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Article

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A power development planning for Vietnam under the CO₂ emission reduction targets

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Abstract

The paper guides three scenarios of power planning for Vietnam for the 2018–2030 period under CO₂ emission targets. The analysis employs a model of energy expansion in the form of an optimization problem with the objective of the discounted entire system cost minimization. With each CO₂ emission allowance, a scenario of the newly installed capacity structure will be carried out. The results indicate that instead of 42.6% coal-fired installed capacity as indicated in the National Power Development Master Plan for the 2011–2020 period with the Vision to 2030 (known as PDP VII), by 2030 the share of this power source will be around 29% (8% CO₂ reduction scenario) and 19% (25% CO₂ reduction scenario). Also, the lower emission sources such as hydro, wind, and solar power will be a priority for investment in the next decade. There is an existence of coal-fired power plants replacement by natural gas stations.

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Keywords: Power planning; Optimization problem; CO₂ reduction target

1. Introduction

Vietnamese government currently faces the controversial topic of coal-fired or wind, solar power source development. Some argue that electricity generation from renewables is not only expensive for Vietnamese but also does not ensure the security of electricity supply while others advocate integrating wind and solar power sources into electricity market because of their environmental benefits. There has been an existence of cost reduction trend of wind turbines and solar panels in recent years. The photovoltaic module price for ground-mounted PV systems in the world decreased 70% after only 15 years from 1.85 USD/W_p (in 2000) to 0.57 USD/W_p (in 2015) [Bloomberg New Energy Finance]. More references on the reduced cost of solar power technologies, see in [1,2]. In contrast, because of the limited coal sources, the cost of electricity generation from this fuel is predicted to increase significantly in the upcoming years [3].

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Responding to the goal of the 21st Conference of the United Nations Framework Convention on Climate Change (COP21), Vietnam commits that by 2030, this nation will reduce 8% (with unconditional objectives) and 25% (with international support of finance, capacity building, and technology transfer) of greenhouse gases (GHGs) emission compared to the BAU scenario (787 MtCO_{2e} by 2030) [4]. In Vietnam, in 2012, the emission share of the energy sector was 66%, in which the power sector made up about 16% [5]. In recent years, with the fast growth of new coal-fired power plants, more and more CO₂ has been emitted into the air [6]. In order to achieve the goal of GHGs emissions, the reduction of emissions in this electricity area would contribute to the overall decrease efforts undoubtedly. Among technologies for power generation, coal-fired power plants have the highest emission factors between 740 and 910 gCO_{2eq}/kWh. The other fossil fuels, including oil and natural gas, also have significantly higher emission factors than the ones of hydropower, solar, and wind power [7,8].

In Vietnam, coal-fired accounted for the highest share of electricity generation (37% in 2016, equivalents to around 70% CO₂ emission from the electricity sector) [NLDC, 2017]. According to the revised National Power Development Master Plan for the 2011–2020 period with the Vision to 2030, the Vietnamese government aims to achieve 25,620 MW (42.7%) in 2020, 55,167 MW (42.6%) in 2030 of coal-fired installation [3]. With those targets, the electricity generation from coal is estimated at around 130 TWh in 2020 (equivalents to 123 MtCO₂), 306 TWh in 2030 (equivalents to 245 MtCO₂) [9]. It is precisely that existing a significant conflict between the CO₂ reduction targets and the master plan for the development of power sources in Vietnam. The Vietnamese government sets the ambitious targets of CO₂ reduction [4], and at the same time, approves the significant expansion of coal-fired power source [3].

To carry out an energy expansion that is consistent with the CO₂ reduction targets, a suitable power planning model is essential. There is the existence of several power planning models focusing on the Vietnamese electricity market. Ha-Duong [10] introduced carbon capture and storage (CCS) technology for coal-fired, gas-fired, and biopower plants. A national energy mix simulation model has been carried out for the planned years 2030, 2050. Nguyen [11] offered a model of Vietnam power system with the objective of least cost expansion. The shares of coal, natural gas, renewables energy in the installed capacity structure were proposed at 24.4%, 22.8%, and 30% by 2030, respectively. Other researches focusing on the integration of wind and solar power with relation to transmission grid capacity can be found out in [12,13].

Looking further into the community of energy planning in the world, variety, and diversity energy planning models have been studied and achieved specific results. Hashim et al. [14] constructed a model for energy planning under three operating modes: economic mode, environmental mode, and mixed-mode, which was applied for the Ontario power grid. The results show two effective ways of the energy transition, including fuel balancing and fuel switching. Recent research on a dynamic investment and dispatch model for the future European electricity market (dynELMOD) has provided a tool to determine future scenarios of the European electricity system under CO₂ constraints [15].

The present study is designed to catch sight of the system cost as well as the pathways of power plant expansion in the upcoming decade, in which CO₂ emission target is one of the main drivers of the investment plan. The paper is organized as follows. In Section 2, we construct a mathematical image of an energy planning model in the form of a cost minimization problem. Section 3 is to investigate the future pathways of power mix for Vietnam under the CO₂ targets. Section 4 is to present some conclusions and policy implications.

2. Proposed model

The model aims to deal with the investment options in electricity generation technologies which support the lawmakers to decide on the targeted installation structure of power in the future. The problem is formulated as linear programming and designed as optimization with the objective of the total discounted system cost minimization under economic and technical constraints. The system costs comprise (1) investment cost, (2) operation and maintenance cost, (3) fuel cost, (4) environment cost, and (5) electricity buying cost. The model has to satisfy demand–supply balance, power system security, CO₂ emission limitation. The base year is the year 2017, and the horizon period is from 2018 to 2030. The model formulation is as follows:

$$\text{Objective function : } TSC = TC_{inv} + TC_{om} + TC_{fu} + TC_{env} + TC_{buy} \Rightarrow \text{Min} \quad (1)$$

The discounted investment cost of new power plants is as follows:

$$TC_{inv} = \sum_{t,i} IC_{i,2017} * (1 + \alpha_i)^{t-2017} * CAP_{new_{i,t}} * (1 + r)^{-(t-2017)} * [r/(1 + r)/1 - (1 + r)^{-Lc_i}] \quad (2)$$

The discounted operation and maintenance cost is as followed:

$$TC_{om} = \sum_{t,i} OMC_{i,2017} * (1 + \beta_i)^{t-2017} * GEN_{i,t} * (1 + r)^{-(t-2017)} \quad (3)$$

The discounted fuel cost is estimated as follows:

$$TC_{fu} = \sum_{t,i} FUC_{i,2017} * (1 + \gamma_i)^{t-2017} * GEN_{i,t} * (1 + r)^{-(t-2017)} \quad (4)$$

The environmental cost is the amount of money paid for CO2 emission:

$$TC_{env} = \sum_{t,i} CP_t * GEN_{i,t} * ef_i * (1 + r)^{-(t-2017)} \quad (5)$$

The buying cost of electricity from outside a country is estimated as follows:

$$F_{buy} = \sum_t BE_t * EC_t * (1 + r)^{-(t-2017)} \quad (6)$$

The objective function (1) has to satisfy the following constraints:

$$\text{demand–supply balance: } \sum_i GEN_{i,t} + BE_t \geq PD_t \quad (7)$$

$$\text{Installed capacity: } CAP_{i,t} = CAP_{i,2017} + \sum_t CAP_{new_{i,t}} \quad (8)$$

$$\text{The upper boundary of newly installed capacity: } CAP_{new_{i,t}} \leq CAP_{max_i} \quad (9)$$

$$\text{Generation and installed capacity relation: } GEN_{i,t} \leq CAP_{i,t} * FLH_i \quad (10)$$

$$\text{Power system security operation: } \sum_i CAP_{i,t} + BP_t \geq (1 + p) * PL_t \quad (11)$$

$$\text{Electricity and power purchased: } a * ED_t \geq BE_t; b * PL_t \leq BP_t \quad (12)$$

$$\text{CO2 emission limitation: } \sum_i GEN_{i,t} * e_i \leq CO2_t \quad (13)$$

Nomenclature

t	Power planning horizon	2018–2030
i	Types of power plants	Coal, CCGT, OCGT, diesel, hydro, wind, solar
$CAP_{i,2017}$	The total installed capacity of power plant i by the year 2017 (MW)	
$IC_{i,2017}$	The specific investment cost of power plant i in the year 2017 (\$/MWh)	
$OM_{i,2017}, FUC_{i,2017}$	The OM, fuel costs of power plant i in the year 2017 (\$/MWh)	
Lc_i	The life cycle of power plant i (years)	
FLH_i	Average full-load hours of power plant i (hours)	
$\alpha_i, \beta_i, \gamma_i$	The change rates of investment, OM, fuel costs of power plant i (%/year)	
ef_i	The emission factor of power plant i (ton CO2/MWh)	
CAP_{max_i}	Maximum annual growth of installed capacity of power plant i (MW)	
ED_t, PL_t	Electricity demand, peak load in year t (MWh, MW)	
EC_t	External purchased electricity price in year t (\$/MWh)	
CP_t	CO2 price in year t (\$/ton CO2)	
$CO2_t$	CO2 emission limitation in year t (ton CO2/year)	
r	Discount rate (%)	
p	Load margin coefficient (%)	
a, b	The rate of purchased electricity purchased power from neighbors (%)	
$CAP_{new_{i,t}}$	The newly installed capacity of the power plant i in year t (MW/year)	
$CAP_{i,t}$	The total installed capacity of power plant i by year t (MW)	
$GEN_{i,t}$	Annual electricity generation from power plant i in year t (MWh)	
BE_t	The amount of electricity purchased in year t (MW)	
BP_t	The amount of power purchased in year t (MW)	

3. Application of the model to power planning in Vietnam

The capacity structure of power plants is collected from different sources [NLDC, 2017], [16,17]. The costs, future development of costs, full-load hours, are referenced from the surveys and researches by Dapice [18], Nguyen [11] and The Vietnamese government [3].

Because of source limitation, government's orientation, economic effectiveness, as well as electricity supply security, the newly installed capacity per year of technologies is limited [3]. The potential of hydropower for future exploitation is limited notably. Meanwhile, existing the high potential exploitation of wind and solar power [19,20]. The economic and technical specifications of power plants are presented in Table 1.

Table 1. Data of power plants.

Technology	CAP17 MW	IC17 \$/MW	OMC17 \$/MWh	FUC17 \$/MWh	Lc years	FLH hours	α *100(%)	β *100(%)	γ *100(%)	ef tCO ₂ /MWh	CAPnewmax MW/year
Coal-fired	15,983	1,200,000	10	28	30	4500	0.015	0.07	0.012	0.82	3000
CCGT	5,000	800,000	4	67	20	6000	0.01	0.03	0.035	0.49	2000
OCGT	2,539	600,000	7	90	15	5000	0.01	0.03	0.035	0.45	2000
Diesel oil	1,229	200,000	10	225	10	200	0.01	0.03	0.062	0.733	500
Hydro	18,123	1,700,000	2.5	0	40	4000	0.015	0.007	0	0.024	1000
Onshore Wind	159	1,980,000	3.5	0	20	2540	-0.01	0	0	0.011	1000
Solar PV	1	1,000,000	1.8	0	20	1500	-0.02	0	0	0.048	3000

The annual electricity generation growth rate is estimated at around 10.5% (2016–2020), 8.6% (2021–2025), and 7.4% (2026–2030) [3]. Vietnam is going to develop CO₂ caps regulation on all sectors of the economy and possibly on individual emitters [4]. It is assumed that Vietnam will introduce the CO₂ price in 2020 at 7 USD/ton CO₂ in 2020 and 20 USD/ton CO₂ after that [21]. In this research, we consider three assumptions of CO₂ emission limitation (Fig. 1) to finding out the future expansion scenarios: BAU scenario, 8%, and 15% reduction of CO₂ emission compared to the BAU case.

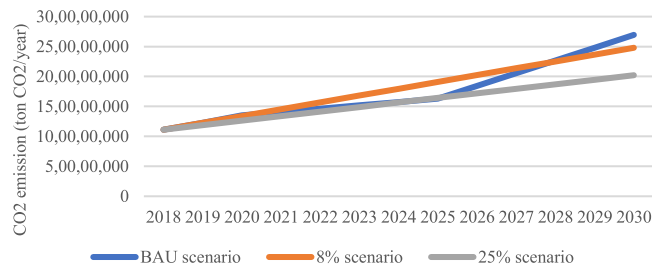


Fig. 1. CO₂ emission scenarios.

Refer to the current values, the parameters of interest rate, load margin coefficient, the rate of purchased electricity, purchased power are assumed to remain at 7%, 20%, 2%, and 2% over the power planning horizon, respectively.

Using the tool GAMS (The General Algebraic Modeling System), the model outcomes provide insights into the future pathways of the power structure in Vietnam.

Fig. 2 reveals that with the lower emission factors, the investment is a priority with the maximum annual values for hydro, wind, and solar power, respectively. No newer coal-fired power plants are constructed from 2029 in the 8% scenario, from 2023 in the 25% scenario. Instead, more investment in gas turbine technologies will be added.

Table 2 compares the shares of installed capacity of coal-fired, gas turbine, wind, and solar PV in two CO₂ reduction scenarios and the PDP VII scenario. Instead of more than 42% coal-fired installed capacity in 2030 as indicated in PDP VII, this power source will account for only around 29% (8% scenario) and 19% (25% scenario). In contrast, the gas turbine technologies will play an essential role and reach 20% (8% scenario) and 29% (25% scenario) instead of 14.7 as in PDP VII. Furthermore, with the maximal installation, the shares of wind and solar are expected to increase from 17% in 2020 to 32% after a decade.

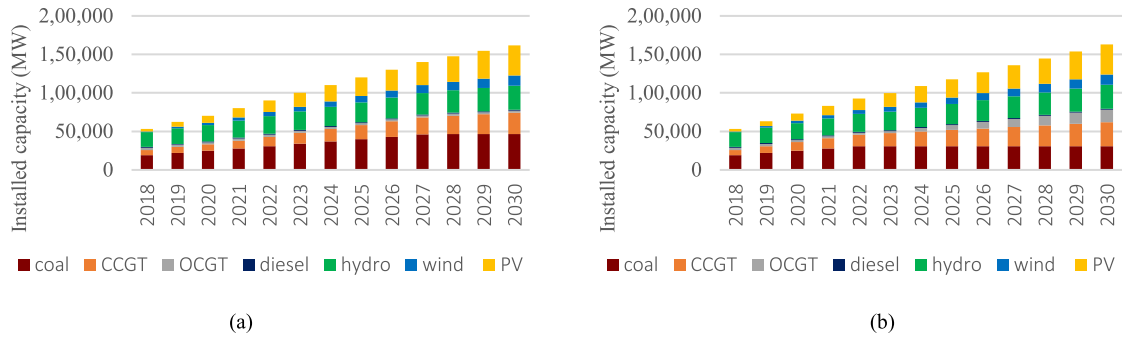


Fig. 2. The installed capacity of different technologies between 2018 and 2030, (a) 8% scenario, (b) 25% scenario.

Table 2. The share of coal-fired, wind and solar PV installation based on different CO2 scenarios.

Year	Coal-fired			Gas turbine			Wind and Solar PV		
	PDP VII	8% scenario	25% scenario	PDP VII	8% scenario	25% scenario	PDP VII	8% scenario	25% scenario
2020	42.70%	35%	34%	14.9%	16%	19%	9.90%	17%	16%
2025	49.33%	33%	26%	15.6%	17%	24%	12.50%	27%	27%
2030	42.60%	29%	19%	14.7%	20%	29%	21%	32%	32%

Fig. 3 shows the contribution of each technology into the CO2 emission. Under the 25% scenario, electricity generation from coal is the primary source of CO2 until 2028 before gas technologies become the main emitters after that.

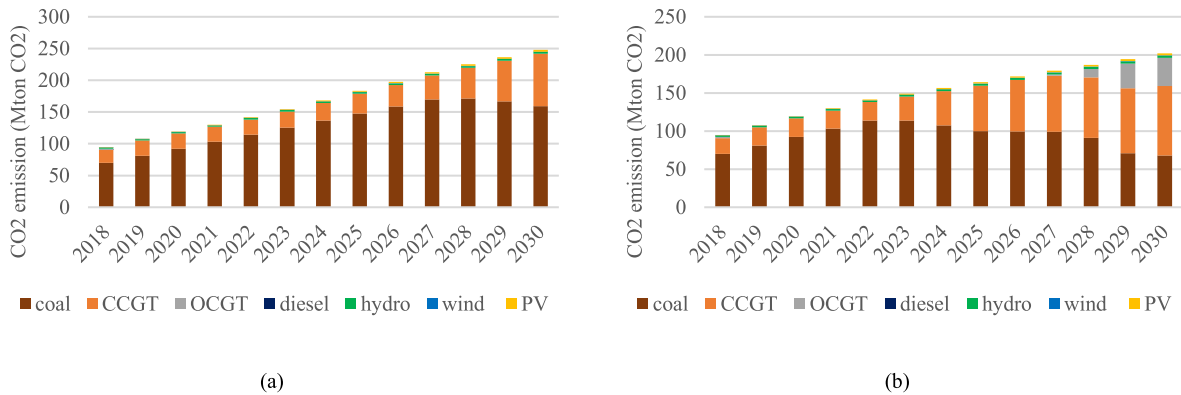


Fig. 3. CO2 emission by fuel between 2018 and 2030, (a) 8% scenario, (b) 25% scenario.

Regarding the discounted system cost, the expenditure is estimated at around 142 billion (8% scenario) and 160 billion (25% scenario). In which, the fuel cost accounts for a considerable portion of the total system cost (61%–66%) while the investment cost makes up only 5%. If the CO2 price is introduced in 2020, the environmental cost is also a significant part of the cost system.

4. Conclusions and policy implications

This paper has developed an optimal energy planning model to discover the power expansion path for Vietnam until 2030 with the consideration of CO2 reduction targets. The costs of power plant investment, operation and maintenance, fuel, environment, and external electricity procurement have been investigated. The designed model is applied to the Vietnamese electricity market, with the assumptions on the future development of electricity demand, peak load, the existence of CO2 price mechanism, and the change rates of costs. The most important constraint is the CO2 emission allowance, which is expected to decrease from 8 to 25% compared to the BAU scenario by 2030.

Through the study, some meaningful conclusions are carried out. Firstly, there is a replacement trend of coal-fired power plants by gas turbine technologies in the next decade. From the years 2028 (8% scenario) and 2023 (25% scenario), more electricity from CCGT and OCGT are generated than the one from coal-fired stations. In other words, the research results show that fuel switching is a useful option to reduce CO₂ emissions. Secondly, wind and solar power play a more and more critical role in the electricity supply system, from 17% in 2020 to 32% after a decade. Also, integrating wind and solar farms into the electricity supply system is the necessary condition to achieve the CO₂ targets. Besides, the outcomes of the research also reveal the different structures of electricity generation technologies until 2030, compared to the PDP VII (as shown in [Table 2](#)).

As planned, the next power development planning for Vietnam (PDP VIII) will be developed in 2019; this research provides a suggestion to the energy policymakers to adjust the targeted installed capacity to get the development of electricity in line with the Paris Agreement.

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