9. Application of AIM/Enduse to Vietnam: A Study on Effects of CO_2 Emission Reduction Targets

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Summary. This study examines the effects of imposing CO_2 emission: reduction targets on the least cost energy resource requirements as well as emissions of CO_2, SO_2 and NO_2 from different economic sectors of Vietnam in 2020 using the AIM/Enduse model. The results show that in 2020 total primary energy requirement in the reference scenario would be 2,170 PJ as compared to 866 PJ in 2000. About 13.5 billion m^3 of natural gas would be required in the reference scenario in 2020 while hydropower capacity needed would be about 5,000 MW. The study also shows that the least cost energy mix for meeting emission reduction targets of 5% to 15% in 2020 would require the use of additional 3.6 to 3.9 billion m^3 of natural gas over and above the quantity of gas needed in the reference scenario. The incremental cost of reducing CO_2 emission by 5 to 15% of the reference scenario emission would be in the range of US$ 9.2 to US$ 58.3 per ton of CO_2.

9.1 Introduction

In recent years, Vietnam has recorded a relatively high economic growth rate (7%), particularly after it has moved towards a market based economy. According to Ministry of Planning and Investment, economic growth rate is projected to be around 6% during 2000-2020 (MPI 2001). Consequently, energy consumption and associated environmental emissions are expected to rise significantly in the coming decades.

Total energy consumption in Vietnam has been growing at an average annual rate of 8.5% recently. Fossil fuel consumption (coal, oil and natural gas) accounted for 75% of total primary energy requirement of the country in 2000 and was growing at an average annual growth rate (AAGR) of 9.2% during 1995-2000. As a result, CO_2 emission from energy use in the country had increased at the rate of 8.7% per annum during the period (Institute of Energy 1999).

Developing countries like Vietnam are facing increasing pressure for a meaningful participation in global efforts for greenhouse gases (GHGs) emission reduction. A reduction of GHG emission would, however, affect not only the energy supply cost but also the structure of energy system and technology mix in both supply and demand sides. In this paper, we analyze the implications of introducing CO_2 reduction targets for energy-mix, technology-mix, emission of local/regional pollutants (SO_2 and NO_2) and total energy supply costs in Vietnam

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in meeting projected demand for energy services in 2020. We also calculate the incremental cost of CO_2 abatement at selected CO_2 emission reduction targets.

9.2. Structure of AIM/Enduse Model for Vietnam

9.2.1 Basic structure

The AIM/Enduse model is a bottom-up linear programming optimization model. It accounts for the flow of energy resources from resource extraction to enduse through energy conversion/refining processes considering energy characteristics of the technologies involved in each stage. The general structure of the model is shown in Fig. 1. The model determines least cost combination of energy resources and technologies needed to meet the projected demand for energy services by various sectors in a study year.

There are several constraints used in the model. These are constraints on old stocks of energy devices, reformable devices, newly introducible devices, energy service demands and energy resource availability (see Part IV, Manual, this volume).

9.2.2 Energy supply sectors

Coal. In Vietnam, there are two kinds of technology in use for coal extraction i.e., open pit technology and underground technology. The options of using coal in electricity generation as well as in industry, residential and commercial sectors are considered in the model. The model also includes the options for import and export of coal.

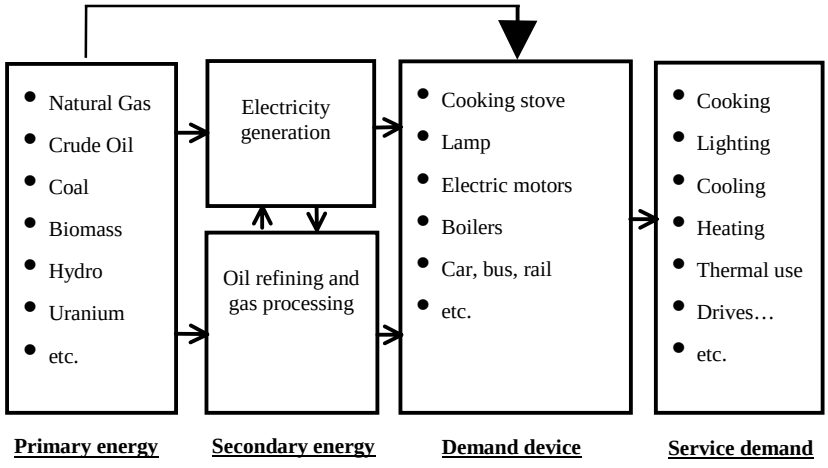

Fig. 1. Structure of the AIM/Enduse model

Crude oil and petroleum products. At present, all crude oil produced in Vietnam is exported, as there is no petroleum refinery in the country. For the energy system development in 2020, the model allows for not only domestic crude oil production but also crude oil export/import as well as petroleum refining and oil product import.

Natural Gas/LPG. The model allows for extraction and transportation of natural gas, transformation of the gas to liquefied petroleum gas (LPG) as well as the use of gas in power generation and industry sectors. The use of LPG is considered in commercial and residential sectors. It also has a provision for gas import.

Renewable energy. Renewable energy resources in Vietnam include hydropower, biomass, solar, geothermal and wind. Use of biomass is considered only for residential cooking while solar, geothermal and wind energy options are considered for power generation.

Electricity. For power generation, options considered in the model include nuclear, coal (both conventional and clean coal technologies), diesel, gas (gas-turbine and combined cycle technologies), hydropower and renewable energy (geothermal, wind, solar). Provisions for export and import of power are also made in the model.

Table 1. Enduse technology options considered in this study

Enduse service	Sector/Sub-sector	Technology option
Lighting	Residential and commercial	Incandescent, fluorescent and compact fluorescent lamp
Cooling	Residential and commercial	Conventional and energy efficient air conditioners
Cooking	Residential	Biomass, kerosene, electricity, and LPG cook stoves.
Hot water	Residential and commercial	Electrical water heaters
Thermal use	Commercial	Kerosene, coal and gas boilers
Electrical drives	Industry (all sub-sectors)	Standard and energy efficient motors
Process heating		
#1	Cement	Coal and natural gas kilns
#2	Iron and steel	Oil fired and electrical furnaces
Steam	Fertilizer and chemical, Iron and steel, pulp and paper and other industry	Coal, natural gas and oil burning boilers (conventional and energy efficient)
Other electrical appliances	Residential and commercial	Electrical appliances
Road	Passenger transport	Existing and new: two-wheelers, cars, vans, jeeps, electric cars, bus-diesel, bus-CNG and electric buses.
Rail	Passenger transport	Existing and new: diesel & electric locomotives.
Air	Passenger transport	Existing and new aircrafts.
Road	Freight transport	Existing and new: light and heavy trucks
Rail	Freight transport	Existing & new: diesel & electric locomotives.
Air	Freight transport	Existing and new cargo aircrafts
Water	Freight transport	Existing and new ships

9.2.3 Energy services

The model covers energy service demand of residential and major production sectors, i.e., commercial, industrial and transport sectors. Agriculture sector is not included here partly because of unavailability of all end-use data and partly due to the sector's small share (2%) in total final energy consumption of the country in 2000 (Institute of Energy 1999). Industry sector is classified into five sub-sectors, i.e., cement, fertilizer and chemical, iron and steel, pulp and paper and others. Transport sector comprises passenger and freight transport services. Passenger and freight transport services are both categorized further into three types (i.e., road, rail and air). Technology options considered in this study for each type of end-use/energy service demand in different sectors are presented in Table 1.

9.3 Scenarios

9.3.1 Reference scenario

The reference scenario in this study is considered as the "business as usual" scenario, i.e., without introduction of any emission mitigation policy. Data on energy service demands in this case are based on the energy demand forecasting study of Institute of Energy carried out using MAED and MEDEE-ENV models (Institute of Energy 1999). Technology data on existing power generation plants are based on Institute of Energy (2000) and that on candidate plants are based on Institute of Energy (2000), IEA (1998) and ADB (1998). The data on oil refineries and natural gas processing are obtained from Petrovietnam (2001a, 2001b, 2002). The data on end-use technology options are taken from COSMO (1999), ADB (1998), Shrestha *et al.* (1998), MOSTE (1997), Hanoi University of Technology (2000) and Minh (2000).

9.3.2 Emission reduction scenarios

Besides the reference scenario, we analyze three different emission reduction (ER) cases in which targets for reducing the CO_2 emission in the reference scenario in 2020 by 5%, 10% and 15% are considered. Hereafter, we call these emission reduction cases as ER5, ER10 and ER15 cases respectively. All others things in the ER cases remain the same as that in the reference scenario.

9.4 Data and Assumptions

An annual discount rate of 6.0% is used in the study. Emission factors for CO_2, SO_2 and NO_2 used in this study are based on Intergovernmental Panel on Climate Change (IPCC).

Table 2. Maximum allowable limits on renewable energy use in Vietnam in 2020

Resource	Availability (GWh)
Hydropower	62,000
Solar PV system	1,450
Geothermal	1,400
Wind power	1,500

9.4.1 Energy resources

Oil and petroleum products. In 2000, oil and natural gas production were about 12.5 million tons and 1.4 billion m^3 respectively. The total proven reserve of oil is estimated to be about 250 million tons (Petrovietnam 2001b). At present, all petroleum products are imported and their prices are determined by the Government Pricing Committee.

Natural gas. The estimated reserve of natural gas discovered so far in Vietnam is about 1,000 billion m^3. An optimistic scenario of natural gas supply potential is estimated to be about 15 billion m^3 per year (bcm/year) in 2020 (Petrovietnam 2002). This is also the maximum allowable limit considered in this study.

Coal. Total coal reserve is estimated to be over 6 billion tons. Most of it is anthracite. In recent years coal production has fluctuated between 4 to 8 million tons per year. According to Vietnam General Coal Company (1998), coal production could exceed 20 million tons in year 2020 if there is enough demand. We have used this figure as the maximum available quantity in this study.

Nuclear. In this study, maximum allowable capacity of nuclear power generation is set at 1,500 MW.

Renewable energy resources. In this study, renewable energy resources are considered to be available for use in 2020 up to the limits specified in Table 2.

9.4.2 Enduse data

Industry sector. The consumption of useful energy (defined as energy output delivered in the form of end-use energy services) of this sector was 127 PJ in 2000 and its average annual growth rate (AAGR) during 2000-2020 is estimated to be 7.8%. In 2000, the levels of useful energy consumption (UEC) of cement, fertilizer and chemical, pulp and paper, iron and steel and other sub-sectors were 18.0 PJ, 11.3 PJ, 13.2 PJ, 32.6 PJ and 52.0 PJ respectively. The AAGR of UEC of these sub-sectors during 2000-2020 are projected to be 6.6%, 8.7%, 8.5%, 8.5% and 7.4% respectively. Consequently, the share of iron and steel in 2020 would be 29.0% while that of pulp and paper, cement, fertilizer and chemical, and other sub-sectors would be 12.0%, 11.0%, 10.0% and 38.0% respectively (Institute of Energy 1999)

Commercial sector. Total energy consumption in the commercial sector was 23.1 PJ in 2000 and it is estimated to increase at an average annual growth rate of 6.6% during 2000-2020. The shares of different energy services in total useful energy consumption of the sector in 2000 were as follows: thermal use 27.7%, hot water 16.0%, air conditioning 11.7%, lighting 5.2% and other appliances 39.4%. In terms of useful energy demand, lighting is projected to have the highest AAGR of 8.6% followed by air conditioning, other appliances, hot water and thermal use with 7.8%, 7.1%, 6.1% and 4.8% respectively (Institute of Energy 1999).

Transport sector. The end-use demand data for the transport sector in 2000 were obtained from the General Statistical Office (2000). The average annual growth rate of service energy demand in the transport sector during 2000-2020 is assumed to be 7.2%. Table 3 presents the end-use demand for and corresponding share of various types of transport services.

Residential sector. Total useful energy consumption (TUEC) in this sector was 29.5 PJ in 2000 and it is estimated to increase at an AAGR of 7.9% during 2000-2020. The shares in the sector's TUEC of different energy services (i.e., end-uses) in 2000 are as follows: cooking 42%, air conditioning 10.5%, water heating 8.8%, lighting 5.8% and 32.9%. The AAGRs of useful energy demand for cooking, air conditioning, water heating, lighting and other end-uses are estimated to be 4.6%, 8.2%, 14.3%, 7.7% and 9.0% respectively (Institute of Energy 1999).

Table 3. Demand for transport services

Service Type		2000		2020	
		Value	Share	Value	Share
Passenger-transport	Road	18,857	70.5%	74,595	70.5%
(10^6 p-km)	Rail	3,462	12.9%	13,695	12.9%
	Air	4,428	16.6%	17,516	16.6%
Sub total, 10^6 p-km		26,747	100%	105,806	100%
Freight- transport	Road	4,799	12.0%	18,984	12.4%
(10^6 ton-km)	Rail	1,921	5.0%	7,599	5.0%
	Air	200	1.0%	791	0.5%
	Water	31,706	82.0%	125,422	82.1%
Sub total, 10^6 ton-km		38,626	100%	152,796	100%

Source: General Statistical Office (2000)

9.5. Simulation Results

9.5.1 Primary energy

The primary energy mix in 2020 under the selected emission reduction scenarios under the reference scenario is presented in Table 4 along with that in 2000. As can be seen from the table, total primary energy requirement (TPER) in Base and ER cases in 2020 would be over 2,140 PJ, i.e., about 2.5 times the figure in 2000. The use of natural gas, hydro and nuclear energy would increase with ER target while coal and oil consumption would decrease. In 2020, natural gas requirement would be 13.5 billion m^3 in the reference scenario. Natural gas use as a percentage of TPER in 2020 would increase from 21.9% in the reference scenario to 29.1% in ER15 case. In order to meet emission targets of 5%, 10% and 15%, additional quantities of natural gas of 3.6, 3.7 and 3.9 billion m^3 over and above that needed in the reference scenario would be required. The share of coal would fall from 36.5% in the reference scenario to 28.2% in ER15 case while that of oil would decrease from 28.7% to 26.7%. It should be noted here that the reduction in coal use is mainly because of considerable fuel switching from coal to natural gas in power generation. The share of hydro energy would increase from 5.7% in the reference scenario to 6.6% in ER15 case.

Table 4. Least cost primary energy requirements in different scenarios, %

Energy Resource	2000	2020			
	Reference scenario	Reference scenario	ER5	ER10	ER15
Biomass	7.1	3.5	3.5	3.6	3.6
Coal	37.8	36.5	31.3	29.4	28.2
Natural gas	8.2	21.9	27.7	28.4	29.1
Crude oil for refinery	-	29.3	25.9	23.2	21.3
Hydro energy	7.1	5.7	5.6	5.8	6.6
Nuclear	-	2.6	2.6	2.7	3.1
Geothermal	-	0.2	0.2	0.2	0.2
Solar	-	0.2	0.2	0.2	0.2
Wind energy	-	0.1	0.1	0.1	0.1
Import of oil product	39.6	-	2.8	5.8	5.4
LPG import	0.1	-	-	-	0.4
Electricity import	-	-	-	0.7	1.9
Total, PJ	866	2,170	2,199	2,163	2,145

9.5.2 Electricity

Electricity generation

The structure of power generation in the emission reduction scenarios is presented in Table 5. As can be seen from the table, total electricity generation in reference scenario in 2020 would be 3.62 times that in 2000. Furthermore, total electricity generation in 2020 would increase with CO_2 emission reduction target i.e., from 89.4 TWh in reference scenario to 103.3 TWh in ER15 case.

Table 5 also shows that the share of natural gas based power generation in 2020 would increase from 21.3% in reference scenario to 47% in ER15 case while that of coal fired power generation would decrease from 13.5% in reference scenario to 2.5% in ER10 case and 0% in ER15 case. Furthermore, there would be no oil based power generation in 2020. The share of hydropower would be 35.0% in the reference scenario and would remain almost at that level in the ER cases. The combined share of other renewable power generation sources (i.e., wind, geothermal and solar) would be about 3% in Base as well as the ER cases considered. Electricity import is found cost effective under ER10 and ER15 cases and accounts for 4.2% and 10.0% of total electricity supply respectively in 2020. The share of nuclear power generation would decrease with CO_2 emission reduction target although the level of generation in absolute term would remain unchanged in ER5 and ER10 cases and increase slightly in ER15 case.

Power generation capacity

As can be seen from Table 6, total power generation capacity in 2020 in the reference scenario would be 2.7 times that in 2000. Total electricity generation capacity would increase with CO_2 emission reduction target: The capacity would increase from 12,856 MW in reference scenario to 13,517 MW in ER5 case and to 14,552 MW in ER15 case. The share of natural gas based generation capacity

Table 5. Electricity generation by type of power plant in different cases, GWh

Type of generation	2000	2020			
	Reference scenario	Reference scenario	ER5	ER10	ER15
Hydro	13,056	31,389	31,667	31,944	36,111
Coal	3,333	13,333	6,111	2,222	0
Natural gas	5,278	37,222	45,278	45,833	48,611
Oil	3,000	0	0	0	0
Nuclear	-	5,000	5,000	5,000	5,556
Geothermal	-	894	906	914	1,022
Solar	-	894	894	894	894
Wind	-	717	725	731	767
Import	-	-	-	3,806	10,333
Total	24,722	89,444	90,556	91,389	103,333

would increase from 43.1% in reference scenario to 48.8% in ER15 case while that of coal fired generation capacity would decrease from 15.0% to 9.5%. The share of hydropower in total generation capacity is about 33.5% in the reference scenario and would remain almost at that level at the ER cases considered. In ER15 case, 4,873 MW of hydropower capacity would be installed which amounts to 65.0% of hydro energy potential. The combined share of other renewable sources (i.e., wind, geothermal and solar) would be about 2.3% in Base and ER cases. The share of nuclear power generation capacity would be about 5.3% in all cases considered.

Table 6. Total power generation capacity in different cases, MW

Power Plant	2000	2020			
	Reference scenario	Reference scenario	ER5	ER10	ER15
Hydro	2,866	4,350	4,258	4,312	4,873
Coal	700	1,932	1,687	1,576	1,382
Natural gas	1,150	5,530	6,517	6,580	7,127
Oil	670	39	39	39	39
Nuclear	-	669	677	684	772
Geothermal	-	109	111	112	125
Solar	-	109	109	109	109
Wind	-	88	89	89	94
Total	5,386	12,856	13,517	13,531	14,552

Table 7. Energy input used for power generation, PJ

Energy Type	2000	2020			
	Reference scenario	Reference scenario	ER5	ER10	ER15
Hydro	62.2	123.0	124.0	125.0	142.0
Coal	49.7	169.0	77.0	29.0	0
Natural gas	65.6	322.0	410.0	413.0	432.0
Oil	38.0	-	-	-	-
Nuclear	-	57.0	58.0	58.0	66.0
Renewable	-	9.8	9.9	10.0	10.5
Import	-	-	-	15.0	41.0
Total	215.5	680.8	677.9	650.0	691.5

Energy mix in power generation

Energy inputs used in electricity generation in 2020 under different cases are shown in Table 7 along with the corresponding numbers in 2000.

In reference scenario, total amount of natural gas used for power generation in 2020 would be 4.9 times of that in 2000. The amount of gas used for power generation in 2020 is found to increase with ER target: It would be 8.5 billion m^3 per year (bcm/year) in reference scenario and 10.8, 10.9 and 11.4 bcm/year in ER5, ER10 and ER15 cases respectively. The power sector share in total natural gas consumption in the country in reference scenario would be 67.7%.

9.5.3 Final energy consumption in sectors

Total consumption of final energy (defined as the quantity of energy delivered or used by final consumers) in reference scenario in 2020 would be 3 times that in 2000. Total final energy consumption (TFEC) in 2020 was found to decrease slightly with ER targets i.e., from 1,648 PJ in reference scenario to 1,633 PJ in ER15 case (Table 8). Industry sector would have the largest share (47.0%) in TFEC in reference scenario in 2020 followed by transport (29.0%), residential (16.3%) and commercial (7.6%) sectors. The shares would remain almost the same under the ER cases considered.

9.5.4 Emissions

CO_2 emissions

The sectoral contributions to total CO_2 emission in 2020 under different cases are shown in Table 9 together with the figures in 2000. CO_2 emission in reference scenario in 2020 would be about 34 million tons, which is 3 times the corresponding figure in 2000.

In 2000, the transport sector was the largest contributor to CO_2 emission (38.8%) followed by the industry, power, commercial and residential sectors. In 2020, the industry sector would be the largest contributor accounting for about 46.0% of the total CO_2 emission in reference scenario followed by the transport, power generation, residential and commercial sectors. With the emission reduction targets, the industry sector would still maintain the highest share in total CO_2 emission. It should also be noted that the shares of the industry and transport sectors in total CO_2 emission would increase in the ER cases considered while that of the power sector would fall. There would be only slight changes in the shares of the commercial and residential sectors.

SO_2 emissions

CO_2 emission reductions are also found to result in mitigation of SO_2 emission due to changes in energy mix. Table 10 gives the levels of SO_2 emission by sector.

Table 8. Final energy consumption by sector, PJ

Sector	2000	2020			
	Reference scenario	Reference scenario	ER5	ER10	ER15
Commercial	38	125	125	125	125
Industry	189	775	775	774	762
Residential	98	270	268	268	268
Transport	229	478	478	478	478
Total	554	1,648	1,646	1,645	1,633

Table 9. Sectoral shares in total CO_2 emission, %

Sector	2000	2020			
	Reference scenario	Reference scenario	ER5	ER10	ER15
Commercial	2.6	1.2	1.2	1.3	1.3
Industry	30.5	46.1	47.8	48.1	48.4
Residential	2.1	1.5	1.3	1.3	1.4
Transport	38.8	26.0	27.0	27.6	29.5
Power generation	26.0	25.2	22.7	20.7	19.4
Total, 10^3 tons	10,993	34,099	32,394	30,689	28,984

Table 10. Sectoral shares in total SO_2 emission, %

Sector	2000	2020			
	Reference scenario	Reference scenario	ER5	ER10	ER15
Commercial	3.0	1.0	1.1	1.2	1.3
Industry	43.5	62.3	70.5	75.6	78.2
Residential	2.6	0.5	0.3	0.4	0.4
Transport	24.0	14.2	16.0	17.2	18.8
Power generation	26.9	22.1	12.0	5.6	1.3
Total, 10^3 tons	198.4	648.6	572.7	533.1	489.0

Table 11. Sectoral shares in total NO_2 emission, %

Sector	2000	2020			
	Reference scenario	Reference scenario	ER5	ER10	ER15
Commercial	1.9	0.6	0.7	0.7	0.7
Industry	31.7	48.1	50.1	51.1	51.3
Residential	1.9	0.4	0.2	0.2	0.2
Transport	37.8	24.7	25.7	27.2	28.2
Power generation	26.7	26.2	23.3	20.8	19.6
Total, 10^3 tons	120.5	377.8	362.2	347.8	330.9

SO_2 emission in reference scenario would be about 648 thousand tons in 2020, which is 3.3 times the corresponding figure in 2000. In 2000, the industry sector was the largest contributor to SO_2 emissions (43.5%) followed by the power, transport, commercial and residential sectors. Industry sector would also be the largest contributor to SO_2 emission in 2020 accounting for about 62.3% of total SO_2 emission in reference scenario followed by the power, transport, residential and commercial sectors. The industry sector share in total SO_2 emission would not only continue being the highest but would also increase with ER target. Similarly, the share of the transport sector would increase with the ER targets while the share of power generation would fall. SO_2 emission in ER5, ER10 and ER15 cases would decrease by 13.2%, 21.7% and 32.6% cases respectively as compared with that in reference scenario.

NO_2 emissions

NO_2 emission in reference scenario in 2020 would be 378 thousand tons which is about 3 times the corresponding figure in 2000 (Table 11).
Transport sector was the largest emitter of NO_2 followed by the industry and power sectors in 2000. In 2020, the industry sector would be the dominant contributor accounting about 48.1% of total NO_2 emission. NO_2 emission in ER5, ER10 and ER15 cases would be reduced by 4.3%, 9.2% and 12.5% respectively as compared to the reference scenario mission. Furthermore, NO_2 emission shares of the industry and transport sectors would increase in ER cases while that of the power sector would decline.

9.5.5 Cost for CO_2 reduction

Table 12 presents the total cost of energy supply and incremental cost of CO_2 reduction in Base and ER cases. The incremental cost increases from $9.2 per ton of CO_2 in ER5 case to $58.3 per ton of CO_2 in ER15 case. Figure 7 shows the CO_2 emission abatement cost curve in year 2020. At the incremental abatement cost (IAC) of 10$/ton of CO_2, about 1.8 million tons of CO_2 could be mitigated while 29 and 46 million tons of CO_2 emission could be reduced at the IAC of $20 and $50 per ton of CO_2 respectively.

Table 12. Total cost of energy supply and incremental cost of CO_2 emission reduction in 2020 at constant prices of 2000

Scenario	Total cost (Million $)	Incremental cost of CO_2 reduction ($/ton-$CO_2$)
Reference scenario	16,835	-
ER5	16,885	9.2
ER10	17,116	25.7
ER15	17,792	58.3

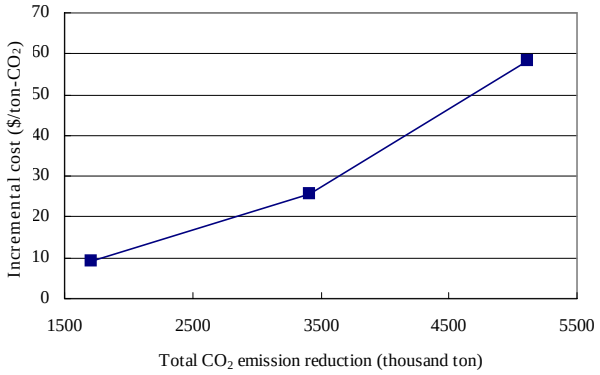

Fig. 2. Incremental CO_2 emission reduction cost curve

9.6 Conclusions

This study has examined the implications of introducing CO_2 emissions targets for the structure of energy use and the cost, as well as SO_2 and NO_2 emissions in Vietnam in 2020 by using the AIM/Enduse model.

Total primary energy requirement in 2020 in Base and ER cases would be in the range of 2,145 PJ to 2,170 PJ as compared to 866 PJ in 2000. The requirements of natural gas, hydro and nuclear energy were found to increase with emission reduction target while that of coal and oil consumption would decrease. In 2020, 92.5% of annual natural gas supply availability and 65% of total hydropower potential would be used up in ER15 case. Additional quantities of 3.6, 3.7 and 3.9 billion m^3 of natural gas would be required in order to meet emission targets of 5%, 10% and 15% respectively in 2020 over that needed in reference scenario.

Total electricity generation capacity requirement for the whole system would increase with CO_2 emission reduction target. Power generation capacity would increase from 12,856 MW in reference scenario to 14,552 MW in ER15 case. Natural gas based generation capacity would account for 43.1% in reference scenario and 48.8% in ER15 case. The share of coal based generation capacity would decrease from 15% in reference scenario to 9.5% in ER15 case.

Industry sector would be the largest contributor to total CO_2 emission in Vietnam in 2020 followed by the transport and power sectors. The power sector is found to be the main contributor to the reduction of CO_2 as well as SO_2 and NO_2 emissions.

Incremental cost of CO_2 abatement would be 9.2 US$/ton CO_2 at the emission reduction target of 5% while it would increase to 58.3 US$/ton CO_2 at the higher reduction target of 15%.

It should be noted that AIM/end-use is a static optimization model in that energy system optimization is carried out for a chosen year. Furthermore, energy production capacities (e.g., power generation capacity) are treated as continuously divisible decision variables. However, in fact, some energy investments (e.g., hydropower, nuclear) are lumpy in nature. Thus, the results of this study could differ somewhat from that of a study based on a dynamic energy system model, that considers explicitly the lumpiness of energy sector investments.

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