研究論文

Considerable Structures of Power Generation System With Biomass for Sustainable Energy Development in Vietnam

Vo Cuong Viet *1 Yoshishige Kemmoku *2 Hirofumi Takikawa *1 Tateki Sakakibara *1

Abstract

Biomass power generation has been proved to be a competitive power generation source for Vietnam. The objective of this study is to find an optimum structure of power generation system in term of least-cost efficiency by applying the biomass to Vietnam's power generation system in 2010 and 2020. The biomass power generation is assumed to serve from 2010; the biomass fuel is assumed to be supplied by short rotation forest of *Acacia hybrid* which is the fastest growing tree in Vietnam. Software named LINDO (Linear, INteractive, and Discrete Optimizer) is used. The parameters are electricity contribution of biomass power generation, and whether or not nuclear power generation is operated in 2020.

The results show that by introducing biomass power generation into power system, Vietnam does not need nuclear power generation in 2020. Moreover, coal and gas fuel power generations do not need to be operated at the maximum output, and that brings higher energy security. Investment cost of non-nuclear case can be reduced of $2.7 billion compared with that of nuclear case in 2020. As biomass power generation increases from 0% to 10%, generation cost decreases from 2.64 to 2.49 $cent/kWh in 2010, and from 3.03 to 2.8 $cent/kWh in 2020. CO_2 emission factor of power generation decreases from 120.3 to 93.8 g-C/kWh. In addition, as nuclear power generation increases from 0% to 13.9%, CO_2 emission factor decreases still more from 93.8 to 78.9 g-C/kWh.

Keywords: Optimum structure, Power system, Biomass, Nuclear, Generation cost, CO_2 emission, Vietnam

1. Introduction

For the last decade in Vietnam, a rapid economic growth has leaded to a big increasing in electricity demand, and this trend will continue in the future. Energy resource for power generation has become one of the national problems in term of sustainable economic development. Electric load energy in 2020 is considered to increases eight times as much as that in 2000 (22.1 TWh). To meet such demand, Vietnam has planed to start using nuclear power generation in 2020 (1). So far, however, there has been no plan for applying biomass power generation.

Biomass power generation, in which the biomass fuel is assumed to be supplied by 6 years short rotation forest of *Acacia hybrid,* has been proved to be a competitive power generation source for Vietnam by a previous study (2). The objective of this study is to find an optimum structure of power system in term of least-cost efficiency by applying the biomass to Vietnam's power generation system.

The biomass power generation is assumed to serve from 2010. LINDO (Linear, INteractive, and Discrete Optimizer) (10), software for finding the optimum solution, is used.

The first parameter is electric production energy of biomass power generation, which is assumed to be 0%, 5% and 10% of the total electric production energy. The second parameter is whether or not the nuclear power generation is at work in 2020.

Daily load curves in 2010 and 2020 are forecasted from that in 2002.

The optimum structure leads to evaluation of investment cost, generation cost and CO_2 emission factor, as well.

*1 Dept. of Electrical and Electronic Engineering, Toyohashi University of Technology
e-mail:cuong@nature.renewal.tut.ac.jp
*2 Toyohashi Sozo College, Toyohashi
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2. Electric load, electric production energy, generation efficiency, and biomass power generation

2.1. Electric load

According to the Master plan on Electric Power Development in Vietnam for the period of 2000-2010, perspective up to 2020 (1), maximum load demand and electric load energy are presented in figure 1. Average increasing ratio of electric load energy is about 12%/y. Maximum load demand and electric load energy in 2020 are seven and eight times as large as those in 2000 (4.61 GW, 22.1 TWh), respectively.

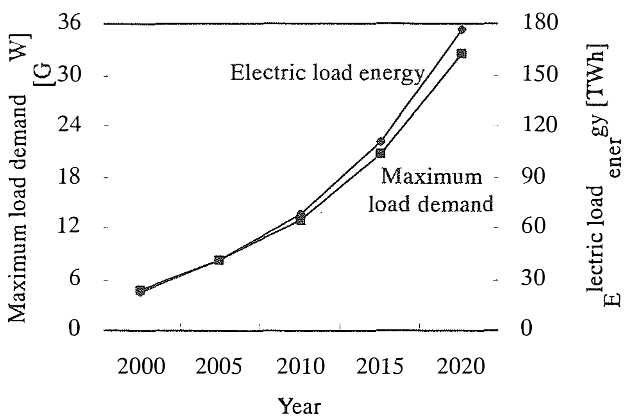

Fig. 1. Maximum load demand and electric load energy from 2000 to 2020

Figure 2 shows transmission and distribution loss of the power system. Electric production energy is the sum of the electric load energy, and the loss of transmission and distribution.

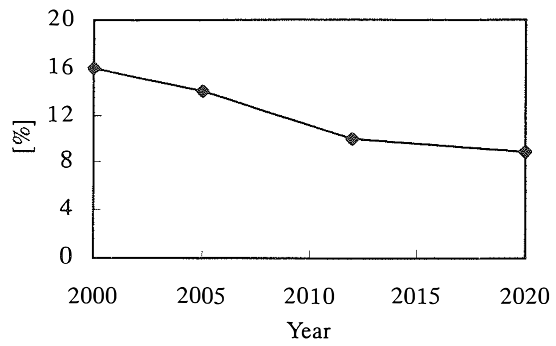

Fig. 2. Transmission and distribution loss from 2000 to 2020 (1)

2.2. Electric production energy

Limit of electric production energy is presented in table 1. Sub-total shows that, without biomass or nuclear power generation, electric energy production could not meet the load in 2020. In this case, coal power generation is assumed to be increased over its limit by increasing domestic coal production or importing coal from Australia. Heavy oil power genration will not be constructed and only use the existing ones.

2.3. Generation efficiency

Currently, the power system are composed of coal, heavy oil, associated gas, gas from fields, and hydro power generations. Generation efficiencies of thermal power generations from 2010 to 2020 are shown in table 2. There is no plan for new heavy oil power plants, and that is the reason why its generation efficiency remains in low value. On the contrary, the gas fuel power plants are all newly constructed. Therefore, its generation efficiency is high.

2.4. Biomass power generation

Biomass power generation, in which biomass fuel is assumed to be supplied from 6 years short rotation forest of *Acacia hybrid*, the fastest growing tree (18 m^3/ha/y) (2), is promising in Vietnam. According to Vo Cuong Viet (2), necessary plantation area for biomass power generation is about 400 ha/MW, and generation cost is about 2.5 $cent/kWh (2002) with 50 MW class. The reasonable size for biomass power generation is from 50 to 100 MW. Therefore, the range of plantation area is from 20,000 to 40,000 ha.

Table 3 presents name of provinces where the area of waste forest is larger than 200,000 ha. There are 14 provinces (about 22% of 64 provinces in Vietnam) and the total is about 4.9 million ha (15% of 32.7 million ha in Vietnam). Therefore, the maximum capacity of biomass power generation is 12.2 GW, and the electric energy production is 85.8 TWh, which equals 42.7% of total electric energy production in 2020. Assuming that biomass power generation contributes 10% of the total electric energy production in 2020, this contribution occupies about 23.4% of its potential.

3. Load pattern and daily load curve

3.1. Load pattern and maximum capacity factor

For reducing variables and constraints in calculation, daily load curves in 2002 are classified into 18 patterns. Criteria for classifying load patterns are set up with electric load energy, maximum load demand, and maximum capacity factors of hydro power generation and import-electricity. Import-electricity is hydro power generation from Laos.

Table 1. Limit of electric production energy (1), (2)

Parameter	Value		Unit
	2010	2020	
Electric load energy (including loss)	78.5	201.4	TWh
Limit electric production energy			
Hydro	29.3	56.5	TWh
Coal	15.4	33.6	TWh
Gas fuel	26.6	69.1	TWh
Associated gas	12.9	12.9	TWh
Gas from field	13.7	56.2	TWh
Heavy oil	3.9	2.7	TWh
Import (from Laos)	5.8	23.1	TWh
Sub-total	81.0	185.0	TWh
Biomass			
5%	3.9	10.1	TWh
10%	7.8	20.2	TWh
Nuclear	0.0	28.0	TWh
Total			
5% Biomass	84.9	223.1	TWh
10% Biomass	92.7	243.3	TWh

Table 2. Generation efficiencies of thermal power generations from 2010 to 2020 (1)

	Coal	Heavy oil	Gas fuel
η_i [%]	25.1/37.9*	31.5	48.0

*: The values of 25.1% and 37.9% correspond to old and new power plants, respectively.

Table 3. Provinces where the area of waste forest is larger than 200,000 ha (3)

No.	Name of province	Area of waste forest [ha]
1	Son La	790,192
2	Nghe An	555,338
3	Gia Lai	434,551
4	Lang Son	390,398
5	Quang Nam	368,977
6	Ha Giang	326,887
7	Yen Bai	309,360
8	Thanh Hoa	306,189
9	Lao Cai	303,664
10	Kon Tum	252,562
11	Cao Bang	233,382
12	Quang Ngai	209,851
13	Dak Lak	209,128
14	Quang Ninh	205,555
Total		4,896,034

Table 4 shows 18 load patterns, and maximum capacity factors of hydro power generation and import-electricity. The maximum capacity factors depend on water flow fluctuation in each country (1). Holidays are every Sunday and other national holidays.

Maximum capacity factors of other power generations (coal, heavy oil, gas fuel, biomass, nuclear) are chosen to be 0.8 for all load patterns.

Table 4. Patterns of daily load curves and maximum capacity factors of hydro power generation and import-electricity

Load pattern	No. of day	Hydro	Import
1: Maximum load demand days (Dec.)	2	0.41	0.67
2: Working days in Oct., Nov.	50	0.52	0.66
3: Working days in Dec.	25	0.41	0.67
4: Working days in Jun.	26	0.50	0.63
5: Working days in Jul.	26	0.69	0.71
6: Working days in Apr., May	51	0.36	0.60
7: Working days in Aug.	27	0.80	0.80
8: Working days in Mar.	26	0.37	0.62
9: Working days in Sept.	24	0.55	0.80
10: Working days in Jan., Feb.	46	0.37	0.58
11: Holidays in Jun.	5	0.50	0.63
12: Holidays in Jul.	4	0.69	0.71
13: Holidays in Mar., Apr., May	15	0.36	0.60
14: Holidays in Aug.	4	0.80	0.80
15: Holidays in Sept.	6	0.55	0.80
16: Holidays in Oct., Nov.,	9	0.52	0.66
17: Holidays in Dec.	6	0.41	0.67
18: Holidays in Jan., Feb.	13	0.37	0.58
Total	365		

3.2. Daily load curves in 2010 and 2020

The daily load curves in 2010 and 2020 are forecasted from those in 2002. Figure 3 presents a typical daily load curve in 2002, and forecasted one in 2010. The forecast method is shown in figure 4 and following procedure:

$$X_0 = \frac{P_{max,\ 2010}}{P_{max,\ 2002}} \tag{1.1}$$

$$X_0 \cdot b_{24} > X_i \cdot b_i \quad (i = 1 \sim 23) \tag{1.2}$$

$$X_i = X_0 + \frac{(x - X_0)}{23} \cdot (24 - i) \tag{1.3}$$

$$x > X_0 \tag{1.4}$$

x is an unknown coefficient that has to be found.

$$\sum_{i,\ q} X_{i,\ q} \cdot b_{i,\ q} \cdot d_q = G_{2010} \quad (i = 1 \sim 24) \tag{1.5}$$

where, P_{max} is the maximum load demand; b_i is the value of load demand after sorting; i is position after sorting of load demand; G_{2010} is electric energy production in 2010; d_q is the number of day of load pattern q.

Then, x is found. After returning the value of $(X_i \cdot b_i)$ to the position before sorting of b_i, the daily load curve in 2010 can be obtained. Using the above method, daily load curves in 2020 are forecasted, as well.

While the load factor of 2002 is 63.4%, those of 2010 and 2020 are calculated to be 67.9% and 70.2%, respectively. This tendency of increasing of load factor is as same as that reported in "Regional Cooperation Strategy on Interconnected Power Networks in Indochina", 2002 [4]. The reason why the load factor increases is that the daily load curve flattens out due to the structural change in industrial and household load, and DSM (Demand Side Management).

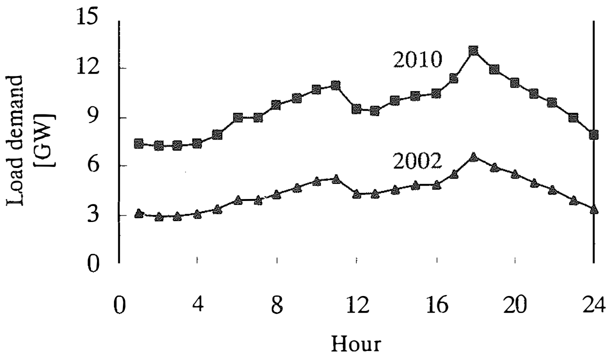

Fig. 3. Typical daily load curve

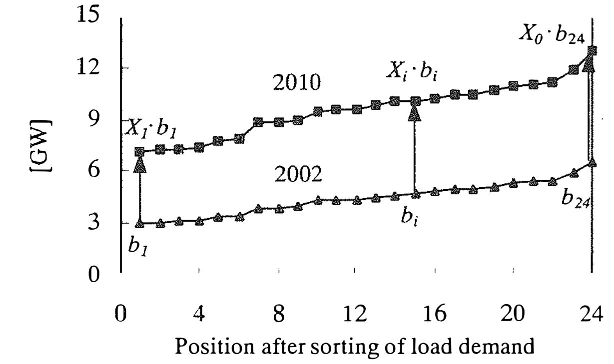

Fig. 4. Sorting in the order of increasing load demand of Fig. 3

4. Objective function and its constrains

Optimum structure of power system is calculated using the linear optimization method consisting of an objective function and a set of constraints of variables.

4.1. Objective function

The objective function is the total generation costs in 2010 and 2020, as follows:

$$O = \sum_{g,\ q,\ t,\ y} W_y \cdot CE_{g,\ y} \cdot X_{g,\ q,\ t,\ y} \longrightarrow \min \tag{2.1}$$

where,

g: Power generations (coal, heavy oil, gas fuel, hydro, import-electricity, biomass, nuclear)

q: Load patterns of daily load curve (1～18, see Table 4)

t: Time (1h～24h)

y: Year (2010, 2020)

$CE_{g,\ y}$: Generation cost of power generation g in year y

$X_{g,\ q,\ t,\ y}$: Output of power generation g in pattern q at time t and in year y

W_y: Conversion coefficient to current price

The W_y is calculated as follows:

$$W_y = \left(\frac{1 + r}{1 + \varepsilon}\right)^{(y - 2002)} \tag{2.2}$$

where, r is the interest rate (average: 8%/y); ε the inflation rate (average: 5%/y)

The generation cost of power generation g in year y, $CE_{g,\ y}$, is calculated as follows:

$$CE_{g,y} = \frac{F_{g,y} + A_{g,y} + MO_{g,y}}{X_{g,y}} \quad [\$/\text{kWh}] \quad (2.3)$$

where, $F_{g,y}$ is the fuel cost; $A_{g,y}$ is the amortization of investment cost; $MO_{g,y}$ is the maintenance & operation; $X_{g,y}$ is the output of power generation g in year y [kWh].

The $A_{g,y}$ is calculated as follows:

$$A_{g,y} = \frac{r_0 \cdot (1 + r_0)^n}{(1 + r_0)^n - 1} \cdot I_{g,y} \cdot C_{g,y} \cdot 10^3 \quad [\$/\text{y}] \quad (2.4)$$

where, r_0 is the interest rate of ODA capital (= 2.6%/y); n is the life time of power generation g [y]; $I_{g,y}$ the is investment cost of power generation g in year y [\$/kW]; $C_{g,y}$ is the installed capacity of power generation g in year y [MW].

Table 5 shows fuel costs for power generations until 2020. Average increasing ratio of fuel costs are 17% and 20% from 2002 to 2010, and from 2010 to 2020, respectively. Price of import-electricity is assumed to be 3.4 \$cent/kWh in 2002 which is as same as the price that EVN buys from independent power generations (IPP). The price will increase to 3.74 \$cent/kWh (10% increase relative to 2002) in 2010 and to 4.1 \$cent/kWh (9.6% increase relative to 2010) in 2020 in the same manner as other thermal power generations.

Table 6 shows investment, operation and maintenance costs. Specific investment cost of heavy oil power generation is low because heavy oil power generations were constructed about 20 to 30 years ago.

Table 5. Fuel cost for power generation in Vietnam [(1),(9)]

	Unit	2002	2010	2020	LHV
Coal	\$/t	20.8	25.2	31.5	5,500 kcal/kg
Heavy oil	\$/t	146.5	164.1	179.4	9,910 kcal/kg
Gas fuel	\$/10^6BTU	2.3	2.7	3.4	
Wood fuel	\$/t	19.2	22.5	26.9	3,334 kcal/kg
Nuclear [(9)]	\$/kg UO_2			1000.0	8,121 Mcal/kg

Table 6. Investment, operation and maintenance costs [(1),(2),(7)]

Power generation	Specific investment cost [\$/kW]	O&M cost Fixed O&M [\$/kW·y]	O&M cost Variable O&M [\$cent/kWh]	Life time [y]
Coal	1,104	31.68	0.24	30
Heavy oil	365	6.12	0.28	20
Gas fuel	591	11.76	0.22	25
Biomass	1,050		0.25*	25
Hydro	1,000		0.31*	50
Nuclear	1,500		0.49*	40

*: Including fixed O&M

4.2. Constraints

The above objective function is constrained by electric load, maximum production energy, maximum and minimum installed capacity, reserve capacity, capacity factor, and load trace-ability ratio.

4.2.1. Electric load

The sum of output of all power generations equals the load demand:

$$\sum_g X_{g,q,t,y} = P_{q,t,y} \quad (3)$$

where, $P_{q,t,y}$ is the electric load demand in pattern q at time t in year y

4.2.2. Maximum production energy

Electric production energy of generation g in load pattern q at time t and in year y is lower than its output at a time of maximum load.

$$X_{g,q,t,y} \le X_{g,q,tmax_q,y} \quad (4.1)$$

where,

$tmax_q$: Time of a maximum load in load pattern q

Electric production energy of generation g in year y is lower than its limit.

$$X_{g,y} \le Q_{max,g,y} \quad (4.2)$$

where, $Q_{max,g,y}$ is the limit of electric production energy from power generation g in year y (see Table 1).

And, following constraints must be met for different power generations.

a. Hydro power generation

Output of hydro power generation is influenced by fluctuation of water flow during the year. Therefore, the output is lower than its maximum operation capacity, which is shown in figure 5 [(1)].

$$X_{g',q,y} \le C_{o,g',q,y} \le C_{g',y} \quad (4.3)$$

where, g' is the hydro power generation; $C_{o,g',q,y}$ is the maximum operation capacity of power generation g' in load pattern q in year y; $C_{g',y}$ is the installed capacity of power generation g' in year y.

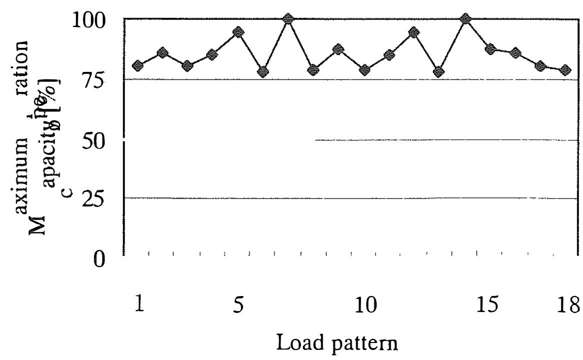

Fig. 5. Maximum operation capacity of hydro power generation (installed capacity: 100%)

b. Other power generations

Output of other power generations g'' in load pattern q at time t and in year y is lower than its installed capacity.

$$X_{g'',q,y} \le C_{g'',y} \quad [\text{kW}] \quad (4.4)$$

where, g'' is the power generation of heavy oil, coal, gas fuel, biomass, nuclear, and import-electricity; $C_{g'',y}$ is the installed capacity of generation g'' in year y.

4.2.3. Maximum installed capacity

Installed capacities of heavy oil, hydro, nuclear power generations and import-electricity are lower than their maximum installed capacities:

$$C_{g*,\,y} \le C_{max,\,g*,\,y} \tag{5}$$

where, $g*$ is the power generation of heavy oil, hydro, nuclear, and import-electricity; $C_{max,\,g*,\,y}$ is the maximum installed capacity of power generation $g*$ in year y.

Table 7 shows the maximum installed capacities of the power generation $g*$ in 2010 and 2020.

Table 7. Maximum installed capacity [1]

Power generation	2010	2020	Unit
Heavy oil	0.563	0.386	GW
Hydro	6.896	13.294	GW
Import	1.000	4.000	GW
Nuclear	0.000	4.000	GW

4.2.4. Minimum installed capacity

Installed capacity of power generation g in 2010 is higher than its capacity in year 2002 minus an abolition capacity from 2002 to 2010. The same statements are valid for the installed capacity in 2020

$$C_{g,\,2010} \ge C_{g,\,2002} - C_{abo,\,g,\,(2002\text{-}2010)} \tag{6.1}$$

$$C_{g,\,2020} \ge C_{g,\,2010} - C_{abo,\,g,\,(2010\text{-}2020)} \tag{6.2}$$

where, $C_{g,\,y}$ is the installed capacity of power generation g in year y; $C_{abo,\,g,\,(y_i-y_j)}$ is the abolition capacity of power generation g from year y_i to y_j.

Table 8 and 9 present the installed capacity of power generations in 2002 and the abolition capacity, respectively.

Table 8. Installed capacity of power generations in 2002 [GW] [1]

Hydro	Coal	Heavy oil	Gas fuel
4.187	1.245	0.563	2.322

Table 9. Abolition capacity of power generations [GW] [1]

Year	Hydro/ import	Coal	Heavy oil	Gas fuel	Bio-mass	Nuclear
2002-2010	0	0	0	0	0	0
2010-2020	0	0.645	0.177	0	0	0

4.2.5. Reserve capacity

For reliability, the sum of installed capacities of power generations in year y has to be larger than the maximum electric load demand including the reserve capacity as follows:

$$\sum_{g,\,y} C_{g,\,y} \ge (1+\alpha_y)\cdot P_{max,\,y} \tag{7}$$

where, $P_{max,\,y}$ is the maximum load demand in year y, and α_y is the reserve margin in year y.

The LOLE (Loss Of Load Expectation) is chosen as an indicator of power system reliability in this study. Table 10 presents the reserve margin of the power system, which was calculated in EVN [1] and JBIC (Japan Bank for International Cooperation) [4]. Nuclear power generation is assumed to be constructed in 2020 [1]. Due to the lack of data for calculating the system reliability in case of non-nuclear in 2020, it is assumed that the reserve margin of the power system is the same for both cases of nuclear and non-nuclear. These values are also adopted in the power system including the biomass power generation because the FOR (Forced Outage Rate) of the biomass power generation is equivalent to that of the thermal power generation.

Table 10. Reserve margin and installed capacity [1], [4]

Year	Maximum load demand [GW]	LOLE target [h/y]	Reserve margin [%]
2010	12.982	24	8.6
2020	32.676	24	8.9

4.2.6. Capacity factor

Constraint of daily electric poroduction energy of power generation g is given by

$$\sum_t X_{g,\,q,\,t,\,y} \le 24\,L_{g,\,q}\cdot C_{g,\,y} \tag{8}$$

where, $L_{g,\,q}$ is the maximum capacity factor of power generation g in load pattern q (see section 3.1).

4.2.7. Load trace-ability ratio

The relationship between the load trace-ability ratio and the output of power generation g is given by

$$(1-\rho_g)\cdot X_{g,\,q,\,t\text{-}1,\,y} \le X_{g,\,q,\,t,\,y} \le (1+\rho_g)\cdot X_{g,\,q,\,t\text{-}1,\,y} \tag{9}$$

where, ρ_g is the load trace-ability ratio of power generation g.

Table 11 shows load trace-ability ratio of each power generation.

Table 11. Load trace-ability ratio of power generations [%/h] [8]

Hydro/ import	Coal	Heavy oil	Gas fuel	Biomass	Nuclear
10.0	20.0	50.0	60.0	20.0	2.0

5. CO_2 emission factor

CO_2 mission factor of power system is calculated from the life cycle CO_2 mission factor of each power generation. Table 12 and 13 show the life cycle CO_2 emission factor of power generations operated in Vietnam. CO_2 emission factor of coal power generation reduces considerably in 2010 and 2020 because of increasing in its generation efficiency. CO_2 emission factor of import-electricity is assumed to be the same as that of hydro power generation in Vietnam.

Table 12. CO_2 emission factor of coal power generation [5]

Year	2002	2010	2020
[g-C/kWh]	401.7	336.6	288.8

Table 13. CO_2 emission factors of other power generations (2010-2020) [g-C/kWh] [2], [5], [6]

Heavy oil	Associated gas	Field gas	Biomass	Hydro/ Import	Nuclear
252.6	134.3	126.5	5.4	3.07	9.6

6. Result

Optimum structure of power system is found from calculation of the linear programming consisting of an objective function and a set of constraints of variables. The objective function is given by equation (2.1) and the set of constraints is given by equations (3) to (9). The calculation results bring installed capacity and electric production energy of power generations. These results lead to evaluation of investment cost, generation cost and CO_2 emission factor of the power system.

6.1. Structure of power system

6.1.1. Installed capacity

Figure 6 shows optimum installed capacity of power generations in 2010, and 2020. Installed capacity was 8.9 GW in 2002 and increases to 15.5 GW in 2010 and 37.8 GW in 2020.

As electric production energy of biomass power generation increases from 0% to 10%, installed capacity increases from 0% to 7.6%. Installed capacity of hydro power generation increases from 4.2 GW in 2002 to 6.9 GW in 2010 and to 13.3 GW in 2020. However, ratio of installed capacity of hydro power generation to the total installed capacity reduces from 47.3% in 2002 to 35.1% in 2020. Installed capacity of heavy oil power generation decreases considerably. Import-electricity is fixed at 1.0 GW (6.5%) in 2010 and 4.0 GW (10.6%) in 2020. Nuclear contributes 4.0 GW (10.6 %) in 2020.

In 2010, although installed capacity of coal power generation does not change (14.2%) with biomass contribution of 0% and 5%, it decreases to 11.8% with biomass of 10%. In case of non-nuclear power generation in 2020, while installed capacity of gas fuel power generation hardly changes (34.3%), the coal power generation decreases from 18.9% to 12.7%. In case of nuclear power generation in 2020, installed capacity of gas fuel power generation decreases from 30% to 26.6% and coal power generation decreases from 12.7% to 8.5%.

6.1.2. Electric production energy

Electric production energy was 35.8 TWh in 2002 and increases to 78.5 TWh in 2010 and 201.4 TWh in 2020 as shown in figure 7.

Hydro power generation operates at its maximum production energy. The production energy increases from 18.2 TWh in 2002 to 29.3 TWh in 2010 and to 56.5 TWh in 2020. However, the contribution reduces from 50.8% in 2002 to 28% in 2020. Gas fuel power generation operates at its maximum production energy, as well. The production energy reaches to 26.6 TWh in 2010 and to 69.1 TWh in 2020.

As electric production energy of biomass power generation increases from 0% to 10%, electric production energy by coal, heavy oil power generations and import-electricity decrease.

In 2010, electric production energy by coal, heavy oil power generations, and import-electricity decrease from 19.6% to 16.5%, from 1.8% to 0.7%, and from 7.4% to 1.8%, respectively. In 2020, in case of non-nuclear power generation, electric production energy by coal exceeds its limit of 33.6 TWh and reaches to 50.2 TWh and to 40 TWh in case of biomass contribution of 0% and 5%, respectively. With biomass contribution of 10%, the coal power generation decreases back to its limit. In case of nuclear power generation in 2020, electric production energy by nuclear is 13.9 %, electric production energy by coal, and import-electricity decrease from 16.7% to 11.1%, and from 7% to 2.6%, respectively. Electric production energy by heavy oil is almost zero.

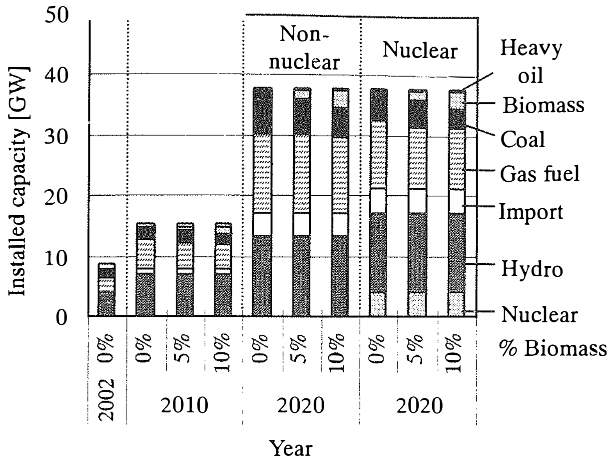

Fig. 6. Optimum installed capacity of power generations

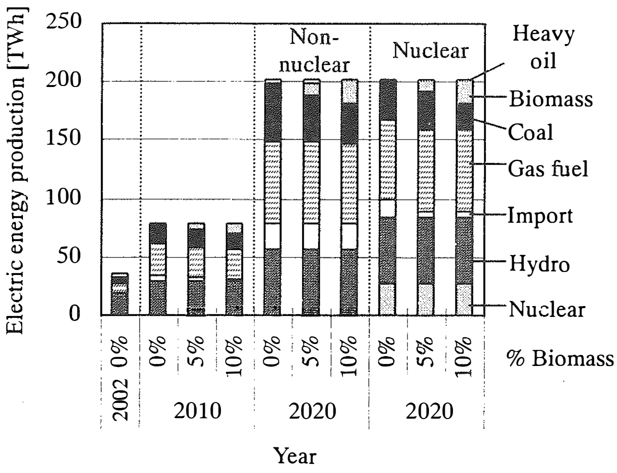

Fig. 7. Optimum electric production energy

6.2. Investment and generation cost

Total investment cost for power system is calculated and presented in figure 8. It reaches to about \$5.5 billion in 2010, \$17.5 billion with non-nuclear and \$20.2 billion with nuclear in 2020.

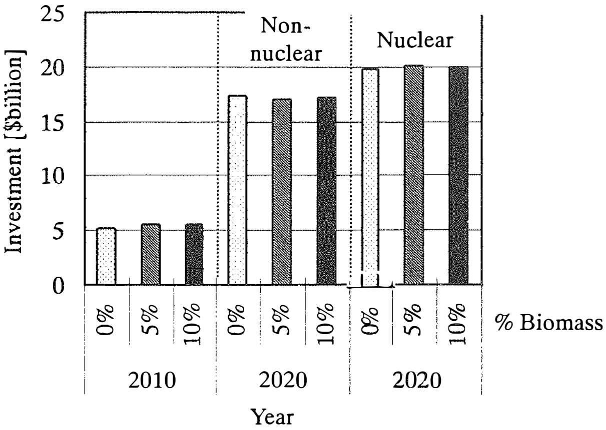

Fig. 8. Total investment cost for power system

Electric generation cost is calculated and shown in figure 9. As biomass contribution increases from 0% to 10%, generation cost decreases gradually.

In 2010, generation cost decreases from 2.64 to 2.49 \$cent/kWh. In 2020, in case of non-nuclear power generation, it decreases from 3.03 to 2.95 \$cent/kWh; in case of nuclear power generation, it decreases from 2.88 to 2.80 \$cent/kWh.

Generation cost in 2002 is 2.69 \$cent/kWh. The structure of power system is not optimum in 2002 but optimum in 2010. Therefore, generation cost in 2010 is a little lower than that of 2002 despite of increasing of fuel cost. Generation cost in 2020 is higher than that of 2010 because fuel cost increases and the contribution of hydro power generation decreases. In 2020, generation cost in case of nuclear operating is lower than that of non-nuclear.

6.3. CO_2 emission

CO_2 emission factor of power system is calculated and shown in figure 10. It decreases as biomass contribution increases or nuclear power generation is operated.

CO_2 emission factor is 124.5 g-C/kWh in 2002. In 2010, as biomass increases from 0% to 10%, it decreases from 120.3 g-C/kWh to 93.8 g-C/kWh. CO_2 emission factor in 2010 is lower than that of 2002. In case of non-nuclear power generation, CO_2 emission factor with biomass contribution of 0% in 2020 is higher than that of in 2010. This is caused by a considerable increase in coal power generation. The smallest CO_2 emission factor is about 78.9 g-C/kWh in case of nuclear and biomass contributions of 13.9% and 10% in 2020, respectively.

7. Discussion

Increasing or decreasing of installed capacity and electric energy production of each power generation depends on its investment cost, fuel cost, and generation efficiency.

As electric production energy of biomass power generation increases from 0% to 10%, installed capacity and electric production energy of hydro power generation are always at their maximum because there is no fuel cost in hydro power generation and its specific investment cost is lower than those of coal and biomass power generations.

Installed capacity of gas fuel power generation hardly changes and remains at high value, and its electric production energy is at its maximum because of its low specific investment cost and high generation efficiency. While, installed capacity and electric production energy of coal power generation decrease because of its high specific investment cost and low generation efficiency. Installed capacity and electric production energy of heavy oil decreases, as well. Because its fuel cost is high and generation efficiency is low. And import-electricity decreases because of its high price.

Investment cost of power system with nuclear is higher than that with non-nuclear because specific investment cost of nuclear power generation is very high.

As biomass contribution increases, generation cost decreases because biomass power generation has competitive generation cost, and CO_2 emission factor of power system decreases because biomass power generation has a very low CO_2 emission factor. Generation cost in case of nuclear is lower than that of non-nuclear case because nuclear power generation has a very low fuel cost.

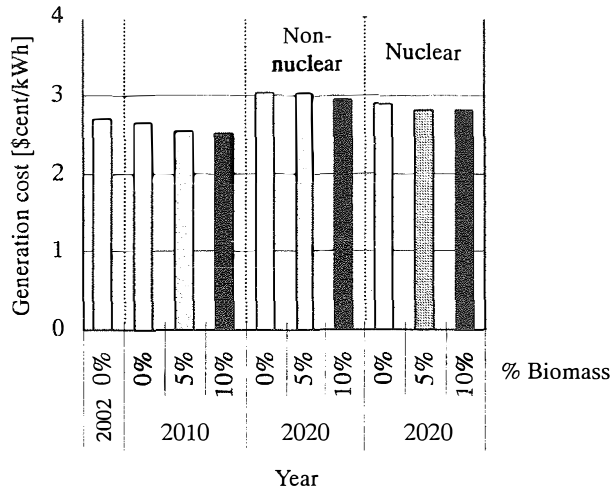

Fig. 9. Generation cost of power system

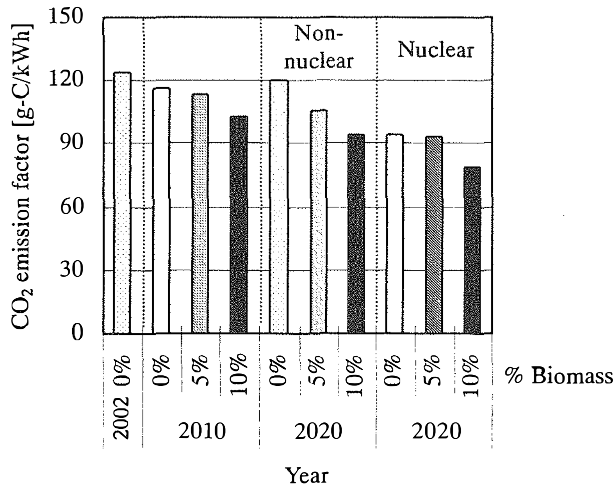

Fig. 10. CO_2 emission factor of power system

Biomass power generation in Vietnam, in which biomass fuel is supplied by short rotation forest of *Acacia hybrid*, is much better than other generations because it is "CO_2-neutral" generation, and its generation cost is competitive. While, generation costs of hydro and nuclear power generations are lower than that of biomass power generation, hydro power generation destructs the environment and nuclear power generation brings radioactive wastes. Thermal power generations emit much GHG, and their generation cost may increase in the future, as well.

When introducing biomass power generation in large scale, however, there are some problems as follows: firstly, it is essential to persuade governors and farmers to start for establishing forest, which supply biomass fuel for power generation. Secondly, more investments are also needed to set up infrastructure in the area of establishing the forest. Thirdly, the forest has to be protected from fire.

8. Conclusion

Optimum structure of power system in Vietnam is calculated in term of least-cost efficiency using the linear optimization programming consisting of an objective function and a set of constraints of variables. The objective function is the total electric generation costs in 2010 and 2020. The biomass power generation is assumed to serve from 2010. Contribution of biomass varies from 0% to 10% of the total electric production energy. Nuclear power generation has been planned to start in 2020 in Vietnam. However, it is still treated as a parameter in this study. Calculation results are as follows:

(1) By introducing of biomass into power system, Vietnam does not need nuclear power generation in 2020. Moreover, coal and gas fuel power generations do not need to be operated at the maximum output, and that brings higher energy security.

(2) Investment cost of non-nuclear case can be reduced of $2.7 billion compared with that of nuclear case in 2020. This is very important because Vietnam is facing a big problem of finding enough investment for the power system. There was a very large blackout of electricity supply in Northern Vietnam in May 2005 because investment for establishing new power plants was not supplied on time.

As biomass power generation increases, generation cost decreases gradually because of its competitive generation cost. Generation costs decrease from 2.64 to 2.49 $cent/kWh in 2010, and from 3.03 to 2.8 $cent/kWh in 2020.

(3) CO_2 emission is reduced considerably by the contribution of biomass and nuclear power generations. It was 125 g-C/kWh in 2002, but could reduce to the smallest value of about 79 g-C/kWh in case of nuclear operating and 10% biomass contributions in 2020.

In conclusion, the biomass power generation would bring significant benefits on economic, environmental for the power generation system and energy security of Vietnam in the future.

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