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Economical analyses of build-operate-transfer model in establishing alternative power plants

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Abstract

The most widely employed method to meet the increasing electricity demand is building new power plants. The most important issue in building new power plants is to find financial funds. Various models are employed, especially in developing countries, in order to overcome this problem and to find a financial source. One of these models is the build-operate-transfer (BOT) model. In this model, the investor raises all the funds for mandatory expenses and provides financing, builds the plant and, after a certain plant operation period, transfers the plant to the national power organization. In this model, the object is to decrease the burden of power plants on the state budget. The most important issue in the BOT model is the dependence of the unit electricity cost on the transfer period. In this study, the model giving the unit electricity cost depending on the transfer of the plants established according to the BOT model, has been discussed. Unit electricity investment cost and unit electricity cost in relation to transfer period for plant types have been determined. Furthermore, unit electricity cost change depending on load factor, which is one of the parameters affecting annual electricity production, has been determined, and the results have been analyzed. This method can be employed for comparing the production costs of different plants that are planned to be established according to the BOT model, or it can be employed to determine the appropriateness of the BOT model.

Keywords: Build-operate-transfer model; Economical analysis; Power plants

1. Introduction

Building additional plants is the most important one among the solution alternatives to meet increasing electricity demand. However, especially in developing countries, high capital requirements of power plants are an important problem and forces the national economies of these countries. The obligation of new power plant construction to meet electricity demand has led to different models to overcome the financing problem. One of these models is the build-operate-transfer (BOT) model [1–4].

Ye and Tiong have analyzed the effect of different concession periods on project efficiency. They have shown the important effect of concession period design on BOT projects via simulation studies. They have used net present value for evaluation. As a result, they have determined that a well designed concession period structure has provided benefit to both the project promoter and the host government [5]. Arıkan has analyzed the BOT model used in electric power projects in Turkey. He has searched about the suitability of funding the hydroelectric power plant by using social benefit cost analysis. As a result, he has pointed out that the BOT model was sensitive to discount rate and concession period, so these values should be determined appropriately [6]. Smith et al. have examined all the steps of installing and operating a 600 MW coal fired power plant with the BOT model [7]. Xing and Wu have performed an optimization study in order to determine the place of the BOT model in the plan for production increase [8]. Yeo and Tiong have developed strategies in

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Nomenclature

C	annual cost (\$/Year)
r	discount rate (%)
n	plant life cycle (Year)
i	interest rate (%)
L	construction period (Year)
j	exchange rate (%)
g	unit cost (\$/kW h)
E	annual electricity production (kW h/Year)
e	escalation rate (%)
LF	load factor (%)
F	fuel price (\$/kg)
LHV	lower heating value (kJ/kg)
I	investment cost (\$)
R	capital cost percentage (%)
Y	cost of investment per year (%)
N	plant capacity (kW)
t_{d}	transfer period (Year)
sfc	specific fuel consumption (kg/kW h)
η	thermal efficiency (%)

Subscripts

c	investment
m	operating and maintenance
f	fuel
e	electricity
L	local
f	foreign
R	reference
k	total
r	real
AW	annual worth

order to decrease and manage the risks in their BOT projects [9]. In the literature, evaluations of the risks in the BOT models were handled by using different methods in many studies [10–13].

In this study, the model giving the unit electricity cost depending on the transfer period, which is determined by the levelized costs method, for the plants build by the BOT model is given. Determination of the effect of transfer period on unit electricity cost for different plants could be possible in this way. Employing this method for alternative plants, the effect of transfer period on electricity cost of these plants will be shown. Furthermore, effect of plant load factor on unit electricity cost for a given transfer period will be investigated.

2. BOT model

The object in the BOT model is to use the private sector's financing power in the power generation sector and decrease the financial burden on the public organizations. In this model, all the mandatory expenses and finance provisions are done by the private sector. In return, the private sector acquires the operation right for a certain period starting from the day of power plant commission [2]. During this period, it sells the electricity that it has generated to the national electricity organization, and at the end of the period, it transfers the power plant. The transfer operation may have a certain price, but a transfer without a price is desired. Thus, the investment sources of the public sector that had to be spent on investments will decrease, and other important projects representing priority will be funded. As well as in the investment phase of these kinds of projects, during the operation phase, project development and service efficiency resulting from high technology transfer by the private sector and effective operation and management intellect are obtained [6,14,15].

The model has advantages and disadvantages for both the private and public sectors. Greater incomes than investment and operation costs, transfer of incomes abroad under certain circumstances, operating the plant according to their own experiences and policies, utilizing national resources during operation, investment discount for BOT model, stamp tax deductions and customs duty exemptions are the main advantages of the model for the private sector. On the other hand, the high sensitivity of the model to the economical and political stability of the country, high investment costs and, especially, possible changes in the government's foreign investment policies are the main disadvantages for the enterprise. In order to overcome these disadvantages, the private sector seeks a guaranty for the return of their investment.

Increased financial opportunities, unaffected national treasury foreign debt stock, increase of country's international trustworthiness due to unnecessary public debt and, thus, affecting foreign capital flow positively are the advantages of the model for the country. Some of the disadvantages of these models for the country are increased sales price because of the high profit demand of the private sector due to reasons like additional risks taken by the private sector and other reasons. The possibility of transfer of the plant before the end of the expected life cycle to national electricity organization due to deduction in operation and maintenance costs in order to achieve a higher profit and negative environmental effects are the other negative sides of the model.

The greatest disadvantage of the BOT model for the state is the high electricity purchase price during private sector operation. The public's desire to take over the plant without paying any price is the main reason for this fact. In order to realize free transfer, the private sector should receive the return of their investment cost during the predetermined transfer period. However, the return of the investment cost in a shorter period than the plant economic life cycle increases the share of the investment cost in the unit electricity cost during this period. The increased investment cost share within the shortened transfer period increases the unit electricity production cost. Even though there will not be any investment share in the unit electricity cost and, thus, lower unit electricity production cost will result after the transfer operation, the unit electricity sales price will be higher than that of other plants during the private sector operation. This difference should be covered by the public or it should be transferred to the electricity price. For this reason, the most important parameter in the BOT model is the transfer period of the plant to the public. This period may be utilized to determine whether the model is appropriate or not, for an alternative plant because comparison of unit electricity prices is widely employed in the economical models that are used in planning power plants. Transfer period influences only the investment cost, and this fact causes the model to affect unit production costs differently for alternative plants. Besides, another important parameter influencing unit electricity sales price is the load factor. Decreasing load factor, which is the ratio of the actual plant operation period of the plant throughout the year to the maximum plant operation period, decreases annual electricity production. This drop in electricity production increases the share of the investment cost in the unit electricity cost [16–18].

3. Unit electricity production cost

Electricity production cost consists of three main components: investment, operating and maintenance and fuel costs. Because of the different dates and different amounts of costs starting from the initiation of the plant construction until the end of the life cycle, these costs that are used in calculating production costs should be levelized to a reference date. The plant's commissioning year is generally selected as the reference date. The total value of the costs at this date is

$$C_{\mathrm{R}} = \sum_{t=-L}^{n} [C_{\mathrm{c}(t)} + C_{\mathrm{f}(t)} + C_{\mathrm{m}(t)}](1+r)^{-t} \tag{1}$$

where $C_{\mathrm{c}(t)}$, $C_{\mathrm{f}(t)}$ and $C_{\mathrm{m}(t)}$ stand for variable annual investment, fuel and operation and maintenance costs, respectively, L represents the construction period, n represents the plant life cycle and r represents the annual discount rate.

The total costs expressed by Eq. (1) are transformed into annual expenses series throughout the plant life cycle as [21]

$$C_{\mathrm{AW}} = \frac{\sum_{t=-L}^{n} [C_{\mathrm{c}(t)} + C_{\mathrm{f}(t)} + C_{\mathrm{m}(t)}](1+r)^{-t}}{\sum_{t=1}^{n} (1+r)^{-t}} \tag{2}$$

The unit electricity cost throughout the plant life cycle (g_{e}) is given below depending on annual electricity production ($E_{(t)}$):

$$g_{\mathrm{e}} = \frac{\sum_{t=-L}^{n} [C_{\mathrm{c}(t)} + C_{\mathrm{f}(t)} + C_{\mathrm{m}(t)}](1+r)^{-t}}{\sum_{t=1}^{n} E_{(t)}(1+r)^{-t}} \tag{3}$$

This calculation method is named the levelized cost method [19]. This production cost equalizes the total income of the plant throughout the life cycle by selling the generated electricity at this price and reclaiming the value of the total costs at the reference date.

The cost components of the unit electricity cost should be determined separately when evaluating the levelized costs method. In the BOT model, the greatest cost component is the capital cost. Levelized unit electricity capital cost (g_{c}) is given

$$g_{\mathrm{c}} = \frac{\sum_{t=-L}^{n} C_{\mathrm{c}(t)}(1+r)^{-t}}{\sum_{t=1}^{n} E_{(t)}(1+r)^{-t}} \tag{4}$$

It is also possible to employ different methods to determine the unit capital cost. The most widely used methods employed in order to realize this are the constant annual capital and linearly decreasing annual capital cost methods.

In this study, the linearly decreasing annual capital cost method is employed as the capital cost calculation method. The linearly decreasing annual cost is obtained by the sum of the interest and capital components

$$C_{\mathrm{c}(t)} = I_{\mathrm{k}}\left[\left(1 - \frac{t-1}{n}\right)i + \frac{1}{n}\right] \tag{5}$$

The total investment cost (I_{k}) should be determined in order to calculate the linearly decreasing annual capital cost expressed by Eq. (5). To realize this, the escalation and interest burden during the construction period should be added to the direct construction cost (I_{d}) at the initiation of the construction. The total expenditure during construction is higher than the direct construction cost due to escalation because local and foreign expenditures during construction are spread over time with variable annual expense percentages. Investment costs of the power plants consist of equipment, construction, land, engineering, license and planning costs. When local sources fail to meet these equipment or services requirements, utilization of foreign sources becomes an obligation. For this reason, the investment cost for the plant should be handled individually as local and foreign costs. If the investment cost including escalation rate is shown by (I_{e}); the direct construction cost by I_{d} having local and foreign capital cost percentages shown by R_{L} and R_{f}, respectively, and the annual local and foreign expenditure distribution throughout construction are shown by $y_{\mathrm{L}(t)}$ and $y_{\mathrm{f}(t)}$, then the total escalated local expenditures (I_{eL}) and foreign expenditures (I_{ef}) throughout construction are expressed by

$$\begin{aligned} I_{\mathrm{e}} &= I_{\mathrm{eL}} + I_{\mathrm{ef}} \\ &= I_{\mathrm{d}}R_{\mathrm{L}} \sum_{t=1}^{L} y_{\mathrm{L}}(t)(1+\dot{e}_{\mathrm{L}})^{t} + I_{\mathrm{d}}R_{\mathrm{f}} \sum_{t=1}^{L} y_{\mathrm{f}}(t)(1+e_{\mathrm{f}})^{t} \end{aligned} \tag{6}$$

where e_{f} represents the annual escalation rate for foreign services and e_{L} represents the annual escalation rate for local services [22]. If the annual exchange rate alteration is shown by j, then the real local annual escalation rate (e_{rL}), which should be employed in Eq. (6), takes the form

$$e_{\mathrm{rL}} = \frac{e_{\mathrm{L}} - j}{1 + j} \tag{7}$$

If the monetary amount required during construction is considered a debt at the beginning of the operation year, the total local investment (I_{kL}) and foreign investment (I_{kf}) at the end of plant construction, including interest burdens, are expressed as below:

$$\begin{aligned} I_{\mathrm{k}} &= I_{\mathrm{kL}} + I_{\mathrm{kf}} \\ &= I_{\mathrm{d}} R_{\mathrm{L}} \sum_{t=1}^{L} y_{\mathrm{L}}(t)(1 + e_{\mathrm{rL}})^{t}(1 + i_{\mathrm{rL}})^{L+1-t} \\ &\quad + I_{\mathrm{d}} R_{\mathrm{f}} \sum_{t=1}^{L} y_{\mathrm{f}}(t)(1 + e_{\mathrm{f}})^{t}(1 + i_{\mathrm{f}})^{L+1-t} \end{aligned} \tag{8}$$

where i_{f} represents the annual interest rate for foreign capital and i_{L} represents the interest rate for local capital [20]. The real annual local interest rate (i_{rL}) that should be employed in Eq. (8), due to changes in exchange rate, is calculated by use of the expression

$$i_{\mathrm{rL}} = \frac{i_{\mathrm{L}} - j}{1 + j} \tag{9}$$

The levelized unit electricity cost is obtained by employing the annual capital cost in Eq. (4), which is obtained by using the I_{k} value determined by Eq. (8) in Eq. (5).

While power plants utilizing renewable energy resources do not have fuel cost, on the other hand, fuel cost is the major component of the unit electricity cost in fossil fuel fired plants. Unit electricity fuel cost is a function of thermal efficiency (η), lower heating value of the fuel (LHV) and fuel price (F). Annual fuel costs increase linearly with generated electric energy. Specific fuel consumption (scf), defined as the fuel amount required for unit electricity is

$$\mathrm{sfc} = \frac{3600}{\eta \cdot \mathrm{LHV}} \tag{10}$$

Annual fuel cost $C_{\mathrm{f}(t)}$ at any given year t, depending on fuel price (F), annual electricity production and specific fuel consumption, is obtained by

$$C_{\mathrm{f}(t)} = F \cdot \mathrm{sfc} \cdot E_{(t)} \tag{11}$$

The increase in fuel price should be included in the unit electricity fuel cost (g_{f}). The unit electricity fuel cost is obtained from additional fuel escalation (e_{f}) in Eq. (12):

$$g_{\mathrm{f}} = \frac{\sum_{t=0}^{n}\left[C_{\mathrm{f}(t)} \cdot (1 + e_{\mathrm{f}})^{t}(1 + r)^{-t}\right]}{\sum_{t=0}^{n} E_{(t)}(1 + r)^{-t}} \tag{12}$$

Material, workmanship and management costs necessary for plant operation with material and workmanship costs for planned and mandatory maintenance operations are defined as operating and maintenance costs. Operating and maintenance cost, which differs depending on plant type, has a dimension of \$/kW. Operating and maintenances cost $C_{\mathrm{m}(t)}$ belonging to the plants at any given year t is

$$C_{\mathrm{m}(t)} = C_{\mathrm{m}} N \tag{13}$$

where C_{m} is specific operating and maintenance cost and N is the plant capacity.

4. Economical analysis of BOT model

In this model, the private sector undertakes all the liabilities regarding operation of the plant starting from construction until transfer. All the economical risks that may arise during construction and operation are undertaken by the enterprise. Return of the investment in a predetermined period and, in order to achieve this return, determining the investment cost accurately is very critical for the enterprise in this model, in which it is assumed that all the monetary expenditures like escalation and interest burden and direct and indirect expenditures belong to the builder [21].

In the BOT model, during construction, no repayment for local and foreign loans is assumed, loans spent during construction, with their interest, are assumed to be paid starting from the commissioning date of the plant throughout the transfer period (t_{d}) according to the linearly decreasing annual capital cost method. Values of all of the investment costs during the plant life cycle that is used for these economical assumptions are assumed as known at the construction initiation date, which is selected as the reference date:

$$\begin{aligned} I_{\mathrm{R}} = \left\{ I_{\mathrm{kL}} \sum_{t=1}^{t_{\mathrm{d}}} \left[\left[1 - \frac{t-1}{t_{\mathrm{d}}}\right] i_{\mathrm{rL}} + \frac{1}{t_{\mathrm{d}}}\right] + I_{\mathrm{kf}} \sum_{t=1}^{n} \left[\left[1 - \frac{t-1}{t_{\mathrm{d}}}\right] i_{\mathrm{f}} + \frac{1}{t_{\mathrm{d}}}\right] \right\} \\ \times (1 + r)^{-(1+t)} \end{aligned} \tag{14}$$

The unit electricity capital cost in this case is

$$g_{\mathrm{c}} = \frac{I_{\mathrm{R}}}{\sum_{t=1}^{t_{\mathrm{d}}} E_{(t)}(1 + r)^{-t}} \tag{15}$$

The unit electricity cost is obtained as the sum of all expenditures as

$$\begin{aligned} g_{\mathrm{e}} = {} & \frac{\left\{ I_{\mathrm{kL}} \sum_{t=1}^{t_{\mathrm{d}}} \left[\left[1 - \frac{t-1}{t_{\mathrm{d}}}\right] i_{\mathrm{rL}} + \frac{1}{t_{\mathrm{d}}}\right] + I_{\mathrm{kf}} \sum_{t=1}^{n} \left[\left[1 - \frac{t-1}{t_{\mathrm{d}}}\right] i_{\mathrm{f}} + \frac{1}{t_{\mathrm{d}}}\right] \right\} (1 + r)^{-(1+t)}}{\sum_{t=1}^{t_{\mathrm{d}}} E_{(t)}(1 + r)^{-t}} \\ & + \frac{\sum_{t=1}^{n} \left[F \frac{3600}{\eta \cdot \mathrm{LHV}} \cdot E_{(t)} \cdot (1 + e_{\mathrm{f}})^{t} + c_{\mathrm{m}} N\right](1 + r)^{-t}}{\sum_{t=1}^{n} E_{(t)}(1 + r)^{-t}} \end{aligned} \tag{16}$$

where the case $t_{\mathrm{d}} = n$ shows that the investment costs will be recovered throughout the plant life cycle. However, n will always be greater than t_{d} ($t_{\mathrm{d}} < n$) in the BOT model, and therefore, the unit electricity capital cost will always be greater than that in the $t_{\mathrm{d}} = n$ case.

The annual electricity production in Eq. (16), depending on load factor, is

$$E_{(t)} = 8760 \cdot N \cdot \mathrm{LF}_{(t)} \tag{17}$$

The load factor may have different values throughout the plant life cycle. Therefore, the annual electricity production will have an average constant value if a levelized load factor throughout the plant life cycle is employed. However, the load factor is dependent on the plant's utilization in the national grid. Plants in the national grid are classified as base load, intermediate load and peak load plants. Base load plants have the highest annual electricity production because of the highest annual operation hours. On the other hand, peak load plants are employed during demand hours in order to answer peak demands. Therefore, the unit electricity cost obtained by employing Eq. (16) is greatly affected by the plant utilization objective and load state. For this reason, the unit electricity cost depending on utilization and load state should be carefully analyzed for plants which will be building according to the BOT model.

5. Comparison of alternative plants for BOT model

The transfer period in the BOT model changes the unit capital cost value. The amount of change is dependent on the value of the investment cost at the reference date, which has different values for the same production capacity for different plant types. This value is determined depending on the unit establishment cost, construction period, expenditure distribution, local and foreign capital shares and escalation and interest rates. Different values of these parameters for different plant types increase the importance of unit electricity capital cost analyses, depending on transfer period in the BOT model, because the price of the electricity generated in a plant established with the BOT model, which is the price including production cost and profit, should not be more than the current price in the electricity market.

In order to compare alternative plants, nuclear, hydroelectric, lignite fired and combined cycle power plants have been investigated, and the technical and economical assumptions employed in the analyses are given in Table 1 [22]. Six hundred megawatt power generation capacity for all the alternative plants has been assumed.

Depending on the transfer period for the plants, the unit electricity capital costs are investigated and presented in Fig. 1. Unit electricity capital costs increase with decreasing transfer period for all plants. Because of high investment cost and longer construction periods, nuclear power plants have the highest unit electricity capital cost, and also, they are very sensitive to the transfer period. Combined cycle power plants have the minimum unit electricity capital cost. Lignite fired and hydroelectric power plants seem to have nearly the same investment cost, however, the hydroelectric power plant unit electricity capital cost decreases with longer transfer periods due to their longer life cycles. A case, where $t_d = n$, represents that plant investment cost is being recovered throughout the plant life cycle. If the transfer period is selected to be 5 years instead of $t_d = n$, unit electricity capital costs increase between 150% and 180%. The shorter transfer period increases unit electricity capital cost and, therefore, unit electricity cost. A longer transfer period decreases the life cycle remaining after transfer, depending on plant life cycle. This period should be quite long because the national power organization will be operating the plant in this period. Therefore, plant types having minimum overall expenditure at the reference date and maximum economical life cycles would be more convenient for the BOT model.

The private sector, who built the plant in the BOT model, will be selling the electricity to the national grid after adding profit over their production cost. Therefore, the unit electricity production cost, which is obtained by adding operating and maintenance costs and fuel costs to unit electricity capital cost, depending on the transfer period, should be analyzed. Unit electricity cost change depending on transfer period is given in Fig. 2. Unit electricity costs, depending on transfer period, have the highest values in nuclear and lignite fired power plants. Because of the high alteration rate of unit electricity cost, depending on transfer period, in nuclear power plants, the unit electricity cost is the highest for short transfer periods ($t_d < 10$). From Fig. 2, it is seen that hydroelectric power plants have minimum unit electricity cost. Although combined cycle power plants have minimum unit capital cost, especially due to the effect of high fuel cost, they have higher production cost than hydroelectric plants. In cases where $t_d = 5$ instead of $t_d = n$, the unit electricity cost increase is 155% for hydroelectric plants, 92% for nuclear plants, 68% for lignite fired plants and 50% for combined cycle power plants. Even though hydroelectric plants have the highest increase, due to their low unit electricity cost, they have minimum production cost in short transfer periods ($t_d < 10$). Low unit electricity cost due to the absence of fuel cost and longer remaining life cycle after transfer due to longer life cycles of hydroelectric power plants compared to other plants, show that these plants are the most convenient plants for the BOT model. Unit electricity fuel cost is one of the most important factors affecting unit electricity cost. Therefore, combined cycle power plants having lower fuel cost than nuclear and lignite fired power plants, despite their shorter life cycles, are more convenient for the BOT model because lower unit electricity cost will result in shorter transfer periods, and therefore, the operation period after transfer ($n - t_d$) will be longer. In Fig. 2, unit electricity cost is additionally expressed when fuel price escalation is 2%. Since there is no fuel cost in hydroelectric power plants, unit electricity cost does not change, and this provides an important advantage when compared to other power plant types. Unit electricity cost importantly increases in other power plants with fuel price escalation. In nuclear power plants, there is an increase in unit electricity cost by 11.08%, in combined cycle by 12.8%, in lignite fired power plant by 13.28% on average. Since these percent worths are close to each other, the biggest increase in value of unit electricity cost is in the lignite fired power plant, which has the highest cost. This is followed by the nuclear power plant and combined cycle plant, respectively.

Table 1
Economical data and technical assumptions

Power plant	Lignite fired	Nuclear	Combined cycle	Hydroelectric
N (MW)	600	600	600	600
I_d (million \$)	840	1100	396	810
R_f (%)	70	80	70	60
R_L (%)	30	20	30	40
i_f (%)	8	8	8	8
i_L (%)	10.3	10.3	10.3	10.3
e_f (%)	7	7	7	7
e_{rL} (%)	3.4	3.4	3.4	3.4
r (%)	10	10	10	10
L (Year)	5	7	4	5
Cost of investment per year (%)				
First year	12	6	11	24
Second year	20	13	19	54
Third year	26	22	45	14
Fourth year	31	14	25	6
Fifth year	11	19		2
Sixth year		18		
Seventh year		8		
Fuel type	Lignite	Nuclear fuel	Natural gas	–
LHV	19,650 kJ/kg		38,500 kJ/Nm^3	
F	0.114 \$/kg	0.82 cent/kW h	0.176 \$/Nm^3	
η (%)	37.8		50.44	
C_m (\$/kW)	48	77	26	10

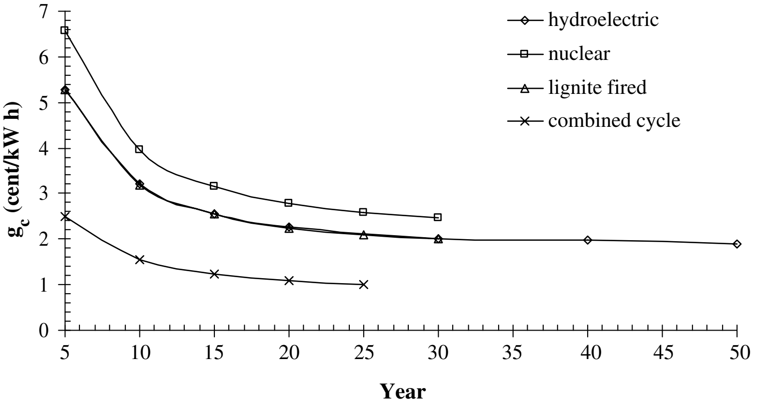

Fig. 1. Unit electricity capital cost change depending on plant life cycle.

Another effect of fuel price escalation is an increase in unit electricity cost boost. For example, in the combined cycle plant, it was calculated that the boost in unit electricity cost was 8.98% when $t_d = 5$ while it was 13.42% when $t_d = 20$.

The load condition (base, intermediate, peak load) of alternative plants in the national grid determines the load factor. Diminishing load factor will decrease electricity production and, therefore, increase unit capital cost. For this reason, unit electricity production costs depending on load factor of the plants scheduled to be build in the BOT model should be analyzed. For a 10 year transfer period assumption, unit electricity production cost change depending on load factor is given in Fig. 3. Unit electricity production costs increase in all plants with a drop in load factor. The amount of increase is greater in plants that have higher investment costs. Therefore, the minimum increase is obtained in combined cycle power plants due to their low investment costs. Besides, it is more convenient to utilize plants, which are planned to be build in the BOT model, as base load plants due to increasing production costs with diminishing load factor. Combined cycle power plants are less affected by load factor, have low unit electricity production cost, and therefore, they may be build as intermediate load plants in the BOT model. Especially in hydroelectric power plants, load factor may be diminished because annual electricity production is dependent on annual rainfall. In this case, the advantage of hydroelectric power plants for the BOT model may disappear.

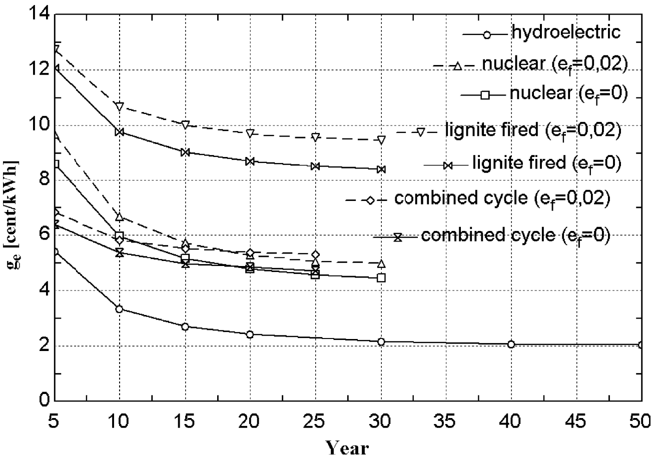

Fig. 2. Unit electricity production cost depending on transfer period and fuel price escalation.

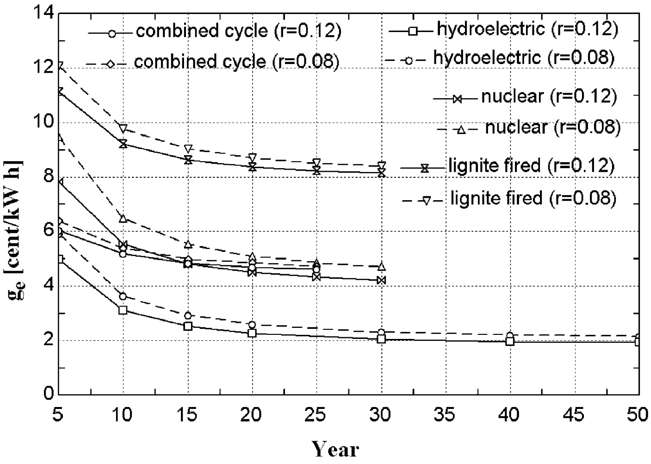

Fig. 4. Unit electricity production cost change depending on transfer period and discount rate.

The BOT model faces many risks. There are a number of ways to handle these risks. In the BOT model being used in Turkey, a minimal amount of annual electricity production and electricty price guarantees are provided by the host government in order to decrease the risks and as an encouragement for installation [6,23]. Another way to handle these risks is to change the discount rate with transfer period. In Fig. 4, for 8% and 12% discount rate values, the changes of unit electricity cost with transfer period for all the power plant types are shown. This figure expresses the effect of discount rate. Unit electricity cost decreases with the increases in discount rate. When the discount rate increases from 8% to 12%, unit electricity cost decreases by 12% in hydroelectric power plants, by 12.88% in nuclear power plants, by 2.93% in combined cycle plants and by 4.31% in lignite fired power plants. These calculations show that discount rates have more effects on unit electricity cost in hydroelectric power plants and nuclear power plants.

6. Conclusion

Unit electricity cost changes depending on the transfer period in the BOT model. The reasons for this change are the desire to transfer the plant at the end of the transfer period without paying any price and the increase in unit electricity capital cost with decreasing transfer period. The unit electricity cost increase with investment cost also determines the economical convenience of plants built in the BOT model. When alternative plants are planned to be built in the BOT model, investment cost and unit electricity cost are important decision parameters. However, in the BOT model, the transfer period determines both of these parameters, and therefore, it is the main parameter. It is this feature that distinguishes the BOT model from other models. Short transfer period has a negative effect by increasing unit electricity cost. Therefore, plants having low investment costs or low fuel costs are more convenient for the BOT model. Another decision parameter in the

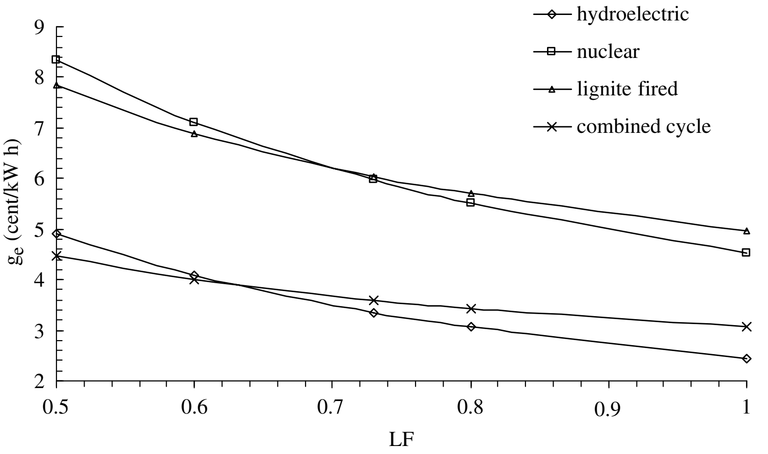

Fig. 3. Unit electricity production cost change depending on load factor for $t_d = 10$ year.

BOT model is the remaining operation life cycle of the plant at the end of transfer period ($n - t_d$). This period is desired to be quite long. This is an important result indicating that plants having longer life cycles are convenient for the BOT model. Load factor of the plant is another important parameter in the BOT model. If the transfer period of the plants built in this model are short, it would be more convenient to utilize them as base load plants. In the BOT model, plants having low fuel costs and low capital costs may also be convenient as intermediate load plants.

All these results indicate that hydroelectric power plants are the most convenient plant type for the BOT model. Short transfer periods due to lower unit electricity costs and longer life cycles are the reasons for this fact. However, production depending on annual rainfall represents the negative aspect of hydroelectric power plants. Another suitable plant type for the BOT model is combined cycle power plants due to their low investment and fuel costs. The relatively low change with load factor in these plants indicates that they may serve as intermediate load plants as well as base load plants. When fuel price escalation is handled, hydroelectric power plants are the most suitable for the BOT model followed by combined cycle plants, which have low fuel cost and unit electricity cost. It was seen that the change in discount rate is an important parameter in power plants with high installation cost.

The BOT model may be employed in developing countries that suffer financial poverty. However, it should be economically compared with other methods.

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