the scope of this paper and need to be considered in a broader context of the next study that is wide-economy impact assessment of the energy options.

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