Integrated Resource Planning with Carbon Tax: Effects on Power Generation Expansion Planning in Vietnam

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Abstract

This paper examines the supply-side and demand-side effects of carbon tax on power generation expansion planning and CO_2 emissions from the power sector in Vietnam by using a least cost model named Wien Automatic System Planning (WASP) [1]. The electric utility planning is carried out with both traditional resource-planning and integrated resource-planning approaches. In the context of integrated resource planning, the demand side is considered with a replacement of standard lamps by high efficiency lamps. The CO_2 emission is calculated by interfuel and emission factors provided by the Intergovernmental Panel on Climate Change (IPCC). Recently, demand-side management has high potential in Vietnam and plays an important role in the power generation expansion planning. In the case of Vietnam, this study finds that carbon tax would remarkably reduce CO_2 emission at a tax level of US$ 50 per ton of carbon and higher due to a shift from coal to gas and nuclear called the substitution effect. The low carbon tax levels would not much reduce CO_2 emission. The demand-side effect is not considerable due to a low price elasticity of electricity demand in Vietnam.

Keywords: Traditional resource planning; integrated resource planning; demand-side management, CO_2 emission; carbon tax.

1. Introduction

With the rehabilitation of the economy and development of the industrial sector, the Electricity of Vietnam (EVN) is facing how to serve this guickly growing electricity demand. Therefore, power planning must be studied thoroughly to solve this problem. Until recently, all investment efforts were concentrated on the expansion of the electricity generating capacity. However, experiences of other countries show that managing the demand side is also a good way to make the electricity supply meet the electricity demand [2]. The concept of integrated resource planning appears to give a very good way to treat the power system by considering both supply side and demand side [3].

Moreover, carbon dioxide emissions from power plants should receive more attention. Fossil fuels that cause very high pollution due to CO_2 emissions are the main resource of the electricity generation in Vietnam. To reduce CO_2 emission, there are two basic elements: increasing energy efficiency and replacing non-renewable energy sources with renewables [4]. In terms of technology, it can be done by improving energy efficiency and developing the technology using renewable energies. In terms of policy, this kind of effort can be promoted by creating economic incentives for increasing energy efficiency and using renewable energy sources. From the second point of view, Baranzini (1999) said that carbon taxes have been frequently advocated as a cost-effective instrument for reducing emissions [5]. Carbon tax could affect carbon dioxide emissions through both supply- and demand-side responses. The supply-side response takes place in the form of interfuel and technological substitutions in power generation. The demand-side response occurs in the form of reductions in electricity demand due to an increase in electricity price with the introduction of carbon tax [6].

This study carries out the power generation expansion planning in Vietnam with an integrated resource planning perspective and examines the supply-side and demand-side effects of carbon tax on the power generation expansion planning in Vietnam. Theoretically, the main purpose of carbon tax is to reduce CO_2 emissions by increasing energy efficiency and replacing non-renewable energy sources with renewable energy sources. From the perspective of economics, the tax could limit negative environmental externalities [4]. In the case of Vietnam, which tax level is cost-effective is still a question as the cost of CO_2 emission abatement and external costs have not been yet calculated. This assessment requires such a large amount of data and complicated methodology that will be considered for. This study only examines, in the case of Vietnam, the effect of carbon tax on the power generation expansion planning and tax level of switching from coal, a high emission-producing energy, to nuclear, a less emission-producing energy.

Power Sector in Vietnam

The EVN is a state corporation established by the government decree in 1995. The eighteen power plants and four transmission companies are dependent accounting companies. The five distribution companies are independent accounting companies [7].

The average annual growth rate of electricity consumption from 1995 to 2000 was about 12.2%. There was a large number of causes for the irregular demand growth patterns such as economic and political problems, as well as changes of consumption structure. Due to the expansion of economic activities after 2000, it is expected that the high annual growth of electricity demand will continue in the two coming decades. The average annual growth rate of electricity demand is projected at the rate of 9.63% from 2000 to 2020 in the base case. The total electricity consumption in 2000 is 26,000 GWh of which the shares are distributed to the industrial, agricultural, residential, commercial sectors and others were 41%, 2%, 48%, 5%, and 4% respectively [8].

The electricity supply situation is different among the three regions of the country. In the north, there is a rich coal resource and the largest hydro power plants. In contrast, in the south, a number of large thermal power plants and gas turbines have been built. By the end of 2000, the total available capacity of all electric generators across the country reached 6,281 MW with a total energy output of 26,562 GWh [8].

Vietnam uses domestic energy resources, including large reserves of coal, hydro, natural gas and oil. In order to meet the forecasted demand, Vietnam plans to build 15 new power stations by 2010. While coal and gas fired technologies will play a large role in the short-term period, increasing hydropower capacity over the long-term period is believed to be the favored route of the government. In 2000, the installed capacity of hydropower is 3,342.5 MW, about 53% of the total installed capacity. To meet a high electricity demand, EVN also imports electricity form Laos. The Vietnamese government is considering construction of a 600-1000 MW nuclear plant by 2015 that has to satisfy the economic and society objectives [8].

WASP-IV model

In this study, the analysis tool is Wien Automatic System Planning Package (WASP) model that is the well-known mainframe electric system-planning model distributed by the International Atomic Energy Agency (IAEA). WAPS-IV model is designed to find the economically optimal generation expansion policy for an electric utility system within user-specified constraints. It utilizes probabilistic estimation of system for production costs, unserved energy cost, and reliability, linear programming technique for determining optimal dispatch policy satisfying exogenous constraints of environmental emissions, fuel availability and electricity generation by some plants, and the dynamic method of optimization for comparing the costs of alternative system expansion policies [1].

There are 7 modules in WASP-IV. Module 1, LOADSY (Load System Description), processes information describing period peak loads and load duration curves for the power system over the study period. The data of existing and candidate power plants is the input of module 2, FIXSYS (Fixed System

Description), and module 3 VARSYS (Variable System Description) respectively. To calculate and find out the results, module 4 CONGEN (Configuration Generator), module 5 MERSIM (Merge and Simulate), and module 6 DYNPRO (Dynamic Programming Optimization) are used. Modules 4, 5, 6 must be executed in order, after execution of Modules 1, 2, 3. Finally, the seventh module, REPROBAT (Report Writer of WASP in a Batched Environment), processes a summary report of the first six modules, in addition to its own results.

The objective function in the WASP-IV model is a cost function including capital investment, salvage value of investment, fuel, operation and maintenance, and energy not served costs. The cost of energy not served reflects the expected damages to the economy of the country or region under study when a certain amount of electric energy is not supplied. The load is modeled by the peak load and the energy demand for each period (up to 12) for all years (up to 30), and their corresponding inverted load duration curves that are expanded in Fourier series by the computer program. For hydroelectric projects, the models are for run-of-river, daily peaking, weekly peaking and seasonal storage regulating cycle. The hydro power plants are assumed to be 100% reliable and have no associated cost for the water in the WASP-IV model.

Data and Assumptions

In this study, most data used for generation expansion planning, e.g. data on existing, committed and candidate power plants are taken from the Institute of Energy of Vietnam (2000) [8]. For all cases of study, the discount rate used is 10% per annum during the planning horizon, from 2003 to 2020. All costs are discounted to the year 2002 in US dollars. CO_2 emissions are calculated using information on optimal fuel requirements and relevant emission factors provided by IPCC [9].

The annual load curve, as an input of WASP model, is divided into 12 periods and each period's load duration curve is presented by 40 points. The peak load is expected to increase from 6,217 MW in 2003 to 26,076 MW in 2020. Respectively, the electricity demand would increase from 36,335 GWh in 2003 to 160,647 GWh.

Additions of 24 hydro power plants are limited to the capacity of 8,065 MW with the total annual energy availability of 29,142 GWh. The O&M cost of hydro power plants is 0.83 $/kW-month [8]. The technical characteristics and cost data of candidate thermal plants are presented in Table 1. The total capacities of combined cycle (CC45), domestic coal-based (NDTB), imported coal-based (NDTN), gas turbine (G145), nuclear (CAN6 and APW6) plants, in the planning horizon, are limited to the capacity of 5,200; 2,400; 1,500; 1,450; 2,040; and 1,800 MW respectively due to the limitation of investing capital of Vietnamese government. Moreover, the capacity of 3,150 MW imported from Lao is considered as candidate plants. The cost of imported electricity is 19.51 $/KW-month.

In this study, fuel prices are assumed to increase by 4% annually over the period of study. In calculating the demand-side effect, the approach is to use electricity price based on long-run marginal cost. The long-run average cost has been used here, as a proxy for long-run marginal cost of generation due to complexities involved in the latter calculation. Long-run average cost of generation is calculated using results of the least cost expansion plans from WASP IV, while long-run marginal cost of transmission and distribution are 1.6 USc/kWh and 2.4 USc/kWh respectively based on Technical Assistance for Preparation of Proposed Rural Energy Project [10].

The values of long-run price elasticity of electricity demand are wide variations. Riaz (1987) reported that values vary from –0.24 to –0.42 across different sectors in the case of Pakistan [11]. Ram M. Shrestha et al (1998) considered the price elasticity of electricity demand for Pakistan to be –0.5 and a lower value of elasticity –0.1 is also conducted in a sensitivity study [6]. In this study, the price elasticity of electricity demand for Vietnam is considered to be -0.1 based on assumption of Institute of Energy (IOE) [12].

In carbon tax literatures, the values are said to be about US$ 100 per ton C. In Sweden, US$158 per ton C was used [6]. Santisirisomboon (2001) chose the values of US$ 5, 7.5, and 10 per ton CO_2 corresponding to US$ 18, 28, and 37 per ton C [13]. In this study, several different carbon tax levels are considered, i.e., US$ 5, 10, 20, 30, 50, and 100 per ton C to estimate the effects of carbon tax on the electricity generation expansion planning.

Table 1 Technical characteristics and cost data of candidate thermal plants

Plant name	Fuel type	Capacity	Fuel cost		O&M cost	
			Domestic	Foreign	Fixed	Variable
		(MW)	(Cents/million kcal)		(US $/kW-m)	($/MWh)
CC45	Gas	435	792.6	0.0	0.81	1.96
NDTB	Coal	300	363.6	0.0	1.95	2.39
NDTN	Coal	300	0.0	692.3	1.95	2.39
G145	Gas-DO	145	0.0	1372.0	1.08	2.99
CAN6	Nuclear	680	0.0	94.0	5.68	1.29
APW6	Nuclear	600	0.0	282.0	5.50	0.50

Note: kW-m stands for kW-month
Source: Vietnam Institute of Energy (2000)

2. Methodology

In this study, the eight cases are carried out.

- The base case or the TRP case, in which only supply side is considered.
- The IRP case, in which both supply and demand sides are considered without carbon tax.
- The IRP5 case is the TRP case with a carbon tax of US$ 5 per ton C.

The IRP10 case is the IRP case with a carbon tax of US$ 10 per ton C.

- The IRP20 case is the IRP case with a carbon tax of US$ 20 per ton C.
- The IRP30 case is the IRP case with a carbon tax of US$ 30 per ton C.
- The IRP50 is the IRP case with a carbon tax of US$ 50 per ton of C.
- The IRP100 is the IRP case with a carbon tax of US$ 100 per ton of C.

Figure 1 presents the framework of the methodology for the generation expansion planning without carbon tax. In the TRP case, only supply-side options are considered to meet the required load and energy. The candidate plants comprise coal-fired steam plants, gas-based combined-cycle plants, diesel gas-turbine plants and nuclear plants. The annual peak loads are obtained from the load forecast of IOE [8]. In the IRP case, besides supply-side options, several DSM options are considered. These DSM options consist of replacing 40-W, 60-W, and 75-W incandescent bulbs with 13-W, 18-W, and 20-W compact lamps respectively, and 40-W fluorescent lamps with 36-W fluorescent lamps and ballast of 12-W loss with ballast of 5-W loss.

To examine the effects of DSM lighting program on the system load profiles, a household survey of lighting in the residential sector was investigated [14]. The lamps' prices are taken from the survey of representative of Philips and Osram Corporation in Hanoi.

Figure 2 presents the framework of methodology for integrated resource planning with carbon tax. This method is based on the study of Ram M. Shrestha et al (1998) [6] for the decomposition into two effects: supply-side and demand-side effects.

The total CO_2 mitigation effect of a carbon tax imposed (ΔE) is:

= Supply-side effect + demand-side effect

where:

- E_0 is CO_2 emission corresponding to the least cost fuel mix without carbon tax for given power demand projections and candidate power plants,
- E_s is CO_2 emission corresponding to the least cost fuel mix with carbon tax, all things remaining the same as in the case of E_0.

- E_p is CO_2 emission corresponding to the least cost generation mix associated with the reduced level of electricity demand due to an increase in electricity price resulting from carbon tax, all other things remaining the same as in the case of E_s.
- ΔE is total CO_2 mitigation effect of carbon tax.

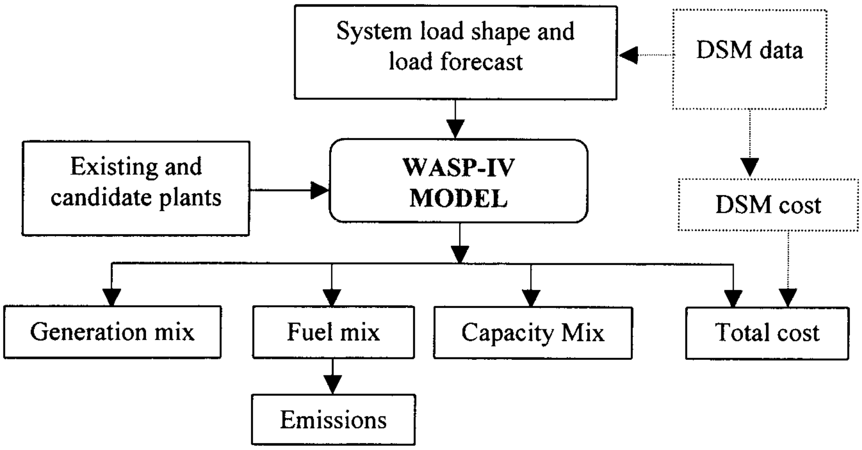

Figure 1 Flowchart of integrated resource planning

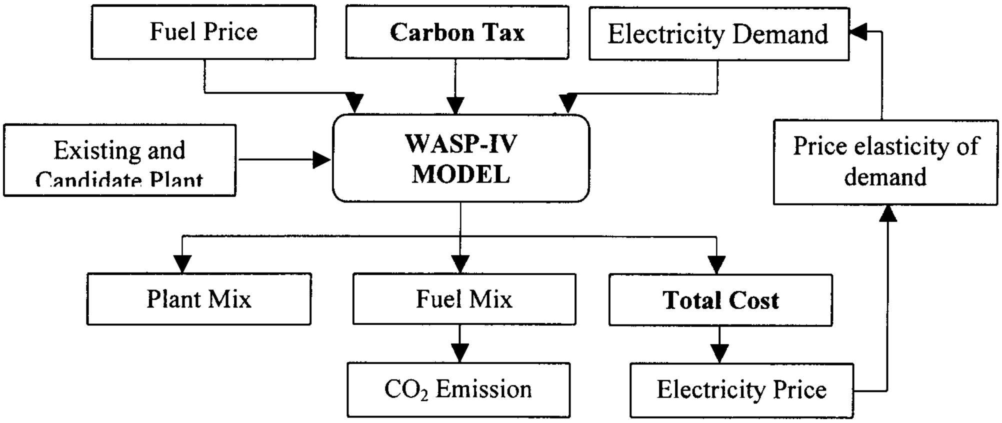

Figure 2 Flowchart of integrated resource planning with carbon tax

For a given power demand (as is the case in substitution effect), carbon tax would result in an increase in electricity price. Using the change in electricity price and price elasticity of electricity demand, the corresponding reduction in electricity demand could be calculated. The model is executed with the new level of electricity demand. After this iteration, the total cost and consequently electricity price would be reduced due to the lower electricity demand. For the case of Vietnam, 5 iterations are carried out till the equilibrium combination of electricity price and output is obtained.

3. Results and discussions

Electricity Planning Implication

In Vietnam, the candidate plants include hydro, combined cycle, coal-based, gas turbine, and nuclear plants and also imported electricity from Laos. Importing electricity from Laos mainly aims to increasing the efficiency in using hydro power energy sources in Vietnam. Due to stable hydro condition in Laos, Vietnam can import electricity even in dry seasons. Moreover, Vietnam can also export the hydropower in raining season to other countries, which connected to the linking system such as Thailand whose thermal power plants have very high proportion. Besides, importing electricity from Laos is required when the power system cannot serve a high electricity demand. In both electricity planning and environmental implications, imported electricity from Laos in case of Vietnam plays the same role with nuclear plants. For simplicity, hereafter, only nuclear power is concerned in the analysis.

Table 2 shows the installed generation capacity of candidate plants during the planning horizon with different cases of the study. In every case, installed generation capacities of hydro, natural gas and oil-based plants are constant due to limitation of capacity of these plants. In TRP case, a high electricity demand requires all generation capacity of hydro and thermal plants and even a 600 MW nuclear plant is required at the end of the planning horizon. However, in IRP case, the nuclear plants are not selected due to capacity avoided by demand-side management. When demand side is paid attention to, the total installed capacity is reduced by 915 MW showing a high potential of demand-side management in Vietnam.

Carbon tax would change relative prices of fuels resulting in a change of generation mix towards less carbon intensive fuels and technologies. However, low carbon tax levels such as US$ 5, 10, 20, and 30 per ton C would not affect the power generation expansion in Vietnam. The effects start at a tax rate of US$ 50 per ton C and higher with a shift from coal to nuclear. Theoretically, carbon tax could affect the shifting from coal to renewable energy and less carbon emission energy such as natural gas or nuclear energy. However, in case of Vietnam, renewable energy has low potential and the installed capacity of candidate natural gas plants is limited due to a lack of investing capital so that nuclear would play this role. In the IRP50 case, a 680 MW nuclear plant is added to the system in 2020. This study also gives a high tax level of US$ 100 per ton C to show more effects of carbon tax and the shifting from coal-based to nuclear plants. In the IRP100 case, nuclear plants replace most coal plants. Maximum installed capacity of nuclear plants, 3 units of 680 MW and 3 units of 600 MW, are requires due to effects of carbon tax.

Table 2 also shows that only tax levels of US$ 50 per ton C and higher affect the power generation expansion planning. Hereafter, to simply, only tax levels of US$ 30 per ton C and higher are given and analyzed. In the IRP case, saving in energy generation by DSM programs is around 47,157 GWh. In addition, effects of carbon tax on energy generation are shown by shifting from coal-based to gas-based and nuclear plants and also reduction of total energy generation in the planning horizon. Table 3 presents the cumulative generation during the planning horizon by fuel type for all cases. The coal-based generation is shifted to both nuclear and gas-based generation. The higher carbon tax is, the lower coal-based generation is. The significant reduction of energy generation appears with a high tax level of US$ 100 per ton C.

In the policy of EVN, considering construction of nuclear plant is one question which has been disputed. The problems are high capital investment (see Table 1) and safety of nuclear plants. In this study, the nuclear plant must be required to serve either the high electricity demand or to reduce the emissions in limit of candidate plants with environmental objectives. In the TRP case, nuclear plant would generate 4,182 GWh in 2020 with very fast growth rate of electricity demand in the planning horizon [8]. In the IRP case, no nuclear plant is required in the planning horizon. The DSM potential is very high in Vietnam [14]. Besides the above objective of using nuclear energy, this energy resource would be incentive to reduce emissions in case of Vietnam. Introduction of carbon tax would give nuclear energy an advantage of cost because the CO_2 emission factors of electricity generation from nuclear plants are approximately zero. At the tax level of US$ 50 per ton C, the nuclear plant is introduced into the power generation system.

Environmental Implication

Although the main purpose of carbon tax is to retrain the carbon dioxide emissions, a low carbon tax could not have any affect on emission reduction in electricity generation. Figure 3 displays the total CO_2 emissions in the planning horizon at different carbon tax levels. It shows that with the tax level lower than US$

50 per ton C, there is no considerable effect of carbon tax on the amount of CO_2 emission. Introduction of carbon tax would change the relative prices of fuels and give incentive to the less emission fuels. In case of Vietnam, there are not many choices for candidate plants under environmental objectives [8]. In other words, in the case of Vietnam, only nuclear energy is the only choice to replace coal or other fossil fuels with high CO_2 emission factors. However, the capital investment of nuclear plants is so high that a low carbon tax would not give any advantage of cost compared with other plants such as coal-based plants.

Table 2 Additional installed capacity during the planning horizon

Case	Additional installed capacity, MW (2003-2020)						
	Hydro	Coal	Diesel oil	Nature gas	Nuclear	Imported	Total
TRP	8,065	3,900	1,450	5,220	600	2,205	21,440
IRP	8,065	3,900	1,450	5,220	0	1,890	20,525
IRP5	8,065	3,900	1,450	5,220	0	1,890	20,525
IRP10	8,065	3,900	1,450	5,220	0	1,890	20,525
IRP20	8,065	3,900	1,450	5,220	0	1,890	20,525
IRP30	8,065	3,900	1,450	5,220	0	1,890	20,225
IRP50	8,065	3,600	1,450	5,220	680	1,575	20,590
IRP100	8,065	300	1,450	5,220	3,840	1,260	20,135

Table 3 Total generations during the planning horizon

Case	Energy generation, GWh (2003-2020)							
	Hydro	Coal	Fuel oil	Diesel oil	Nature gas	Nuclear	Imported	Total
TRP	525,460	318,960	3,118	3,819	669,228	4,182	36,144	1,560,911
IRP	524,554	293,437	3,178	3,615	656,984	0	31,986	1,513,754
IRP30	525,460	263,036	3,876	3,980	678,197	0	33,372	1,507,921
IRP50	525,460	252,822	3,648	3,164	682,162	4,821	31,986	1,504,063
IRP100	524,554	96,873	4,372	3,990	725,811	78,615	51,390	1,485,605

Figure 4 presents the annual CO_2 emissions in the planning horizon with different cases. Tax levels less than US$ 50 per ton C give an inconsiderable effect. In 2013, a large amount of hydropower units is available to access to the power system according to the schedule that may cause the reduction of CO_2 emission. In the end of the planning period, the decrease of CO_2 emission is due to shifting from coal-based to gas-based and nuclear generation under carbon tax effects.

Furthermore, the CO_2 emission from 2018 to 2020 in the IRP case is higher than in the TRP case (see figure 4), resulting from the addition of nuclear plants in the power system. Due to higher energy consumption in the TRP case, the nuclear plant has to be operated earlier in the TRP case in 2018. The generation of nuclear plants would replace the generation of fossil fuels. Moreover, the CO_2 emission of nuclear plants equals to zero, so the emission is lower in the TRP case.

Carbon tax could affect CO_2 emissions through supply-side and demand-side effect. Table 4 shows the CO_2 emissions reduction divided by the two effects in which the supply-side effect is the main cause of reducing CO_2 emission. The demand-side effect is not significant because the price elasticity of electricity demand in this study is as low as – 0.1. One reason is that EVN is a monopoly state company so that the customers have only one choice in buying electricity. Moreover, there is not much substitution of electricity. Therefore, a change in price of electricity would result in less effect on electricity demand. The demand-side effect is approximately equal to 3, 15, and 6% of the substitution effect for the carbon tax levels of US$ 30, 50, and 100 per ton C, respectively (see in Table 4).

Table 4 CO_2 emission reduction by supply-side and demand-side effects

Level of emission	CO_2 emission (million tons) Carbon tax, US $/ton C			
	0	30	50	100
Eo	405	-	-	-
Es	-	391	386	309
Ep	-	390	383	303
Supply-side effect (ΔEs)	-	14	19	96
Demand-side effect (ΔEp)	-	1	3	6
Total (ΔE)	-	15	22	102

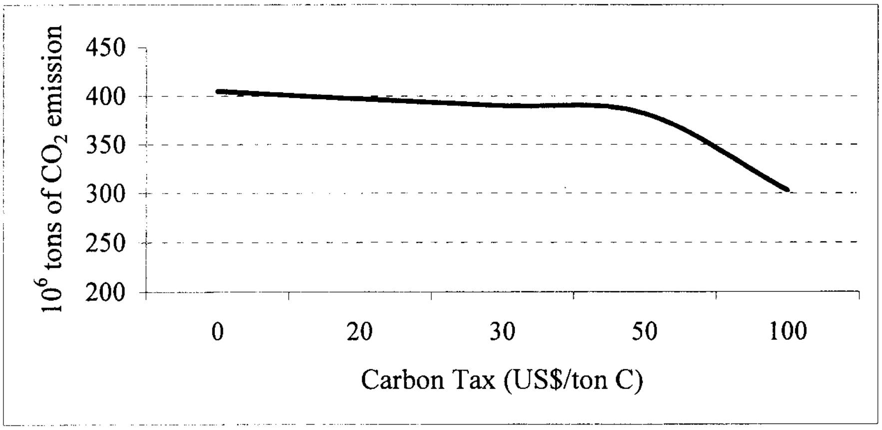

Figure 3 Total CO_2 emissions at different carbon tax, 10^6 ton of CO_2

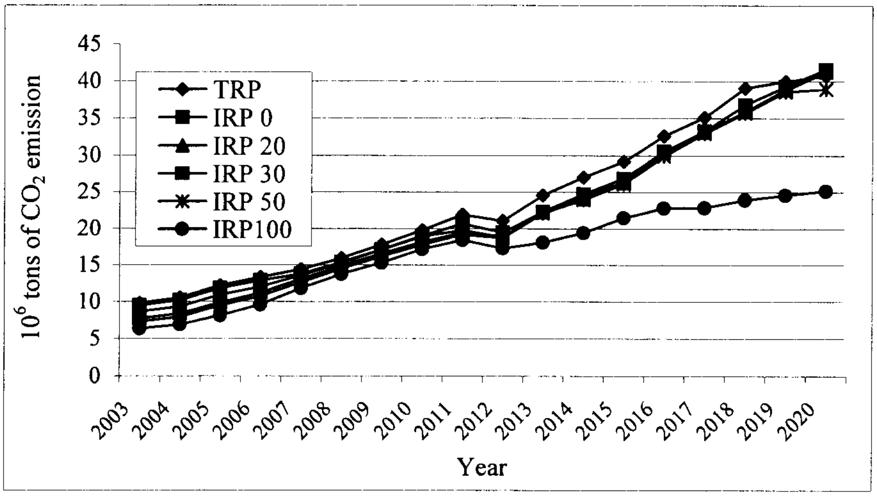

Figure 4 Annual CO_2 emissions during the planning horizon (2003-2020)

4. Conclusion and Recommendation

This paper has examined how carbon tax could affect CO_2 mitigation by both supply-side and demand-side effects in Vietnam. The supply-side effect being mainly due to shifting from coal-based to gas-based and nuclear plants. The demand-side effect is not considerable due to a low price elasticity of electricity demand in Vietnam. At the low carbon tax levels, CO_2 mitigation would be only due to shifting from coal-based generation to gas-based generation. However, the CO_2 mitigation is not significant because of a limit in candidate gas-based plants. The carbon tax levels of US$ 50 per ton C and higher would have the substitution effect in replacing coal-based generation by not only gas-based generation but also nuclear generation resulting in a remarkable reduction of CO_2 emission.

Recently, the construction of nuclear plants is an important subject in the policy of EVN that has been discussed at the national level. With the assumptions in this study, nuclear plants are required if the IRP concept is not paid attention to or if high tax level is proposed for the environmental objectives. Actually, the basic elements of environmentally sustainable energy policy are increasing energy efficiency and replacing non-renewable with renewable energy sources [4]. The data in this study are taken from the Fifth Master Plan of IOE [8] in which candidate plants do not include any power plants using renewable energy. Therefore, the major conclusion almost refers to nuclear energy as substitution for coal. Finally, to examine more clearly the effects of carbon tax, several power plants using renewable energy should be candidate plants in the future study. To examine the effects of carbon tax with economic implication, the cost of CO_2 emission abatement and external costs would be found out.

5. Acknowledgement

The authors gratefully appreciate the financial support from the Joint Graduated School of Energy and Environment (JGSEE) and instrumental supports from Sirindhorn International Institute of Technology, Thammasat University (SIIT-TU). Our gratefulness is due to the International Atomic Energy Agency (IAEA) for providing the WASP-IV model used in this study. The authors are only responsible for the views expressed and remaining errors in the paper.

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