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TIME-SERIES ANALYSIS IN POWER SUPPLY SYSTEM TO ACHIEVE A SUSTAINABLE ECONOMIC GROWTH IN BANGLADESH

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ABSTRACT

This study clarifies how power generation capacity and composition affect to economic growth with dynamic national economic model. To simulate it, a dynamic evaluation model is built up with considering power generation portfolio. The model is based on CGE model which seeks equilibrium of market by change of power generation facility composition, and time series variation of real GDP and electricity price are simulated in Bangladesh case. In result, it is simulated that capacity of power generation has critical impact on economic growth. Therefore, the effective investment to promote economic growth is, investing to low cost technology during the constraint of power generation capacity exists, and after enough capacity acquired, shifting to renewable energy.

Keywords: Power Generation, Renewable Energy, Economic Growth.

1. INTRODUCTION

Sustainable economic growth with modern technology could be afforded through a sufficient and continuous electricity generation. Especially, it has potential to be significant constraint for countries on beginning stage of rapid growing, like Bangladesh.

In current situation, Bangladesh needs to develop capability of power generation because blackout or load shedding damages to economic activity. In the other hand, current power generation which depends on natural gas extremely has much risk in viewpoint of energy security. Therefore it is necessary to change the power source portfolio to multi-source. Here, the affordable portfolio is to be selected with viewpoint both cost and sustainability among exhaustible resources and natural one in long-term.

Therefore, a long-term investment plan is needed which makes the power generation portfolio match to demand for economic growth with balance among the technology progress and cost. Thus dynamic economics evaluation is vital to achieve the changing to sustainable path.

There are many models to evaluate an international demand and supply in energy field so far, like EPPA [1], AIM model [2] and so on. These models are based on Computable General Equilibrium (CGE) model, and revised to be able to calculate energy demand, supply and environment impact dynamically with sequential equilibrium. The models recognize electricity as normal goods, and then the prices are calculated by supply-demand balance. However, electricity price is to be calculated by cost based approach because the electricity is necessary goods for economy, different from the other goods. On the other hand, There is MERGE model [3] which can express world energy supply and demand for each energy resources. However it does not work in analysis for a national decision making, since does not focus on a national economic ripple effect.

Therefore, the objective of this study is clarifying how power generation capacity and composition affect to economic growth with dynamic national economic model.

2. CALCULATION MODEL

In this study, the calculation model is based on the applying general equilibrium model. Essential theory of the model is constructed by Léon Walras, which explain the behavior of supply/demand side and prices in a whole economy in each goods and production factors markets, by seeking to prove that a system of prices exists that will result in equilibrium. It is useful to express how a policy effects to economy system in a circumstance set by actual world data

This study’s model is designed as 8 sectors and 8 goods applying general equilibrium model, can analyze electricity price and ripple effect to national economy with investment target for power generation, i.e. as change of capital accumulation for each power generation technology.

There are some assumptions in this model. First of all, perfect competitive equilibrium is assumed except power sector, so that the players act as price taker in the market. In power sector, electricity price is determined by the cost calculated from composition of power generation facilities. Secondary, all sectors produce goods under constant returns to scale. It means input coefficient for economy is the homogeneous system of liner equations. Finally, representative household assumption is adopted. Hence, final consumption, saving/investment, and labor supply are derived by it. In addition, full employment is also assumed.

In this dynamic model, real GDP for 20 years is calculated from 2010 to 2030 with sequential equilibrium. An investment for power supply facility is given as scenario, and then it determines a capital stock of electricity sector for next year. Since, it becomes a capability of power generation as constraint condition in next year. Productions of each sector are calculated following demand of each sector under the constraints of production factors; labor number, capital stock, and power generation. In the other word, the model solves a distribution problem of the three elements.

The power generation portfolio contains 7 technologies; solar, wind, and hydro power as renewable energy, nuclear, coal, natural gas, and oil as exhaustible energy.

2.1. PRODUCTIVE STRUCTURE

Production side has 8 sectors that have multi-stage nested Constant Elasticity of Substitution (CES) production function. The function is easy to descript a complicate production/consumption structure, since also adopted EPPA [1] and so on.

The structure contains 3 layers as shown in Fig.2. 1st layer has final goods Y_j produced by sector j (j=1,2,..,8). 2nd layer expresses the production factor and intermediate goods X_n input from other sectors. 3rd layer shows contents labor L and capital K. Electricity is treated as intermediate goods. These factors are integrated by considering substitutability. Concretely, Leontief type function for 2nd layer, CES type for 3rd layer is adopted.

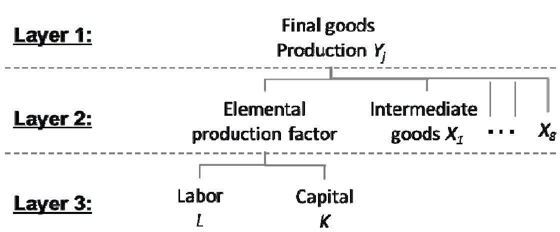

Fig 1. Production structure

Eq.(1) is formulated from Fig.1; where α is scale parameter, means Total Factor Productivity (TFP), and β is share parameter in CES function. σ means elasticity of substitution which are constant in each layer. The elasticity is determined later by calibration under actual current situation.

$$Y_{j,t} = min\left[\frac{\alpha_{j,t}\left\{\beta_j L_{j,t}^{\frac{\sigma-1}{\sigma}} + (1-\beta_j) K_{j,t}^{\frac{\sigma-1}{\sigma}}\right\}^{\frac{\sigma}{\sigma-1}}}{a_0}, \frac{X_{1,t}}{a_i}, \cdots, \frac{X_{i,t}}{a_i}\right] \quad \textbf{(1)}$$

The variables, K, L can move inter-sectors freely, and are distributed to minimize the production cost. Each variable is given the limitation volume in every year. TFP and labor are set exogenously, and capital volume is determined by investment endogenously from last year.

In this model, export and import trading is treated as linear relation to national production. In other words, exchange ratio of volume between export and import goods is fixed exogenously, and the trading does not affect to rest of the world, i.e. the global price system.

2.2. CONSUMPTION STRUCTURE

Consumption side is explained by representative household who act to maximize own utility. The consumer has elemental production factors, labor and capital, and gains income by providing them to production sectors without taxes. Therefore, added value produced by each sector is distributed to household as the income directly.

The utility function is defined in the same structure as production function, and contains 3 layers as shown in Fig.2. 1st layer has utility U which is equal to the income in this model, and also to the added value produced by whole sectors. Next, in 2nd layer, the utility (i.e. the income) is distributed to consumption of composite goods and electricity. The consumption means the final demand balanced to production described above. 3rd layer contains detail of composite goods consumption. These variables are integrated by CES type function.

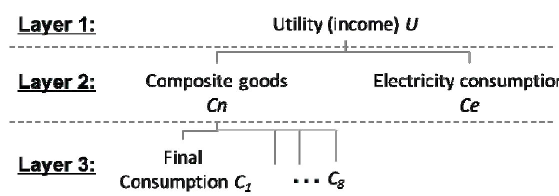

Fig 2. Consumption structure

The above structure gives Eq.(2); where γ_m is share parameter, φ_m is elasticity of substitution in CES type integration.

$$U = \left\{\gamma_m \cdot Cn_t^{\frac{\varphi_m - 1}{\varphi_m}} + (1-\gamma_m) \cdot Ce_t^{\frac{\varphi_m - 1}{\varphi_m}}\right\}^{\frac{\varphi_m}{\varphi_m - 1}} \quad (2)$$

The investment is included in final consumption, equal to the income. In this model, it is assumed that the household purchases the investment goods. A part of the investment is used for power generation facility constantly, following to the investment portfolio. Here, the investment includes also household saving in this model, because the saving is banked and the production sectors use it as investment. Thus, the saving/investment are financed for the production in this model.

Next, a demand function can be derived from eq.(2) and the assumption; the household act to maximize the utility. The household can decide how much volume in the income to use as consumption of each goods. Therefore, the problem is to maximize consumption under income constraint condition, and can be solved by

Lagrange multiplier method. The income *In* is expressed following equation.

$$In = p_n Cn + p_e Ce \tag{3}$$

where, *p* is price of goods, and composite goods *Cn* is written by below equation.

$$Cn = \left\{ \sum_j \gamma_{n,j} \cdot C_j^{\frac{\varphi_n - 1}{\varphi_n}} \right\}^{\frac{\varphi_n}{\varphi_n - 1}} \tag{4}$$

where, γ_n is share parameter, and φ_n is elasticity of substitution. Lagrangian is expressed with eq.(2) and eq.(3);

$$\mathcal{L} = \left\{ \phi \cdot Cn_t^{\frac{\varphi-1}{\varphi}} + (1-\phi) \cdot Ce_t^{\frac{\varphi-1}{\varphi}} \right\}^{\frac{\varphi}{\varphi-1}} - \lambda(p_n Cn + p_e Ce - In) \tag{5}$$

Differentiating partially by *Cn* and *Ce*, erasing λ, and following condition is derived.

$$\frac{\gamma_m}{1-\gamma_m} \left(\frac{Ce}{Cn} \right)^{\frac{1}{\varphi_m}} = \frac{p_e}{p_n} \tag{6}$$

This equation and eq.(3) lead the demand functions below.

$$Cn = \frac{\gamma_m^{\varphi_m} \cdot In}{p_n^{\varphi_m} \{ \gamma_m^{\varphi_m} \cdot p_n^{1-\varphi_m} + (1-\gamma_m)^{\varphi_m} \cdot p_e^{1-\varphi_m} \}} \tag{7}$$

$$Ce = \frac{(1-\gamma_m)^{\varphi_m} \cdot In}{p_e^{\varphi_m} \{ \gamma_m^{\varphi_m} \cdot p_n^{1-\varphi_m} + (1-\gamma_m)^{\varphi_m} \cdot p_e^{1-\varphi_m} \}} \tag{8}$$

The demand of each goods also be derived by eq.(4) under the same procedure above, i.e. maximize *Cn* under a condition expressed in eq (9).

$$p_n \cdot Cn = \sum_j P_j \cdot C_j \tag{9}$$

In result, the following equation is given.

$$C_j = \frac{\gamma_{n,j}^{\varphi_n} \cdot p_n \cdot Cn}{p_j^{\varphi_n} \sum_k \gamma_{n,j}^{\varphi_n} \cdot p_k^{1-\varphi_n}} \tag{10}$$

Through above process, the demand functions about Cn, Ce, Cj are derived.

In this model, the investment ratio for each power generation facility is set exogenously, and the each production sectors uses electricity from it. The electricity generated by 7 technologies are integrated to an electricity goods. The volume of electricity matches to consumption explained as above. Thus, the electricity is distributed to each production sector by equilibrium calculation under capacity of power generation.

2.3. DYNAMIC CALCULATION

This model treats economic growth by sequential equilibrium. Dealing with utility maximization of the household economy in a time series, the household decision making should be based on net present value of the earning acquired from future capital. However, the method is difficult to obtain a solution because annual variables must be treated as independent, and needs enormous calculation load. Therefore, this model adopts sequential procedure with some exogenous variables.

The factors of explaining the dynamic economic growth are three, labor growth, capital accumulation and technology improvement in this model.

First of all, the growth forecast of labor force is set exogenously, referring to *World Population Prospects* [4]. Wage rate *w* is standard price of equilibrium price system in the model.

Secondary, capital accumulation is described with different way for electricity and non-electricity sector. In electricity sector, the power generation facilities are constructed by investment portfolio given as scenario, with considering capital wastage and technology improvement of renewable energy as below mentioned. The volume of investment has fixed rate relative to final consumption. About non-electricity sector, the annual investment is going to be divided by capital rent *r*, and then is set for capital accumulation for next term, after deducting capital wastage.

Finally, two factors are affected by technology improvement. That are total factor productivity α in eq.(1), and production technology for renewable energy sources. TFP includes all factors of economic growth except what labor and capital cannot explain. For example, effect of education, management skills, and so on. In this model, the TFP is estimated under assumption that Bangladeshi economic growth will close to China and India in these 2o years. Since these countries have similar characters, that are located in Asia and have high population. On the other hand, the production technology for renewable energy, solar and wind, let the cost down. This process is explained by learning effect, and is represented by the ratio of cost down when the product is installed double of standard year. The learning effect is formulated like following equation.

$$FC_t = FC_0 \cdot (1 - LE)^{\log_2 \frac{K_t}{K_0}} \tag{11}$$

where, *FC* is power facility cost, *LE* is learning effect i.e. cost down ratio, and *K* is world accumulate facilities installed. The index *t* means time and *0* is standard time. The *LE* is 17% for solar, 7% for wind, and world installation projection of solar and wind power system are used from *World Energy Outlook* [5].

2.4. CALCULATION PROCEDURE

In this section, procedure to seek equilibrium is described step by step. The product of goods and production factor are distributed to keep excess demand equal to zero under the price system in the equilibrium calculation. The excel solver is used to searching solution of the nonlinear problem in this model. Six steps is going to be described following.

Step 1: Setting the constants and conditions

First of all, investment ratio for each power generation technology as scenario is set (See 3.2.). Dynamic calculation conditions and constants are also determined by calibration (See 3.1.).

Step 2: Calculating the price system

The price of goods P_j is described by next equation.

$$p_j = p_1 a_{1j} + p_2 a_{2j} + \cdots + p_8 a_{8j} + w l_j v_j + r k_j v_j \qquad (12)$$

Where l_j, k_j are production coefficient, v_j is ratio of added value. a_{ij} is input coefficient which means input from i to j (i, j = 1,2…8), given by a social accounting matrix (input-output table). The equation includes goods cost in production and added value, which is standardized by v_i. l_j and k_j are derived from eq.(1) and a condition of minimizing production cost. Therefore, the problem is solved by Lagrange multiplier method in the same way of the demand function mentioned in 2.2., with the problem recognized as minimizing input of production factor under eq. (1). A Lagrangian for this problem is;

$$\mathcal{L} = wL_{j,t} + rK_{j,t} - \lambda_j \left[\alpha_{j,t} \left\{ \beta_j L_{j,t}^{\frac{\sigma-1}{\sigma}} + (1-\beta_j) K_{j,t}^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}} - V_{j,t} \right] \qquad (13)$$

Following equation about l_j and k_j are acquired from eq.(13) with the same process in eq. (7), (8).

$$l_j = \frac{1}{\alpha_{j,t}} \left[\beta_j + (1-\beta_j) \left\{ \frac{\beta_j r}{(1-\beta_j) w} \right\}^{1-\sigma} \right]^{\frac{\sigma}{1-\sigma}} \qquad (14)$$

$$k_j = \frac{1}{\alpha_{j,t}} \left[\beta_j \left\{ \frac{\beta_j r}{(1-\beta_j) w} \right\}^{\sigma-1} + (1-\beta_j) \right]^{\frac{\sigma}{1-\sigma}} \qquad (15)$$

These eq. (13)-(15) are used for solving eq.(12) as simultaneous equation of 8 sectors. Here, v_j is given by actual current national accounting, and the above price system is determined by standardized vector with r as a standard price.

Step 3: Calculating the income and final demand

Next, the final consumption is calculated. Income (i.e. budget) of household is equal to added value in this model, so that the income is given as $wL_{j,t}+rK_{j,t}$. This relation and eq.(3), (7), (8) give consumption of the composite goods *Cn* and electricity *Ce*. In this model, comparing the *Ce* and capacity of power generation calculated from the capital accumulation, the capability of power generation is determined as constraint condition.

Step 4: Calculating the demand of production factor

The demand of production factor is calculated with considering export/import in this step. The import and export are treated with fixed rate estimated from actual data in 2009. First, production of each goods x_j is derived from next matrix equation.

$$\left[I - \begin{bmatrix} 1-m_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1-m_8 \end{bmatrix} \begin{bmatrix} a_{11} & \cdots & a_{18} \\ \vdots & \ddots & \vdots \\ a_{81} & \cdots & a_{88} \end{bmatrix} \right] \begin{bmatrix} x_1 \\ \vdots \\ x_8 \end{bmatrix} = \begin{bmatrix} 1-m_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1-m_8 \end{bmatrix} \begin{bmatrix} C_1 \\ \vdots \\ C_8 \end{bmatrix} + \begin{bmatrix} e_1 \\ \vdots \\ e_8 \end{bmatrix} \qquad (16)$$

where, m and e are import/export coefficient for sum of $a_{ij}x_j$ and final consumption C_j. Added value from a sector is calculated by the production x_i times the added value ratio v_j, so that the production factor, labor and capital accumulation are determined with eq.(14) and (15).

Step 5: Solving the equilibrium

Equilibrium is defined as that there is no excess demand of production factors. Therefore, objective function for equilibrium is;

$$\left(\sum_j L_j - \bar{L}\right) + \left(\sum_j K_j - \bar{K}\right) \equiv 0 \qquad (17)$$

where, $\bar{L}$ and $\bar{K}$ are initial conditions set at step 1. This non-linear problem is solved with r as operation variables. Generalized Reduced Gradient solver in Microsoft Office Excel (http://www.solver.com/) is used for searching solution.

Step 6: Calculating the capital accumulation and electricity price for next term

Capital accumulation for next term is calculated from the investment. The investment is separated for non-electricity sectors and power generation facilities. In this model, it is determined by fixed rate for final consumption, 22.53% for amount and 6% of it for the power generation facilities [6]. The investment ratio of power generation is arranged to match to current policy for increment of capacity. The capital wastage rate is set as 7% for non-electricity, and different rates are given for each power generation facilities. The wastage for solar is 5%, 6.6% for wind and 2.5% for the others.

Electricity price in next term is determined by the power generation cost based on the composite ratio of the facilities by the investment, as mentioned above. The composite ratio is consisted by over-night cost (includes owner's, construction, and contingency cost), operation and maintenance, and fuel cost. These factors ratio is given by *Projected Cost of Generating Electricity* [7], and fuel price prospects are based on *World energy outlook*'s new policy scenario [6]. Initial composite ratios are given with current electricity price as standard. The current share of power facilities are 0.24GW for hydro, 0.24GW for coal, 1.14GW for oil (diesel), and 4.93GW for natural gas [8].

After calculation of equilibrium as above, going back to step 2, and repeating the procedure until the end of the calculation duration.

3. DATA AND CALCULATION SCENARIOS

3.1. CALIBRATION AND DATA

In this section, calibration method for parameters and data about production, consumption are expressed. The result of calibration and data are shown in table.1.

The constants and parameters in production structure are α, β, and σ. α is scale parameter as TFP, offered in last section, and β is derived by following process. Differentiating partially Lagrangian in eq.(13) by L and K, next condition is derived.

$$\frac{\beta_j}{1-\beta_j} \left(\frac{L_j}{K_j} \right)^{-\frac{1}{\sigma}} = \frac{w}{r} \qquad (18)$$

where, w and r are 1 in equilibrium situation (i.e. actual current economy), so that β is described as following;

$$\beta_j = \frac{L_j^{\frac{1}{\sigma}}}{L_j^{\frac{1}{\sigma}} - K_j^{\frac{1}{\sigma}}} \quad (19)$$

In consumption structure, there are γ and φ for composite and individual goods, whose index are *m* and *n*. Using same procedure of above production structure with eq.(6), the following equation is acquired.

$$\gamma_m = \frac{P_\gamma Cn^{\frac{1}{\varphi_m}}}{P_n Cn^{\frac{1}{\varphi_m}} - P_c Cs^{\frac{1}{\varphi_m}}} \quad (20)$$

In result, γ_m is 0.999 in this model. γ_n is given by following equation considering eq.(4) and sum of γ_n is 1, since γ_n is share parameter.

$$\gamma_{n,j} = \frac{C_j^{\frac{1}{\varphi_n}}}{\Sigma_i C_i^{\frac{1}{\varphi_n}}} \quad (21)$$

Elasticity of substitution σ and φ are determined past investigation in generally. $\sigma = 0.5$, $\varphi_m = 0.6$, and $\varphi_n = 0.5$ are set in this model. The constants set above are shown in table.1.

Table 1: Parameters set by calibration

Sector	α	β	γ_n
Agriculture	1.905	0.287	0.721
Mining	1.007	0.000	0.190
Industry* (Electricity)	1.998	0.532	0.006
Industry (Others)	1.502	0.067	0.000
Construction	1.403	0.042	0.055
Electricity	1.114	0.003	-
Infrastructure	1.690	0.138	0.012
Service & public	0.991	1.000	0.015

* Part of industry sector which relates to construct power facilities.

3.2. CALCULADION SCENARIO

There are 4 scenarios in this study, for the investment portfolio of power generation facilities, which are shown in table 2. Basically, the scenarios are made with focusing on coal, solar and LNG, since coal has low cost, solar price will go down, and current composition is based on LNG. Scenario 1 is business as usual (BAU), is close to current policy, keeping current facilities composition and shifting to coal base generation. Scenario 2 is set as changing to coal base composition strongly. Scenario 3 is renewable energy (RE) base investment, especially solar power. Scenario 4 includes the feature of scenario 2 and 3, and changes the strategy in 2020.

Table 2: Investment portfolio as scenarios

Power sources	1	2	3	4	
	BAU	Coal base	RE base	Coal to RE	
				-2020	-2030
Solar	-	10%	80%	10%	80%
Wind	-	-	10%	-	10%
Hydro	5%	10%	10%	10%	10%
Coal	40%	80%	-	80%	-
Oil	15%	-	-	-	-
LNG	40%	-	-	-	-
Nuclear	-	-	-	-	-

4. RESULT AND DISCUSSION

Simulation result of time series in real GDP growth is shown in fig.4. Scenario 1 and 2 reach to 2,000M$ in 2030, on the other hand scenario 3 stay half of it. The deffences are caused mainly by gap of facility cost among solar, coal, and natural gas. Construction cost of coal and gas plant are lower than solar. On the other hand, running cost of solar is cheaper. In this case, cost down of solar system is not enough to reach even level, comparing to increasing fuel cost of coal and gas (Fig.5).

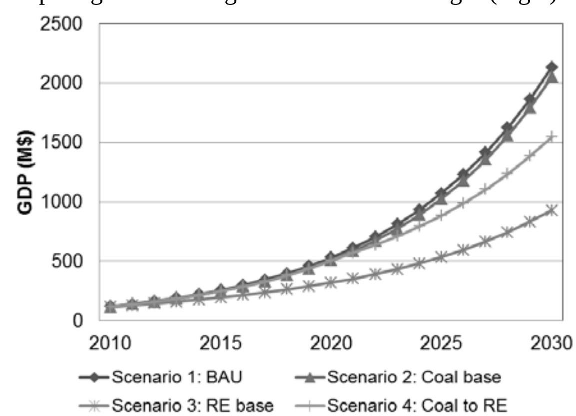

Fig.4. GDP growth in each scenerio

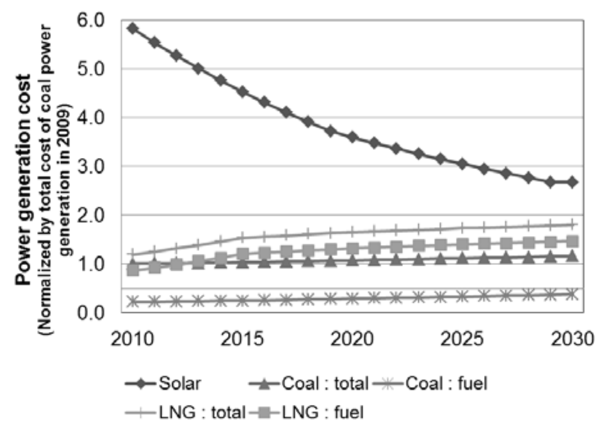

Fig.5. Power generation cost normalized by total cost of coal power generation

Next, temporary changing in electricity price is shown in Fig.6. Price increasing is shown in all scenarios because natural gas cost is going up, which position as main power generation source in current situation. RE installing forces electricity price up immediately, but converges lower price by cost down. On the other hand, though the price is going up continuously in BAU scenario which is invested to gas, the price of coal base scenario is going down after 2015. Therefore, investing to coal power plant is the best from viewpoint of cost until 2030.

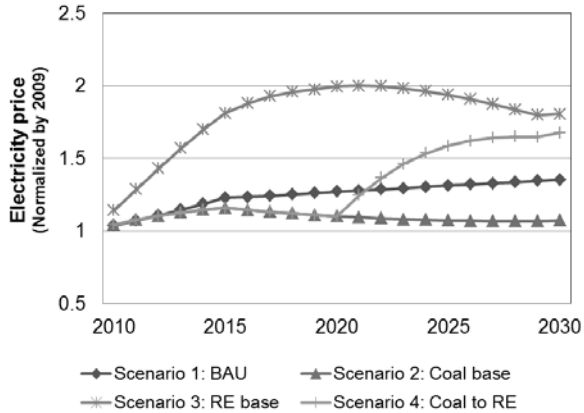

Fig 6. Time series variation in electricity price normalized by the price in 2009

Considering energy security and environmental impact, RE installation is important option. However, immediate installation constricts economic growth like scenario 3 in fig.4, so that it is necessary to decide the install timing carefully with monitoring technology improvement and fuel price. Thus, a balanced portfolio should be investigated like scenario 4.

Here, the calculation condition above gave constraint to power generation capacity. Hence, real GDP variation in change of investment volume is investigated below in BAU scenario. Fig.7 shows the result.

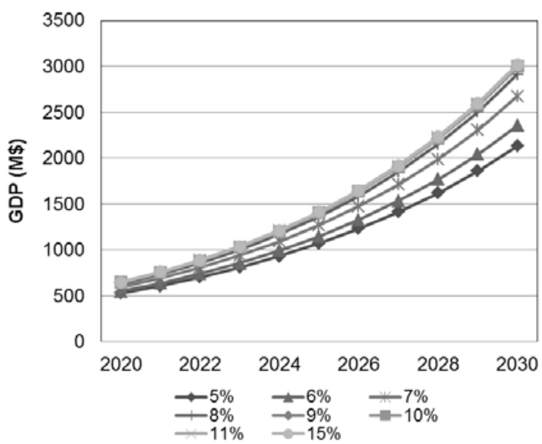

Fig 7. Time series variation in difference of investment rate for power generation facilities

The power generation constraint is released in case over 10% of annual total investment. Comparing between over and less than 10%, there is smaller difference over 10%. It means that increasing the capacity of power generation affects economic growth strongly in current industrial structure.

6. CONCLUSION

The result reveals that coal power plant is the best from viewpoint of cost until 2030. Moreover, increasing the capacity of power generation should be focused for economic growth in current industrial structure. Investing to low cost technology first during the constraint of power generation capacity exists, after enough capacity acquired, shifting to renewable energy is effective to promote economic growth.

This study contributes a feasible R&D planning and policy making by the economic growth evaluation model with power generation capacity and composition. On another front, there are some revising points. First, the industrial structure is fixed through calculation duration, hence, industry sector relating to the power facility is still small (8% of GDP in 2030). In addition, the risks should be considered in model. For example, fuel price rising causes lack of resources for power generation, it is also a constraint. If the points are revised, more accurate simulation can be done especially about renewable energy resources.

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