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The Potential for Mitigation of CO2 Emissions In Vietnam's Power Sector

Nhan T. Nguyen*
Minh Ha-Duong*

* Centre International de Recherche suur l'Environnement et le Développement (CIRED), France

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Abstract

This manuscript examines CO_2 emissions from Vietnam's power sector using an expanded Integrated Resource Planning model. The potential effects of the following alternative policy options are examined: energy efficiency, favorably imported generation fuels, nuclear energy, renewable energy, and an internalized positive carbon value. The baseline in terms of cumulative CO_2 emissions over 2010-2030 is 3.6 Gt. Lighting energy efficiency improvements offers 14% of no-regret abatement of CO_2 emissions. Developing nuclear and renewable energy could help meet the challenges of the increases in electricity demand, the dependence on imported fuels for electricity generation in the context of carbon constraints applied in a developing country. When CO_2 costs increase from 1 \$/t to 30 \$/t, building 10 GW of nuclear generation capacity implies an increase in abatement levels from 24% to 46%. Using renewable energy abates CO_2 levels by between 14% and 46%. At 2 \$/tCO_2, the model predicts an abatement of 0.77 Gt from using wind power at prime locations as well as energy from small hydro, wood residue and wood plantations, suggesting Clean Development Mechanism opportunities. At 10 \$/tCO_2, the model predicts an abatement of 1.4 Gt when efficient gas plants are substituted for coal generation and when the potential for wind energy is economically developed further than in the former model.

Key words: integrated resource planning, carbon value, abatement of CO_2 emissions, Vietnam, electricity generation.

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1. Introduction

The demand for electricity in Vietnam has increased twice as fast as the Gross Domestic Product over the last decade, and annual growth rates of approximately 18% have been predicted for the period of 2010-2030 by the Institute of Energy. It is also estimated after the year 2015, domestic sources of electricity energy supply in Vietnam could be unable to meet the growth in electricity demand so that fuels and electricity energy would need to be imported for electricity generation. And the electricity generation capacity is largely being expanded with coal-fired power plants (2006a, 2008b). As a result, CO_2 emissions are expected to increase rapidly by 14% per year, reaching approximately 352 Mt of CO_2 in 2030 (Nguyen and Ha- Duong, 2009). However, the heavy dependence on fossil fuels for economic development and energy security goes against global efforts to prevent dangerous climate change, and has detrimental effects on local health and the environment.

In response to increasing concerns about scarce primary energy resources, the environment, and risks, the traditional planning process emphasizing lowest cost has been redesigned, and utility planners have moved towards the so-called integrated resource planning process (B. F. Hobbs, 1995; Swisher, J.N et al., 1997). This process requires considering a broader array of options in the portfolio of potential resources, including technologies to improve energy efficiency, demand-side management, and decentralized and non-utility generating sources (Eto, 1990; Fernando, et al. 1994). Integrated planning also considers a wider range of cost components beyond direct economic costs, such as customer value, externalities and social costs (Hirst and Goldman, 1991; Hoog and Hobbs, 1993; Fernando, et al. 1994), as well as various uncertainties which could affect the performance of electric utility planning (Hobbs and Centolella, 1995; Hobbs and Meier, 1994).

This framework has been used to analyze options to achieve targets for reductions in CO_2 emissions. In Asia, Chattopadhyay and Parikh (1993) and Chattopadhyay (1994) examined alternative options for achieving reduction targets for CO_2 emissions in India. More recently, Shrestha et al. (1998) developed the integrated resource planning (IRP) model, which has been applied to several developing countries in the region. This model was used by Shrestha and Marpaung (1999, 2002) to analyze the abatement of greenhouse gases by integrating supply- and demand-side options in an electric utility plan considering the effects of carbon taxes and CO_2 emissions targets.

Focusing on Vietnam's power sector, Nguyen, Q. Khanh (2007b) used a least-cost MARKAL model to simulate the impacts of wind power generation and carbon constraints on future choices of fuels and technologies. Nguyen and Ha-Duong (2009) explored the potential of all renewable energy sources together for electricity generation in Vietnam using the IRP model extended to include a broad portfolio of grid-connected renewable energy technologies. The present paper further develops the IRP analysis approach, which realistically mirrors marginal abatement costs of carbon emissions reduction by considering non-zero carbon values and a large panel of energy generation technologies as well as demand-side management (DSM) options to provide a more exhaustive assessment of the current state and future prospects for the electricity sector in Vietnam.

Section 2 discusses Vietnam's power sector, its outlook up to the year 2030, and the environmental factors at stake. Section 3 then presents the original development of the IRP model to consider a positive carbon value. Several policy options for development of Vietnamese power sector are analyzed including demand-side management, favorable importation of generation fuels, nuclear energy, and renewable energy. Section 4 presents results on the technical abatement potential of carbon values from 1 $/tCO_2$ to 30 $/tCO_2$. Section 5 focuses on energy efficiency improvements as a potential free lunch, and also discusses wind power. Section 6 discusses policy implications for future prospects of Vietnamese power sector development in the context of future constraints on CO_2 emissions in the world economy then concludes.

2. Overview of Vietnam's power sector

2.1 Power sector development

Currently, the Electricity of Vietnam (EVN), a state-owned utility established in 1995 with more than 50 subsidiaries under the Ministry of Industry (MOI), is the established leader in electricity generation, transmission and distribution. However, the electric power sector is a growing market and represents one of the most promising areas for domestic and foreign service prospects in Vietnam.

Electricity consumption in Vietnam grew at 14.9% annually between 1996 and 2000, and at 15.3% over 2000-2005, faster than the GDP, which grew at 7.2% between 1996 and 2005. The contribution of households to total electricity consumption has decreased from 49% in 2000 to 44.2% in 2005, while the industry sector's share increased from 40.6% to 45.8%. The electricity consumption per capita in 2005 was 538 kWh/yr, and is expected to increase up to 2058-2350 kWh/yr by 2020 and 3096-3752 kWh/yr by 2030 depending on different scenarios of economic development and population growth (Electricity of Vietnam, 2006a, 2008a; Institute of Energy, 2006a, 2006b, 2008b).

At the end of 2007, the total electricity generation capacity in Vietnam was 12 948 MW, of which Electricity of Vietnam (EVN) facilities accounted for approximately 71.9%, distributed as 34.6% hydropower, 22.7% gas-fired based power plants, 11.6% coal-fired, 1.4% oil-fired, and 1.5% small hydro and diesel plants. Next to EVN, 23.9% of the total capacity was produced by local and foreign independent power producers, and 4.2% of power was imported, mainly from China. Transmission and distribution loss in Vietnam has been reduced significantly from 22% in 1995 to 12% in 2005, and the EVN's goal for 2025 is to reduce this loss to less than 8% (Institute of Energy, 2006a, 2006b, 2008a, 2008b).

The Vietnamese Government manages the development of the power sector using a Power Development Master Plan, which anticipates the need for electricity services and schedules the sector's overall development over a ten-year period, taking the previous ten-year period into account. According to the sixth and current plan, the electricity demand is projected to increase by 15% per annum in a low-electricity-demand scenario (corresponding to a low economic development scenario), and by 18% per annum in a high-electricity-demand scenario (corresponding to a high economic development scenario) over the period 2010-2030. In the public administration and residence sectors, electricity is primarily (80%-85%) used for lighting. Overall, more than 40% of the total electricity supply in Vietnam is used for lighting, which is blamed for the occurrences of overloading during peak periods. This figure is projected to increase slightly in the coming years and then gradually decrease to 30% by the year 2030 (Electricity of Vietnam, 2006a, 2008a; Institute of Energy, 2006b, 2008c).

Vietnam is not obligatorily committed to reduce CO_2 emissions but it could achieve sustainable socio-economic development through the Clean Development Mechanism (CDM). Due to growing electricity energy needs, highly inefficient energy use and an ample potential for renewables, Viet Nam is a promising country with enormous opportunities, especially in energy sector, for developing projects under the CDM. This mechanism allows net global greenhouse gas emissions to be reduced at a much lower global cost by financing emissions reduction projects in developing countries where costs are lower than in industrialized countries. Although the CDM has recently received increased criticism, it still appears as a path that could lead to the global objective of sustainable development.

2.2 Vietnam in the context of climate change risk

Specific scientific research reports of international organizations suggest that Vietnam is very sensitive to rising sea levels caused by global warming. According to the World Bank (2008), the sea level rise of between 30 cm and 1 m over the next 100 years anticipated by the IPCC (2007) could cause a yearly capital loss in Vietnam of up to 17 billion USD, and could cause the country to lose over 12% of its territory, where 23% of the 84 million Vietnamese people reside. UNDP (2007) estimates that a rise in sea levels will worsen saline water intrusion in coastal zones in Vietnam. The Mekong River Delta will be the most severely affected region, with 1.77 million ha of land vulnerable to salinization, accounting for 45% of the delta's surface. A scenario of a 30 cm sea-level rise by the year 2050 would increase the salinity of the main tributaries of the Mekong River as far as 10 km inland. The inundation and consequent land loss caused by saline water intrusion in the Mekong Delta and parts of Red River Delta will result in a serious threat to farmers, decreasing exports such as rice and potentially harming national food security.

Climate change could increase Vietnam's exposure to extreme weather events. Flood damage is expected to worsen with the predicted 12-19% increase in daily rainfall by 2070 in some areas, and drought problems will intensify through increased variation in rainfall and increased evaporation (3% in coastal zones and 8% in inland areas) by 2070. The typhoon and the intensity of storms are expected to grow so that 80-90% of populations could potentially be directly affected by typhoons.

With regards to local pollution, the air pollution problem in Vietnamese cities is less catastrophic than in other Asian cities, but is still serious. For example, air pollution caused approximately 22% of cases of chronic pneumonia and one-third of respiratory inflammations in Vietnam during 2001-2003 (USAID, 2007). Although the concentrations of SO_2 and NO_X in the air of Ha Noi and Ho Chi Minh cities during 1997-2002 were generally below the national levels, they are likely to increase given the increase in fossil fuel use, and may soon exceed these levels.

There is a conflict in the Vietnamese electricity planning process between increasing capacity in a rapid and cost-effective manner by adding more coal-fired power plants and addressing environmental issues. While today's Master Plan prioritizes capacity expansion over environmental concern, climate change must be taken into account in future plans. This study presents an integrated planning process that would internalize the external costs of CO_2 emissions, allowing for a better balance between expansion and environmental protection.

3. Methods

We assumed a hypothetical and unspecified climate policy in which planners include a positive carbon value ranging from 1 \$/tCO_2 to 30 \$/tCO_2 in order to assess the potential for the abatement of greenhouse gases in Vietnam's power sector between 2010 and 2030. It is possible that the price of carbon will rise in real terms over the next 20 years due to carbon accumulates. However, the higher the price of carbon becomes, even the more potential the abatement of greenhouse gases in Vietnamese power sector is.

In addition to internalizing carbon values, there are four discrete main policy alternatives to be considered for Vietnamese power sector development: demand-side management, favorable importation of fuels (coal, gas, and electricity) for electricity production, nuclear energy, and renewable energy. These scenarios suit the forecast and estimates from official Vietnamese Government agencies. For each development scenario and carbon value, we used the IRP model to compute the CO_2 emissions in the sector over the outlook period. The abatement is the difference from the value of the baseline scenario, which includes favorably imported fuels and very few renewables.

Due to unavailable statistic data on price elasticity of electricity demand, this paper assumes to ignore the decrease of electricity demand that could be caused by the electricity price increases because of environmental costs inclusion.

In this paper, the stand-by capacity requirement is modeled for the whole electricity generation system under a utility's least cost perspective because electricity market is not available yet in Vietnam. For stand-by supply, there are reliability system constraints simulated in the IRP model and the reserve system capacity is set to decrease gradually, from 30% in year 2010 down to 0.25 in 2025 and 0.2 in 2030. For wind turbine technology, 10% of additional wind capacity (over total capacity installed) on reserve is included as current worldwide practice. Based on the reserve capacity and the reliability constraints, the most risky cases (i.e. no wind, no sunlight, no water) due to renewables' intermittent nature are simulated in which the total capacity of the generation system always satisfy peak load demand at any moment.

3.1 The Integrated Resource Planning (IRP) model

Shrestha and Nguyen (2003) presented the Integrated Resource Planning (IRP) model[1], which was developed in 1998 by the Energy Program of the School of Environment and Resources Development of the Asian Institute of Technology. This model uses mixed-integer linear programming (MILP) to compute a lowest-cost electricity generation capacity expansion plan subject to the following constraints:

(i) Demand constraint: The total power generation by all power plants (current and future) and the generation avoided by demand-side management options should not be less than the total projected power demand in all periods (blocks)[2], seasons, and years of the planning horizon;

(ii) Plant availability constraint: The power generation of each plant is limited to the capacity and availability of the plant during each period of the day;

(iii) Reliability constraint: The total power generation capacity of all the plants and the generation capacity avoided by demand-side management options must not be less than the sum of the peak power demand and the reserve margin in each year of the planning horizon;

(iv) Annual energy constraint: A maximum limit is set on the energy generation at each plant based on its existing capacity, availability, and maintenance schedule;

(v) Hydro energy availability constraint: The total energy output of each hydro plant in each season should not exceed the plant's maximum available quantity of hydro energy;

(vi) Maximum potential capacity constraint: The total installed capacity of each type of power plant must not exceed the maximum allowable capacity of that plant type;

(vii) Minimum operation capacity constraint: All selected thermal generating units, depending on their characteristics (off-peak, intermediate, peak plants, etc.) must be operated to generate electricity energy production at a certain minimum running capacity;

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[1] The objective function of the IRP model is to compute the least cost combination of generation capacities of different generation sources, the level of end-use electrical appliances to be added (i.e. demand side), and the level of electricity generated by different plants.

[2] The daily chronological load curve in the model is divided into several blocks (i.e., time intervals) in order to adequately reflect the effects of the variation in power demand throughout the day.

(viii) Fuel or resource availability constraint: Energy generation from a plant cannot exceed the maximum available quantity of fuel or resource supply;

(ix) External power availability constraint: Imported energy cannot exceed the maximum available quantity of external power generation resources; and

(x) Demand-side management constraint: The level of energy efficient devices selected in a year must not exceed the maximum feasible level of such devices in the year.

To integrate a positive carbon value scenario in the power generation capacity expansion plan, we developed the IRP model to include the carbon values in the cost objective function as follows:

$$TC = SC + CV * \left\{ \sum_{t=1}^{T} (E_t - E_t^{REF}) / (1+r)^t \right\}, \qquad (1)$$

where TC is the current value of the total planning cost; SC is the present value of total system costs including capital, fuel, operation, and maintenance, demand-side management, and electricity import costs; CV is the carbon value; E_t^{REF} is the baseline value of CO_2 emissions (computed assuming CV =0) in year *t*; E_t is the quantity of CO_2 emissions in year *t* in cases in which the carbon value $CV \neq 0$; *r* is the discount rate; and *T* is the planning horizon.

Through IRP simulations, two seasons (rainy and dry) are modeled each year. The load curve in each day of a season is divided into 24 blocks (1 h/block). The load shapes, based on load demand forecast data, are also modeled differently for the two seasons in each year and for certain time of years in the study. Energy generation from renewable sources (such as wind, solar, and small hydro) is modeled in accordance with its intermittent nature. In the IRP, plant dispatch is modeled under the merit order method, and the ability to generate electricity from renewable plants depends on the availability of energy sources (i.e., the generation of wind/solar technology depends on the quantity of available wind or sunlight in each block of a day, and the quantity of small hydro technology depends on the water level in each season). Furthermore, renewable energy technologies are considered to have a quicker lead time than conventional plants (gas and coal), which can take three to five years to construct. Quicker lead times for construction of renewable energy plants enable a more accurate response to growth in demand. For large and small hydro technology plants, the lead time ranges from two to five years for construction, depending on the site. Lead times for different technologies are modeled by inputting the "earliest available year of the candidate plant's operation" and the "annual allowable maximum candidate plant units" that could be feasibly put into service. The details of the IRP model are described in the appendix.

3.2 Parameters

This study considers fifteen alternative generation technologies, including seven renewable generation technologies and eleven fuel types. Table 1 summarizes the assessment of the economic potential for renewable energies to produce electricity. Table 3 describes the technical, economic and environmental characteristics of the various generation technologies. The renewable energy generation technologies considered were: small and mini hydro, geothermal, wind turbines, solar grid, combined-cycle biomass-based integrated gasification, and direct biomass combustion.

This study considers a variety of fuels for electricity production, including domestic and imported fossil fuel resources, and imported electricity. The available domestic fuels supply was based on estimation scenarios of local natural gas and coal-mining industries. The imported fuel or electricity sources were estimated depending on their available supply and the country's financial resources. The electricity imports were estimated mainly from hydro generation sources that were negotiated and constructed in collaboration with neighboring countries such as China, Laos, and Cambodia. Vietnamese government agencies have also carried out an overall assessment of the feasibility of importing electricity and the potential purchasing prices from these sources (Institute of Energy, 2006a, 2006c, 2008b; Electricity of Vietnam, 2008b). In the model, electricity imports are simulated as different major hydro generation sources and a minor part of non-hydro generation sources with electricity prices varying from 4.3 to 4.9 $cent/kWh. In this study, price escalation is defined as the total annual rate of increase of a cost, including the effects of both inflation and real escalation. Table 4 displays the fuel prices with the escalations used in the model, in which we assumed that prices would increase between one to four percent per year, based on current price estimations by Electricity of Vietnam, 2008b; Institute of Vietnam, 2008b; and World Energy Outlook, 2006. These prices are reflective of the market levels observed in recent years. A discount rate of 10% is used for the study's present analysis, as recommended by the World Bank in an analysis of the technological selection in Vietnam (Institute of Energy, 2006a, 2006b, 2008b; Nguyen, Q. Khanh, 2007b).

3.3 Scenarios

To adapt to different scenarios of economic development over 2010-2030, the Vietnamese Government is considering policy alternatives for the development of the electricity generation industry such as: (i) focusing on improvements in energy efficiency and energy savings; (ii) utilizing economically efficient domestic energy resources; (iii) importing fuels (coal, gas) and electricity to produce electricity; (iv) promoting the research and development of renewable energies; and (v) developing nuclear power for electricity usage.

The favorably imported fuels option considers importation of natural gas (7.5 GW), coal, and electricity are imported to meet the expected future demand for electricity over 2010-2030. Table 7 assumes that the maximum available amount of fuels (domestic and imported) and electricity are imported over 2010-2030.

The nuclear option considers a 10 GW nuclear power generation capacity that could be developed by the country over 2020-2030 to replace the importation of natural gas (7.5 GW), coal, and electricity under scenario baseline.

The favorable renewable energy option, likewise, considers the available national renewable resources that could be used in an optimal situation to replace the importation. We assume that a wind power capacity of 22 GW (this capacity equals 20% of the total generation system capacity in the year 2030 plus 10% of additional wind capacity reserves) could be integrated into Vietnam's electricity network by 2030.

The DSM option examined in the study involves the replacement of incandescent light bulbs (IL) and fluorescent light bulbs (IL) with compact fluorescent and high efficiency fluorescent light bulbs in residential and service sectors (detailed data is given in Table 5). Additionally, the two energy efficiency options of replacing current air-conditioners with high efficiency air conditioners in the same sectors will be considered in the sensitivity analysis of the study (Table 6).

This study considers a baseline scenario, which was defined by assuming that today's national development plan is enacted. This provides an estimate of the expected total cumulative CO_2 emissions in Vietnam's power sector between 2010 and 2030. Under this scenario, fuels (coal, natural gas) and electricity are favorably imported to generate electricity, a few renewable energy sources are integrated, and no demand-side management (DSM) options are considered. Other scenarios were considered to be the most interesting to study: DSM only, DSM + nuclear, DSM + renewable energy, and a scenario of DSM + nuclear+renewable energy that allows all mitigation options can compete on a level playing field based on their merits regarding climate change mitigation.

The scenarios were otherwise identical in all other aspects. The same average load demand forecast, transmission and distribution loss, and electricity use were applied to all scenarios (see Table 2). A positive carbon value scheme ranging from 1 $/t$CO_2$ to 30 $/t$CO_2$ (all prices are based on 2007 $) was then imposed on these scenarios.

4. Results for the potential for mitigation of CO_2 at positive carbon values

4.1 The baseline scenario

This section describes the simulation results of the IRP model for our baseline scenario. This scenario involves an optimal selection of fuels and technologies used to expand electricity generation capacity in Vietnam, and an estimate of the total cumulative CO_2 emissions emitted by the sector between 2010 and 2030.

Electricity Planning

As demonstrated by simulations, the power sector in Vietnam will mainly rely on fossil fuels for the next twenty years. From 2010 to 2030, fossil fuels are expected to dominate the energy generation mix, and may account for 73.6% of the total cumulative electricity production of 7,383 TWh, in which coal, natural gas, and oil would account for 41.3%, 32%, and 0.3% of this production, respectively. Hydro and renewable energy would account for 18.6% and 4%, respectively, and the remaining 3.7% of electricity production would come from imports. Table 8 illustrates the evolution of the power sector and the fuel requirements for expanding the generation capacity from 2015 to 2030.

In the baseline scenario, from 2010 to 2030, the sector's huge capacity expansion requires an average growth rate in installed capacity of 7.3% to reach approximately 107.8 GW in 2030. The energy generation mix would change significantly by time period depending on the availability of generation resources. The proportion of generation accounted for by hydro resources would decrease from 27.8% in 2010 to 13.8% in 2030, whereas of the share produced using fossil fuel sources would increase drastically. In this case, the share of coal-fired generation (including domestic and imported) increases from 28.5% in 2010 to 60.7% in 2030. The proportion of generation contributed by natural gas (including domestic and imported) decreases from 37.2% in 2010 to 18% in 2030. This is because some of the gas-fired plants would be retired during the period from 2028-2030. Likewise, the proportion of generation by oil-fired plants would decrease from 1.1% in 2010 to 0.1% in 2030 because some of these plants would be retired after 2015. Under this baseline scenario, the proportion of energy generation from renewable energy is modest, decreasing from 5.1% in 2010 to 3% in 2030. Small hydro plants account for approximately 60% of this renewable energy production. While wind power is not cost-effective in the IRP model compared to the other generation options, it was introduced at a limited level (500 MW) in the baseline scenario during 2010-2030 in accordance with the official development plan from the Vietnamese government agencies. However, a decline share of renewable energy in a situation of fast electricity growth still implies absolute expansion of the contribution to supply of these technologies (Table 8).

As the demand for electricity over 2010-2030 exceeds the domestic sources, the country would need to import fuels (coal, natural gas) and electricity as early as 2010. The imported electricity would play an increasing role in the sector, increasing from 0.3% (0.45 TWh) of production in 2010 to 4.5% (26.9 TWh) in 2030. Imported coal fuel would account for 42.6% of the total coal consumption (24 232 PJ) for electricity generation between 2010 and 2030, increasing from 116 PJ in 2015 to 1134 PJ in 2030. Natural gas fuel, only imported after 2016 when the Southeast Asian interconnection pipeline system will become available, would account for 13.9% of the total gas consumption (370.5 billion m^3) for the same period. Imports of fuels for electricity generation will influence the country's balance of payments and cause a major drain on foreign exchange reserves.

Cost and Pricing

To expand the electricity generation industry in order to meet the electricity demand over 2010-2030, the country would need a total of 73.3 billion $. Of this investment, 21.8% will need to be invested in constructing new power generation plants, and 67.7% will be reserved for fuel, variable-operation and maintenance expenses, including importation costs. The remaining 10.5% will be required for fixed operation and maintenance expenses. The financing for this huge development plan would be expected to come from EVN's funds, Official Development Assistance (ODA) loans, Vietnam's Development Assistance Funds (DAF), service loans and foreign export credit, as well as IPP developers and private sectors.

In the IRP model, the electricity price in terms of the average incremental cost (*AIC*) and the long run average cost (*LRAC*) does not play an important role in calculating the optimal solution. These costs are calculated based on the optimal solution computed for the electricity generation capacity expansion plan.

The process used to calculate cash flow in the IRP model permits the long run average cost (LRAC) and average incremental cost (AIC) of electricity production in Vietnam to be computed over the period from 2010 to 2030. LRAC is calculated as 3.75 $cent/kWh, and the electricity pricing in terms of AIC would reach 4.41 $cent/kWh for the specified period.

Environmental Implications

The sector's dependence on burning fossil fuels could have a significantly negative effect on the country's emissions. Overall, the power sector could emit 3.6 Gt of CO_2 emissions into the atmosphere between 2010 and 2030. This represents a 14% annual growth in CO_2 emissions, reaching 357 Mt of CO_2 in 2030, or approximately 10 times the estimated 36 Mt of total CO_2 emissions emitted in 2006 (Nguyen and Tran, 2005). Therefore, the stabilization of atmospheric GHG emissions requires policies designed to achieve significant cuts in CO_2 emissions during the development stage. Moreover, the sector could become a large emitter of local pollutants, with emissions of up to 2.4 Mt of SO_2 and 5.5 Mt of NO_X.

4.2 Technical and economic implications of a positive carbon value

Before turning to CO_2 emissions, we first examine the implications of a positive carbon value for the electricity generation sector. Figure 1 depicts changes in the generation mix at different carbon values under the scenarios of renewable development with and without DSM. This shows that at higher carbon prices, more coal-fired plants would be replaced by low- or zero-carbon technologies such as supercritical and IGCC coal, NGCC gas, hydro, and renewable energy plants. Note that at 1 $/t$CO_2$ imposed on the baseline scenario, a few supercritical and IGCC coal-fired plants could substitute for some of the conventional coal-fired plants in the last years of the planning horizon (2028-2030), and from the level of 5 $/t$CO_2$ onwards, all candidate conventional plants would be replaced by these advanced efficiency technologies in all scenarios. Tables 9a and 9b present the IRP simulation results of changes in the optimal fuel selection (PJ) for electricity production over 2010-2030 at different carbon values in all considered scenarios, compared to the baseline scenario. Table 10 simulates the overall technical effects of introducing a positive carbon value scheme in the power sector over 2010-2030.

With no DSM considered, the total planning costs required in the nuclear development scenario would be less than those required in other scenarios at the same carbon prices. The fuel and variable cost, however, is lowest in the renewable development scenarios with or without DSM, except at the carbon price of 1 $/t$CO_2$. The interpretation of this result is that at a carbon price of 1 $/ t$CO_2$, wind power would not be cost-effective, yet the sector's generation mix would switch to less carbon-intensive fuel generation sources such as NGGC gas and IGCC imported coal. At carbon prices of more than 2 \$/tCO_2, however, more and more wind power, together with other renewable energy, would become cost-effective generation sources that contribute to lower fuel and variable costs.

The AIC would be lowest in the renewable development scenarios at the same carbon prices imposed, compared to the other scenarios. This is because most power plants based on renewable energy are simulated in the IRP model with a diversity of smaller capacity sizes. Thus, there were smaller total initial capital investments per plant unit compared to fossil fuels options, which have larger capacity sizes and higher total initial capital investment per plant unit. Therefore, renewable-based generation units would contribute to a lower the average incremental cost.

4.3 The potential for the abatement of CO_2 emissions in Vietnam's power sector

Table 12 summarizes the technical potential of mitigating CO_2 emissions in Vietnam's power sector between 2010 and 2030 for different scenarios. According to the model results, internalizing carbon values from 1 \$/tCO_2 to 30 \$/tCO_2 in the power sector's optimal expansion plan could reduce cumulative CO_2 emissions by 11% to 28.7% from the baseline scenario. Emissions reduction comes from the penetration of highly energy efficient thermal generation technologies (supply side) such as NGCC gas-fired, supercritical, and IGCC coal-fired technologies, as well as only a few renewable energy plants such as small hydro power plants.

The mitigation potential is between 22.7% and 41.6% in the DSM-only scenario. The difference from the previous scenario is a demand-side reduction potential on the order of 10% from end-use improvements in the energy efficiency of lighting.

Table 12 suggests that a large reduction in the carbon emissions of Vietnam's power sector is potentially achievable. Overall, 2 \$/tCO_2 leads to reductions of 0.77 Gt of CO_2 below the baseline CO_2 emissions, while 10 US/tCO_2 saves 1.4 Gt. Thus, significant CO_2 emissions reductions in Vietnam's power sector seem to be achievable at 10 \$/tCO_2. In today's economic conditions, some of the renewable-based grid connected generation sources, such as solar, wind, biomass wood, and small hydro (with no good hydrographic conditions) are not competitive in terms of cost when compared to fossil fuel options. These renewable energy sources could be expected to enter the generation portfolio if a carbon value was internalized.

Except for small hydro plants with good hydrographic conditions that are cost competitive to fossil fuels options already, some of others are economically simulated at 1 to 3 \$/tCO_2.

The Institute of Energy (2008a) argues that wood plantations could potentially become a competitive commercial fuel for electricity generation in Vietnam relative to fossil fuels, in the context of a shrinking fossil fuel supply and increasing environmental concerns. Our results support this suggestion. Wood residue appears to be cost-effective compared to fossil fuel options at 1 \$/tCO_2. Wood plantation, which has a higher assumed fuel price, has a cost of 2 \$/tCO_2. This carbon price is much lower than that recently observed in the international carbon emissions market. This suggests that more attention should be given to the possibility that developing wood plantations for electricity production in Vietnam could potentially benefit from funding opportunities through the Clean Development Mechanism (CDM). However, a more complete assessment of available land that could be utilized for such wood plantations is required to more precisely assess the electricity generation potential of this approach.

In contrast to other types of renewable energy, solar energy is never cost-effective under the selected model because the current technology cost of 5 500 \$/kW is too expensive, even with the climate change initiatives simulated in the IRP model. Nevertheless, solar power may become more affordable as a result of a more proactive climate change policies along with improvements to solar power technology.

5. Results on energy efficiency, nuclear and wind energy

5.1 Energy efficiency: the free lunch

Like other developing countries, energy efficiency improvements in Vietnam, have been considered to be high priorities in the development of sustainable energy strategies. The Energy Conservation and Efficiency (EC&E) program was initiated by the Government in 1996, and showed that the major opportunities in the short-term could provide savings of 15% and 35%-50% in the long-term (mainly in industry), including important opportunities for reducing the peak-load demand (Institute of Energy, 2004). The Institute of Energy (2008c) estimates that the energy conservation potential in the electricity sector is above 20%, including energy savings from lighting equipment and air-conditioning appliances. This analysis section examines the technical potential benefits of end-use energy efficiency improvements from DSM options listed in Table 5 and Table 6.

IRP simulations under the scenario of only DSM development suggest that by replacing incandescent and fluorescent light bulbs with compact fluorescent and high efficiency light bulbs in the household and service sectors, the country could cut down the sector's cumulative CO_2 emissions by 14.1% (over 3.6 Gt) and avoid 5.6% of total SO_2 and 5.5% of total NO_X emissions emitted during the 2010-2030 period. The CO_2 emissions reduction of 14.1% implies an average reduction of 24.3 Mt annually, which is a large fraction of about 36 Mt of CO_2 emissions emitted from the Vietnamese electricity sector in 2006. In other words, this reduction helps decrease the intensity of carbon emissions from the baseline value of 0.49 tCO_2/MWh to 0.45 tCO_2/MWh. Moreover, under this scenario the capacity of coal-fired plants would be reduced by improvements in end-use energy efficiency. As modeled here, they could help avoid 5.7 GW in coal-fired capacity installation by 2030, and could reduce electricity generation by 19.5% over 2010-2030.

Furthermore, the study simulates additional options for end-use energy efficiency improvements to be in place in Vietnam by replacement of existing air-conditioners with high efficiency air conditioners in residential and other sectors (see detailed technical descriptions in Table 6) between 2010 and 2030. As simulated results in Table 14, energy savings through the application of high efficiency lighting and air-conditioning appliances could potentially lessen the soaring electricity demand, reduce investments, and cut carbon emissions by 16.4% (over 3.6 Gt) over 2010-2030.

Particularly, IRP simulations suggest that improving energy efficiency on the demand side in Vietnam is a "no-regret" option. Financially, this would represent a "free lunch" for reductions in

CO_2 emissions. With this “free lunch” effect, the cost of abatement is negative, which is typical of technology-rich bottom-up models that include a broad array of technological options on the demand side. However, while substantial opportunities clearly exist for improving energy efficiency on the demand side in Vietnam, the “free lunch” has not been significantly internalized by the market. There are a number of key barriers that have prevented the development of meaningful impacts to date. These include: (i) inadequate information and skepticism, (ii) lack of technical expertise, (iii) high capital investment costs, (iv) high project development costs, (v) lack of affordable financing, (vi) poor customer creditworthiness, (vii) limited interest of end-users, (viii) limited local energy efficiency and high quality equipment, (ix) inadequate electricity tariffs, (x) a lack of supportive tax policies (World Bank, 2003; Institute of Energy, 2004; PREGA, 2005; Institute of Energy, 2008c).

5.2 Focus on nuclear energy and wind power

Table 13 summarizes the technical potential of mitigating CO_2 emissions for the two development scenarios with no DSM if the carbon prices vary from 1 $/t$CO_2$ to 30 $/t$CO_2$ in the 2010-2030. These results indicate that the cumulative CO_2 emissions could be reduced by 12%-35% (over 3.6 Gt) under the nuclear development scenario (with no DSM) compared to the baseline scenario while a lower reduction of 4%-33% is observed under a renewable development scenario (with no DSM), in which wind power contributes 23%-91% of the total reduction in emissions. The sector’s cumulative CO_2 emissions could even fall by 24%-46.4% in a nuclear development (with DSM) scenario as presented in Table 12. What is more, IRP simulation result suggests that a combined scenario of nuclear development with all other mitigation options (renewable energy and DSM options listed in Table 5 and Table 6 together) could potentially reach even about 23.7%-52% in reduction of cumulative CO_2 emissions (see Table 14).

Nuclear power has advantages given the increases in electricity demand, the insufficient domestic energy resources of electricity supply, the volatility in fossil fuel market prices, and the increasing threats of the effects of global climate change. However, there are also many limits associated with nuclear energy, such as risks of nuclear waste disposal, negative public perceptions. In a developing country such as Vietnam, the lower technological, technical and scientific capability, the weak industrial infrastructure and regulatory system, and the lack of human resources and professional specialists are important factors to take into account when considering the development of 10 GW nuclear power capacities within 20 years.

Figure 2 provides a graphical illustration of the technical potential for reduced CO_2 emissions under specified power sector development scenarios. As depicted, at carbon prices of less than 3 \$/tCO_2, the reduction in emissions under the renewable energy scenario (with no DSM) would be lower than that of the baseline scenario with the same carbon price level imposed. Similarly, the simulation results in a lower reduction for the renewable energy scenario (with DSM) compared with the DSM-only development scenario. This suggests that carbon prices of less than 3 \$/tCO_2 would provide less of an incentive to make wind power plants more cost-effective in Vietnam's power sector. The distribution of power generation sources at carbon prices of less than 3 \$/tCO_2 under the scenarios of renewable energy development (with or without DSM) would be dominated by coal-fired generating sources. This would result in higher CO_2 emissions compared to the baseline and DSM-only development scenarios, in which less carbon-intensive fuels (i.e., imported natural gas) were used for energy production. Note that imported natural gas was not considered in any of the scenarios different from baseline scenario. In other words, if the price of carbon emissions is higher than 3 \$/tCO_2, wind power technology would become more cost-competitive than natural gas options in Vietnam's power sector. This finding indicates that a significant portion of projects to integrate wind power into Vietnam's power sector could be funded by the Clean Development Mechanism (CDM).

Comparing the results for the development of wind power in Vietnam with those of Nguyen, Q. Khanh (2007b) and Nguyen and Ha-Duong (2009), this study highlights the great potential of wind energy generation in Vietnam to address increasing environmental concerns. Our IRP simulation finds that wind power, classified with various feed-in tariffs, could compete against other energy production scenarios over a range of different carbon prices. Simulated production costs at different carbon prices are as follows: 5 US cent/kWh (but with a limited quantity of generation) at 2 \$/tCO_2; 5.5 US cent/kWh at 3 \$/tCO_2; 6 US cent/kWh at 4 \$/tCO_2; and 6.5 US cent/kWh at 5 \$/tCO_2. This implies that the wind power has a great potential to be a cost-competitive source of energy in Vietnam's energy production portfolio under a policy that is supportive of climate change mitigation (i.e., electricity pricing that is reflective of the additional benefits of clean energy).

Given that the weighted average retail electricity tariff (excluding the 10% value added tax) in Vietnam was 5.2 US cent/kWh in 2007 (Electricity of Vietnam, 2008a) and that wind energy could be cost-competitive with fossil fuel options under this condition, why is wind energy not more widespread in Vietnam? The answer is that the single buyer in the market, Electricity of Vietnam (EVN), often runs the business by minimizing its expenditures on renewable energy projects. Moreover, there are no incentive schemes and no adequate policies on issues such as renewable portfolio standards or green electricity tariffs that are regulated by the government, which means that EVN is not able to treat wind energy projects any differently from fossil fuel projects.

5.3 The potential of CDM projects for Vietnam's power sector: an assessment

As of February, 2009, the Vietnamese Designated National Authority (DNA) had approved 78 CDM Project Design Documents (PDDs), of which only 44 projects have made it all the way through the domestic approval cycle since 1 August 2008. As estimated initially, these 44 projects would offer a total reduction of 31.6 Mt CO_2eq (CO_2 equivalent) over a 10-year period, and the country would gain 63 million \$/year between 2008 and 2012 by selling certified emission reductions (CERs) from these projects. CDM activity has increased in 2008 and early 2009 and many new CDM projects are being undertaken in Vietnam. However, Vietnam is still ranked at the lower end of countries in the Asian region in terms of the number of currently registered projects and in terms of the volume of CERs expected by 2012 due to various practical barriers (Nguyen et al, 2009). Up to April 2009, Vietnam had four CDM projects registered with the CDM Executive

Board (CDM EB): a large-scale gas flaring reduction project, a small-scale 2 MW hydropower project registered in 2006, a landfill gas project, and a wind power farm (30 MW) registered in early 2009. The emission reductions from these projects are estimated at approximately 887 KtCO_2eq per annum (UNFCCC, 2009).

According to local CDM consultants, Vietnamese CDM projects are recently fetching approximately 12€ (equal to 17 $ at exchange rate of 0.705 $/€) in the emissions reduction purchasing agreements. This paper considers the transaction costs and risk factors associated with completing a CDM project cycle as well as its commercial viability under the current price of 12€/ton CO_2 in the context of Vietnam. In addition, this paper attempts to explore the technical economic potential of CO_2 emissions reductions under mechanisms that could be technically produced at a plausible price of 5 $/t$CO_2$. IRP results show that at this carbon price, over 1 Gt of CO_2 could potentially be saved under the scenarios of energy efficiency development with nuclear energy or with renewable energy (Table 12) over the period from 2010 to 2030. This represents an average savings of 50 Mt of CO_2/year, representing 850 million $/year in estimated selling carbon value. Compared to the CDM potential estimated in the current pipeline for the 44 approved projects mentioned above, the IRP results suggest that the technical economic potential of CO_2 emissions reductions in the power sector alone could offer a high potential for sustainable development and could even achieve a 13-fold increase in emissions reduction under this system.

More specifically, compared to the indentified GHG emissions mitigation alternatives for the electricity sector in selected developing countries studied by ECN (2007; Table 15), the study's modeling results suggest that in the year 2010, the Vietnamese power sector could offer a range of GHG emissions reduction options. These options appear to be potentially competitive with energy options in other developing countries in terms of marginal abatement costs in the context of implementation of power projects under the CDM. However, proper policies and improvement measures need to be taken to remove the practical barriers to the deployment of CDM projects so that in the future, Vietnam can capitalize on its full CDM potential and can maximize its benefits from the mechanism.

6. Policy implications and conclusions

That the world economy surely has future constraints on CO_2 emissions because of the challenges of climate change is an increasing issue of great concern recently in developing countries, which currently contribute a little more to the world CO_2 emissions but can become large future polluters due to economic growth and the dramatically expected increases in CO_2 emissions that will get them into a riskier-CO_2 situation if proper actions are not taken seriously to switch to cleaner energy sources. In this respect, Vietnam is a country having experienced unprecedented economic growth and sharp electricity growth rates, and unplentiful native fossil fuel sources, and is becoming an increasingly dependent country on imported energy. Besides, the country seems to be highly vulnerable to severe climate change effects, which can be expected from sea-level rise, flood damage, drought and landslides.

Using the expanded Integrated Resource Planning model, this article gives a more realistic overview and a more reliable assessment of the current state and the future prospects evolution of Vietnamese energy sector. IRP simulation result shows that without a price on carbon emissions, fossil fuels will likely dominate the energy generation mix in Vietnam. Coal is expected to dominate the overall energy generation at 41.3%, while renewable energy would account for only 4%. This could affect the country's CO_2 emissions inventory, currently projected to have an annual growth rate of 14% over 2010-2030, reaching approximately 357 Mt in 2030.

Mainly it draws out policy challenges of developing countries in a future world with constraints on CO_2 emissions and permits to create new insights about what it is possible to do a better balance between expansion of Vietnamese power sector and environmental protection. There are many cleaner technological solutions available which could help to overcome the challenging global problem of climate change and its detrimental local consequences.

IRP results suggest technical improvements on the demand side could offer negative or very low cost reductions in carbon emissions in Vietnam. Energy efficiency improvements (such as more efficient lighting in households and services) could potentially cut down the sector's cumulative emissions by 14.1% (over 3.6 Gt in the baseline scenario) of CO_2, 5.6% (over 2.6 Mt) of SO_2, and 5.5% (over 5.9 Mt) of NO_X during the 2010-2030 planning period. Looking at several countries in the region such as Australia and the Philippines, we observe that they are already taking steps to phase out incandescent light bulbs. Therefore, Vietnamese authorized agencies need to take proper measures and necessary mechanisms to eliminate the key barriers to the DSM improvements in order to get more fully co-benefits including mitigating or controlling the growth of country CO_2 emissions and environmental effects from the energy efficiency.

Particularly, the article explores the technical potential of CO_2 emissions abatement in Vietnam's power sector over the period from 2010 to 2030, for different combined policy options (DSM, nuclear energy, renewable energy) and for carbon values from 0 to 30 $/t$CO_2$.

To develop a 10 GW nuclear capacity for the next 20 years could help meet the challenges of the increases in electricity need, the scarce domestic energy resources for electricity generation, and the increasing threats of the effects of global climate change in which developing 10 GW nuclear capacities in a scenario with DSM could potentially reduce the sector's cumulative CO_2 emissions by 24%-46.4% (over 3.6 Gt) if the carbon prices vary from 1 $/t$CO_2$ to 30 $/t$CO_2$. However, the country still has a lot of essential works need to be taken for such an ambitious nuclear power development plan.

Though renewable energy still takes a very minor contribution in terms of energy generation and capacity to a situation of fast electricity growth and limited native fossil fuel resources in Vietnam, it could take an increasingly important role for the future prospects of constraints on CO_{2eq} emissions in the world economy. Specifically, developing renewable energy for Vietnamese power sector could potentially help get the country off a riskier CO_2 situation and detrimental health and environmental effects locally.

To develop renewable energy in a scenario with no DSM could potentially reduce the energy sector's cumulative CO_2 emissions by 4%-33%, and avoid 1%-71% of total SO_2 and 9%-26% of total NO_X emissions emitted over the 2010-2030 period if carbon prices vary from 1 $/tCO_2$ to 30 $/tCO_2$. The reduction of CO_2 emissions could be more significant, reaching approximately 46.5% if energy efficiency improvements are included in a scenario of renewable development with DSM.

The Vietnamese power sector could have a great potential for Clean Development Mechanism (CDM) funding. At relatively low carbon prices (or marginal abatement costs), there are several options for CDM projects: wood residue is economical at 1 $/tCO_2$, wood plantation is economical at 2 $/tCO_2$, and wind power is economical at 3 $/tCO_2$. For small hydro energy, some of small hydro plants with good hydrographic conditions are already cost competitive (or at 0 $/tCO_2$) to fossil fuels options in Vietnam while others are only economical at 1 to 3 $/tCO_2$. In terms of marginal abatement costs, many renewable energy projects in the power sector that would be competitive with energy projects in other developing countries would be possible under the CDM system at the conceivable price of 5 $/tCO_2$.

Together with small hydro energy, Vietnam has an ample source of wind power that could make an important contribution to highlight in a country like Vietnam the significant potential for mitigation of CO_2 emissions. IRP simulation result indicate that wind power accounts for 23%-91% of the total CO_2 emissions reduction potential from the scenarios of renewable energy development and wind turbine is a more cost effective technology for CO_2 emissions mitigation implementation in Vietnam than other conventional technologies at a carbon price of above 3 $/tCO_2$. This implies for effective investment in wind turbine could be implemented in Vietnam under the current CDM or other like-CDM mechanism in the future, if any.

Atmospheric releases of CO_2 emissions by Vietnam's power sector are not inevitable, but rather are a consequence of choosing fossil fuel-based electric power generation. There are many cleaner technological solutions available which could help to overcome the challenging global problem of climate change and its detrimental local consequences.

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Figures and Tables

Table 1: Assessment of the potential for renewable energy electricity production in Vietnam

Energy resources	Economical potential	Future development planned up to 2025 by Vietnamese agencies	Maximum potential simulated to 2030 in the IRP model	Reference sources
Hydro		84 TWh/yr (1)		Electricity of Vietnam, 2006a, 2006b, 2008a; Institute of Energy, 2006a, 2006b, 2008a, 2008b; Nguyen Khac, 2007.
+ Large hydro (>30 MW)	18-20 GW	16.6 GW by 2020	18 GW	
+ Small hydro (<30 MW)	4 GW	2.5-3.2 GW	4 GW	
+ Mini hydro (<1 MW)	100 MW			
Hydro pump storage	10.2 GW	10.2 GW	10.2 GW	
Geothermal	1.4 GW (2)	400(3) MW by 2020	400 MW (3)	Hoang, H. Quy, 1998; Hoang and Ho, 2000; Institute of Energy, 2006a, 2006c, 2008a, 2008b.
Wind energy	120.5 GW	500 MW	22 GW (5)	TrueWind, 2001; Nguyen, Q. Khanh 2007a; Institute of Energy, 2006a, 2006c, 2008a, 2008b.
Solar energy	1 GW (4)	2-3 MW	1 GW (4)	Institute of Energy, 2006a, 2006c, 2008a, 2008b.
Rice husk	250 MW	500 MW	250 MW	Nguyen L.T, and Q.C. Tran 2004; Enerteam 2001; BCSE, 2005; Institute of Energy, 2006a, 2006c, 2008a, 2008b.
Paddy straw	550 MW		550 MW	
Bagasse	200 MW		200 MW	
Wood residue	100 MW		100 MW	
Wood plantation (6)	Available (6)	Not defined (6)	Not defined (6)	Institute of Energy, 2008a; MARD, 2000

(1) This economic potential consists of large, medium, small, and mini hydro energy; (2) This economical potential is estimated for both electricity generation and heating usage up to 2020. (3) This part of the total economic potential is determined for electricity generation up to 2020 by Vietnamese authorities. (4) This economical potential is assumed to be the input potential in the IRP model.

(5) The economic potential of wind energy in Vietnam is estimated with different feed-in tariffs varying from 5-8 $cent/kWh. Due to the intermittent nature of wind energy, it is a common technical assumption that only 20% of total generation system capacity installed could be realistically integrated by wind capacity before 2020 (Hannele Holttinen et al., 2006). Thus, 22 GW of wind capacity, equivalent to 20% of total generation system installed capacity in Vietnam in 2030, plus 10% of any additional wind capacity on reserve, is assumed to be the maximum wind energy that could feasibly be developed for the production of electricity after 2010-2030 in the IRP model.

(6) Wood plantations have the potential to produce electricity, but this means of energy production has not yet been officially assessed by Government agencies. Thus, in this study, the potential of wood plantation is not included as a generation source in the base analyses. However, the price of the wood plantation is used for a sensitivity analysis of its cost-competitiveness for electricity generation, and is favorable compared to fossil fuel options.

Table 2: Estimated electricity demand under different scenarios for the 2010-2030 period. The same transmission and distribution loss (%) and proportion of electricity used (%) were applied in all scenarios.

Items	Scenario	2010	2015	2020	2025	2030
Peak load demand (MW)	Average	18947	31037	46696	68416	83165
Peak load demand (MW)	High	19730	32430	48570	70790	86620
Peak load demand (MW)	Low	17940	27639	39286	55376	68473
Transmission and distribution loss (%)	Common	10.8	9.6	8.5	7.5	7.5
Used electricity (%)	Common	3.0	3.6	4.0	4.2	4.3

Source: Institute of Energy (2006a, 2006b, 2006c); Electricity of Vietnam (2006a, 2008a).

Table 3: Characteristics of selected candidate technologies.

Candidate plants	Capital cost ($/kW)	Efficiency (%)	Fixed O&M cost ($/kW.month)	Variable O&M cost ($/MWh)	Emission factor (kg CO_2/MWh)
Conventional coal	1100	40	2.8	0.15	880
Supercritical coal	1200	43	2.8	0.15	800
IGCC coal	1300	45	3.55	0.15	704
NGCC gas	700	54.63	1.98	0.99	370
Steam Oil	900	43.57	1.63	1.48	730
Solar grid connected	5500	100	2.5	0	0
Wind turbine	1000-1300	100	1.35	0	0
Geothermal	1700-2000	100	2.38	0	0
Very large hydro	1120	100	0.54	0	0
Medium and large hydro	1100 – 1500	100	0.76	0	0
Small and mini hydro	1200 – 1600	100	1.5	0	0
Bagasse direct combustion	850	23	3.58	5	71.64
Biomass IGCC	1600	38.30	3.75	2.9	71.64
Wood IGCC	1600	38.30	3.75	2.9	71.64
Nuclear	2300	34	5.84	5	0

Source: Institute of Energy (2008a, 2008b; 2006a, 2006b); Electricity of Vietnam (2008b).

Table 4: Fuel prices (based on the 2007 price) assumed in the different scenarios in the study.

Fuel type	**Scenario analysis**	
	Fuel prices ($/Gcal)	**Escalation rate (%)**
Domestic coal (Anthracite)	7.14	1.5
Imported coal (Bitum)	7.69	1
Imported FO	58.76	4
Imported DO	61.59	4
Domestic natural gas	15.87	3
Imported natural gas	18.25	3
Bagasse	0.391[4]	1.5
Rice husk	0.71	1.5
Paddy Straw	0.625	1.5
Wood residue	1.94[5] and 4.4[6]	1.5
Nuclear	1.19	1.5

Source: Institute of Energy (2008a, 2008b; 2006a, 2006b, 2006c); Electricity of Vietnam, 2008b.

Table 5: Technical details and costs of existing and energy efficient light bulbs.

Existing equipment to be replaced				Energy efficient equipment			
Sector/type of appliance	Ratings (Watt)	Cost ($)	Life	Type of appliance	Ratings (Watt)	Cost ($)	Life
Residential & Service							
DSM1	40	0.5	1500	CFL	9	6.75	10000
DSM2	60	0.55	1200	CFL	13	6.75	12000
DSM3	75	0.55	800	CFL	18	7.65	12000
DSM4	100	0.6	800	CFL	27	8.10	10000
DSM5-Fluorescent	40	1.5	8000	FEF	36	2.26	12000

Note: CLF: Compact Fluorescent Light bulb; EFL: Efficient Fluorescent Light bulb. Source: Institute of Energy Institute of Energy (2006c, 2008c), Electricity of Vietnam (2006a, 2008a).

Table 6: Technical details and costs of existing and energy efficient air-conditioners,

Existing equipment to be replaced				Energy efficient equipment			
Sector/type of appliances	Ratings (Watt)	Cost ($)	Life	Type of appliance	Ratings (Watt)	Cost ($)	Life
Residential & Service							
9000 BTU	950	319	10 years	EEAC	750	500	10 years
12000 BTU	1300	430	10 years	EEAC	1050	650	10 years

Source: Institute of Energy (2006c, 2008c), Electricity of Vietnam (2006a, 2008a).

[4] This price is assumed for co-generation plants where the plants are identified by the baggage supply sources.
[5] This price does not take into account the costs of land usage and plantation processes used for the wood residue itself.
[6] This price takes into account the costs of land use and plantation processes. This market price is only used for sensitivity analysis of the cost-competitiveness of wood plantations compared to fossil fuel options.

Table 7: Fuels (domestic and imported) and electricity imports required to meet electricity demand in Vietnam during the 2010-2030 period. Simulations were conducted using the IRP model (expressed in units/year).

Fuel/electricity imported	Maximum quantity (unit/year)
Domestic Coal (million tons)	no limitation
Domestic Gas (billion m^3)	20
Imported Coal (million tons)	32
Imported Gas (billion m^3)	9
Imported Electricity (TWh)	30

Source: Institute of Energy (2006a, 2006b, 2006c, 2008b); Electricity of Vietnam (2006a, 2008a).

Table 8: Future capacity development, electricity generation production, and fuel required to expand the Vietnam power sector in the 2010-2030 period. Numbers are produced from the baseline scenario and the IRP model.

Year	Renewable sources			Fossil fuel sources					Imports
	Wind	**Other renewable**	**Hydro**	**Domestic Coal**	**Imported Coal**	**Domestic Gas**	**Imported Gas**	**Oil**	
				Future generation capacity installed (MW)					
2010	50	1429	9609	5694	0	6969	0	1736	770
2015	200	2219	14217	8534	2400	10719	0	1538	1787
2020	350	3052	14217	8094	7200	14469	7500	975	5356
2025	500	3194	14767	8094	21600	16930	7500	975	5356
2030	500	3194	14608	27894	24000	13950	7500	600	5356
				Future electricity generation (GWh)					
2010	130.2	6714	37510	38453	0	50207	0	1533	447
2015	520.9	10539	55201	58629	17107	78850	0	1357	447
2020	911.5	16073	59459	55926	51322	107492	16700	858	10768
2025	1302.1	16645	62260	55926	153965	129064	26382	858	26860
2030	1302.1	16645	61447	193940	171072	101717	6570	526	26860
				Fuels requirement (PJ)					
2010	-	-	-	367	0	346	0	16	-
2015	-	-	-	546	116	534	0	14	-
2020	-	-	-	517	348	723	110	8	-
2025	-	-	-	517	1023	862	110	8	-
2030	-	-	-	1774	1134	675	43	4	-

Table 9: Changes in fuel requirements in the Vietnam power sector at different carbon values over the 2010-2030 period relative to the baseline period.

Scenarios		Carbon value ($/tCO2)	Domestic coal			Imported coal			Domestic gas			Imported gas			Oil		
			2015	2020	2030	2015	2020	2030	2015	2020	2030	2015	2020	2030	2015	2020	2030
No DSM	Baseline	1	-193.8	-193.8	-1308.8	0	-159.6	512.9	37.7	0.0	33.4	0	168.5	315.8	0	0	0
		5	-230.4	-226.3	-1475.4	-116	-333.6	593.0	113.2	151.0	33.4	0	154.8	324.8	0	0	0
		10	-477.0	-438.1	-1484.0	-116	-348.1	574.5	277.2	188.7	33.4	0	267.4	334.2	0	0	0
		20	-500.8	-462.1	-1446.5	-116	-348.1	538.9	288.4	212.4	33.4	0	267.4	334.2	0	0	0
	Nuclear	1	-193.8	-193.8	-1308.8	0	137.1	419.7	37.7	0.0	6.1	0	0	0	0	0	0
		5	-243.3	-269.8	-1493.9	-116	-89.4	537.0	113.2	109.3	-17.2	0	0	0	0	0	0
		10	-488.8	-360.3	-1503.9	-116	-119.6	477.0	277.2	188.7	33.4	0	0	0	0	0	0
		20	-499.6	-377.7	-1522.4	-116	-124.3	483.6	287.9	212.4	33.4	0	0	0	0	0	0
	Renewable energy	1	-193.8	-193.8	-908.6	0	166.2	512.9	37.7	0.0	19.3	0	0	0	0	0	0
		5	-277.6	-236.4	-1431.5	-116	-174.1	565.3	113.2	146.3	-24.0	0	0	0	0	0	0
		10	-500.8	-360.5	-1478.5	-116	-142.9	475.6	253.8	188.7	33.4	0	0	0	0	0	0
		20	-500.8	-344.8	-1497.6	-116	-170.9	483.6	253.8	212.4	33.4	0	0	0	0	0	0

Scenarios		Carbon value ($/tCO2)	Domestic coal			Imported coal			Domestic gas			Imported gas			Oil		
			2015	2020	2030	2015	2020	2030	2015	2020	2030	2015	2020	2030	2015	2020	2030
With DSM	DSM only	1	-177.9	-177.9	-1413.7	-29.0	-261.1	373.0	-37.7	-37.7	-4.4	0	210.1	319.6	0	0	0
		5	-222.7	-226.3	-1475.4	-116.0	-324.8	402.1	37.7	37.7	33.4	0	189.8	270.0	0	0	0
		10	-500.8	-372.0	-1488.2	-116.0	-348.1	324.0	217.0	75.5	33.4	0	267.4	334.2	0	0	0
		20	-500.8	-395.4	-1485.9	-116.0	-348.1	317.4	219.8	99.2	33.4	0	267.4	334.2	0	0	0
	Nuclear	1	-158.8	-158.8	-1379.9	0	39.6	307.8	-37.7	-37.7	-81.7	0	0	0	0	0	0
		5	-267.0	-249.6	-1462.7	-116.0	-145.1	220.2	75.5	146.3	33.4	0	0	0	0	0	0
		10	-500.8	-321.8	-1487.3	-116.0	-152.3	213.2	226.2	188.7	33.4	0	0	0	0	0	0
		20	-500.8	-337.0	-1527.1	-116.0	-156.9	234.3	229.6	212.4	33.4	0	0	0	0	0	0
	Renewable energy	1	-177.9	-162.0	-1165.9	-29.0	55.4	471.0	-37.7	-37.7	-8.8	0	0	0	0	0	0
		5	-229.6	-206.2	-1455.7	-116.0	-275.6	290.2	0.0	146.3	16.3	0	0	0	0	0	0
		10	-481.1	-297.1	-1525.9	-116.0	-263.7	255.4	164.0	188.7	33.4	0	0	0	0	0	0
		20	-500.8	-341.7	-1502.3	-116.0	-250.2	234.3	172.9	212.4	33.4	0	0	0	0	0	0

Table 10: Technical implications of a positive carbon value in the Vietnam electricity sector from IRP simulations over the 2010-2030 period.

Scenarios	**Technical effects**	**Carbon value ($/tCO$_2$)**					
		0	**1**	**5**	**10**	**20**	**30**
Baseline	Total capacity added (MW)	82307	75122	75011	75011	75411	75411
	Conventional thermal efficiency (%)	48.6	50.6	51.4	53.5	53.6	53.7
	Average capacity factor (%)	62.40	63.98	64.12	62.96	62.82	62.55
DSM only	Total capacity added (MW)	77857	69775	70911	69611	69611	70211
	Conventional thermal efficiency (%)	49.5	50.3	51.1	53.2	53.3	53.7
	Average capacity factor (%)	62.69	64.35	63.95	62.74	62.56	62.11
Nuclear with DSM	Total capacity added (MW)	-	71503	69511	69711	70311	70311
	Conventional thermal efficiency (%)	-	49.8	50.8	52.8	52.9	53.6
	Average capacity factor (%)	-	64.05	63.85	63.09	62.99	62.14
Renewable energy with DSM	Total capacity added (MW)	-	71338	83074	84874	84574	85174
	Conventional thermal efficiency (%)	-	49.9	50.6	52.6	52.8	53.6
	Average capacity factor (%)	-	63.88	62.59	61.6	61.36	60.36
Nuclear, no DSM	Total capacity added (MW)	-	75675	76311	75411	75711	75711
	Conventional thermal efficiency (%)	-	50.4	51.1	53.0	53.0	53.8
	Average capacity factor (%)	-	63.70	63.78	63.38	63.32	61.95
Renewable energy, no DSM	Total capacity added (MW)	-	76738	88980	89674	89974	90574
	Conventional thermal efficiency (%)	-	49.9	51.0	53.0	53.0	53.7
	Average capacity factor (%)	-	63.45	62.64	61.7	61.76	60.97

Table 11: Economic implications of a positive carbon value in the Vietnam electricity sector produced from IRP simulations in the 2010-2030 period.

Scenarios	**Economical effects**	**Carbon value ($/tCO$_2$)**					
		0	**1**	**5**	**10**	**20**	**30**
Baseline	Fuel & variable cost (billions $)	49.6	51.1	52.6	54.5	54.7	54.7
	AIC (US cent/kWh)	4.41	4.47	4.53	4.62	4.64	4.66
DSM only	Fuel & variable cost (billions $)	-	49.3	50.45	52.3	52.5	52.4
	AIC (US cent/kWh)	-	4.46	4.41	4.55	4.59	4.61
Nuclear development (with DSM)	Fuel & variable cost (billions $)	-	45.4	46.9	48.3	48.31	48.2
	AIC (US cent/kWh)	-	4.27	4.26	4.34	4.36	4.42
Renewable energy (with DSM)	Fuel & variable cost (billions $)	-	45.7	45.9	47	47.03	47.0
	AIC (US cent/kWh)	-	4.17	4.02	4.05	4.09	4.16
Nuclear development (no DSM)	Fuel & variable cost (billions $)	-	46.8	48.2	49.8	49.9	49.7
	AIC (US cent/kWh)	-	4.31	4.39	4.42	4.43	4.56
Renewable energy (no DSM)	Fuel & variable cost (billions $)	-	47.3	47.9	49.1	49.2	49.1
	AIC (US cent/kWh)	-	4.22	4.14	4.13	4.14	4.21

Table 12: The technical potential of mitigating CO_2 emissions in the following scenarios: the baseline and in three scenarios with DSM in the 2010-2030 period. Simulations of Vietnam's power sector were carried out using the IRP model.

Cases	Emissions	Carbon value ($/tCO$_2$)						
		0	1	2	5	10	20	30
Baseline	**Total CO_2 emissions (Mton)**	**3621.3**	**3221.3**	**3209.8**	**2931.7**	**2599.1**	**2586.0**	**2580.3**
	CO_2 emissions avoided (Mton)	-	400.0	411.5	689.7	1022.3	1035.4	1041.0
	CO_2 emissions avoided (%)	-	11.0	11.4	19.0	28.2	28.6	28.7
	Total SO_2 emissions (Kton)	2563.0	2397.8	2353.0	1742.1	838.2	782.7	726.0
	Total NO_x emissions (Kton)	5869.6	5827.0	5677.1	5557.8	5469.1	5471.0	5451.5
	CO_2 intensity (tCO_2/MWh)	0.49	0.44	0.44	0.40	0.36	0.35	0.35
DSM only	**Total CO_2 emissions (Mton)**	**3110.2**	**2916.2**	**2889.2**	**2684.5**	**2359.0**	**2340.8**	**2328.8**
	CO_2 emissions avoided (Mton)	511.1	705.1	732.1	936.8	1262.3	1280.5	1292.5
	CO_2 emissions avoided (%)	14.1	22.7	23.5	30.1	40.6	41.2	41.6
	Total SO_2 emissions (Kton)	2420.3	2322.9	2270.4	1736.0	849.8	801.0	659.0
	Total NO_x emissions (Kton)	5546.5	5603.5	5517.4	5323.4	5237.7	5240.9	5184.3
	CO_2 intensity (tCO_2/MWh)	0.45	0.42	0.42	0.39	0.34	0.34	0.34
Nuclear development + DSM	**Total CO_2 emissions (Mton)**	**-**	**2871.7**	**2847.5**	**2534.4**	**2209.7**	**2196.1**	**2177.1**
	CO_2 emissions avoided (Mton)	-	749.7	773.8	1086.9	1411.6	1425.2	1444.2
	CO_2 emissions avoided (%)	-	24.1	24.9	34.9	45.4	45.8	46.4
	Total SO_2 emissions (Kton)	-	2387.1	2342.4	1706.0	922.5	883.0	671.5
	Total NO_x emissions (Kton)	-	4776.1	4653.9	4502.2	4272.7	4271.5	4188.7
	CO_2 intensity (tCO_2/MWh)	-	0.41	0.41	0.36	0.32	0.31	0.31
Renewable energy +DSM	**Total CO_2 emissions (Mton)**	**-**	**3167.2**	**3058.1**	**2532.8**	**2218.8**	**2201.1**	**2174.9**
	CO_2 emissions avoided (Mton)	-	454.1	563.2	1088.5	1402.5	1420.2	1446.5
	CO_2 emissions avoided (%)	-	14.6	18.1	35.0	45.1	45.7	46.5
	Total SO_2 emissions (Kton)	-	2455.2	2369.1	1674.1	989.1	945.2	669.7
	Total NO_x emissions (Kton)	-	4970.8	4761.6	4488.6	4267.7	4265.7	4151.3
	CO_2 intensity (tCO_2/MWh)	-	0.45	0.44	0.37	0.32	0.32	0.31

Table 13: The technical potential of mitigating CO_2 emissions under the scenarios with no DSM in the 2010-2030 period. Simulations of Vietnam's power sector were carried out using the IRP.

Cases	Emissions	Carbon value ($/tCO$_2$)						
		0	1	2	5	10	20	30
Nuclear development (no DSM)	**Total CO_2 emissions (Mton)**	**-**	**3173.9**	**2963.8**	**2703.2**	**2383.4**	**2375.8**	**2351.6**
	CO_2 emissions avoided (Mton)	-	447.4	657.6	918.2	1237.9	1245.5	1269.7
	CO_2 emissions avoided (%)	-	12.4	18.2	25.4	34.2	34.4	35.1
	Total SO_2 emissions (Kton)	-	2462.3	2382.1	1723.1	948.7	917.1	656.8
	Total NO_x emissions (Kton)	-	5105.0	4829.2	4568.7	4418.8	4417.1	4315.5
	CO_2 intensity (tCO_2/MWh)	-	0.43	0.40	0.37	0.33	0.33	0.32
Renewable energy (no DSM)	**Total CO_2 emissions (Mton)**	**-**	**3482.5**	**3360.6**	**2804.0**	**2478.3**	**2474.2**	**2452.3**
	CO_2 emissions avoided (Mton)	-	138.8	260.8	817.3	1143.0	1147.2	1169.1
	CO_2 emissions avoided (%)	-	3.8	7.2	22.6	31.6	31.7	32.3
	Total SO_2 emissions (Kton)	-	2537.7	2427.0	1673.7	993.6	987.8	746.9
	Total NO_x emissions (Kton)	-	5331.0	5113.2	4655.3	4452.8	4457.8	4362.4
	CO_2 intensity (tCO_2/MWh)	-	0.47	0.46	0.38	0.34	0.34	0.34

Table 14: The technical potential of mitigating CO_2 emissions using additional DSM with high efficiency air-conditioners and all mitigation options scenarios. Simulations of Vietnam's power sector were carried out using the IRP.

Case	Emissions	Carbon value ($/tCO$_2$)						
		0	1	2	5	10	20	30
Additional DSM	**Total CO_2 emissions (Mton)**	**3110.2**	-	-	-	-	-	-
	CO_2 emissions avoided (Mton)	511.1	-	-	-	-	-	-
	CO_2 emissions avoided (%)	16.4	-	-	-	-	-	-
All mitigation options	**Total CO_2 emissions (Mton)**	-	2763.1	2637.8	2129.8	1764.3	1759.3	1742.7
	CO_2 emissions avoided (Mton)	-	858.2	983.5	1491.6	1857.0	1862.1	1878.7
	CO_2 emissions avoided (%)	-	23.7	27.2	41.2	51.3	51.4	51.9

Table 15: Options identified for reducing GHG emissions in the electricity sector in selected developing countries in 2010.

Electricity sector	National potential [Mt CO_2eq/yr]	Country study's abatement costs [$/tCO$_2$eq]
China		
CFBC (Circulating Fluidized bed combustion)	0.5	-2.0
Renovation & reconstruction of conventional plants	13.9	2.9
Supercritical coal	2.5	5.4
Hydro power	20.7	20.0
Natural gas	0.4	22.1
Scrap & Build (modify smaller coal power plants)	35.6	8.3
Modification option (modify larger coal power plants)	9.2	28.3
IGCC & other advanced conventional technologies	1.3	28.8
Biogas and other biomass energy	9.2	35.2
Wind energy (Grid In)	2.6	36.8
Wind Power	0.5	57.4
Fuel-switching (Coal to Natural gas)	45.6	61.5
Total identified potential	**142.6**	-
India		
Demand-side energy efficiency	132	2.7
Supply-side energy efficiency	94	1.8
Renewable electricity technologies	68	2.7
Fuel switching (gas for coal)	24	3.6
Total identified potential	**318**	-
Brazil		
Electricity conservation	35.9	-74.3
Natural gas	5.2	-11.2
Wind energy	7.0	4.3
Ethanol with electricity cogeneration	16.9	5.7
Total identified potential	**65**	-
Other East Asian countries		
Energy conservation (Indonesia)	7.0	-60.8
Co-generation (Pakistan)	5.3	-27.4
Fuel switch from coal to natural gas (Thailand)	3.0	2.0
Substitution of oil & coal with natural gas (Pakistan)	11.9	2.6
Natural gas combined cycle gas turbine (Philippines)	1.8	2.6
BIGCC (Thailand)	6.7	3.2
Further fuel switching for power generation (Thailand)	3.0	9.3
Solar energy (Indonesia)	1.4	16.6
Geothermal (Indonesia)	7.6	30.8
Biomass steam power plant (Indonesia)	1.3	45.3
Wind (Pakistan)	3.3	62.2

Source: ECN, 2007.

Figure 1. The shift in the mix of power generation sources with increasing carbon values produced using IRP model simulations. The top panel does not use DSM, while the bottom panel uses DSM.

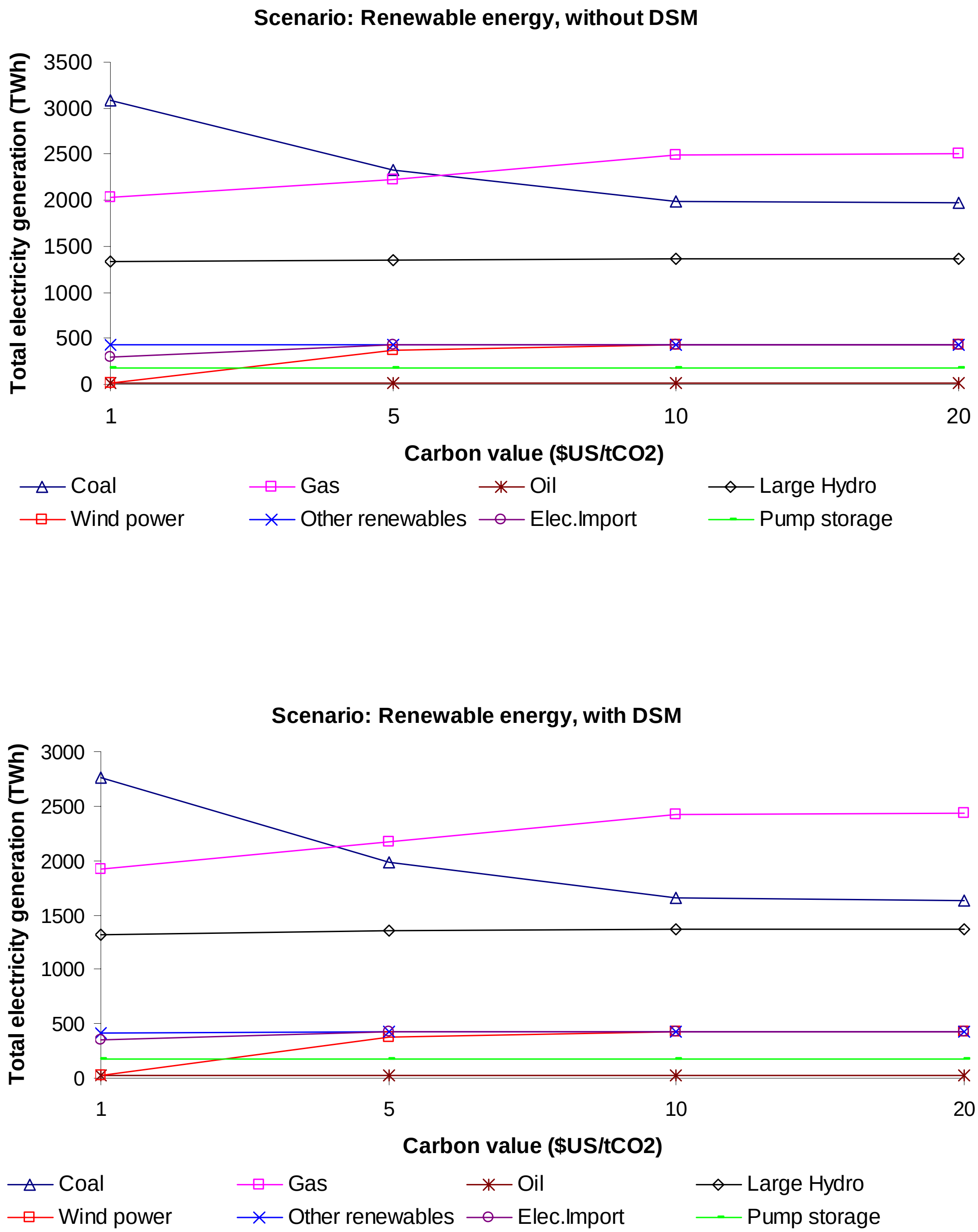

Figure 2. Assessment of the results of the CO_2 emissions mitigation potential using various scenarios of development for Vietnam's power sector in the 2010-2030 period.