Strategy of investment in electricity sources--Market value of a power plant and the electricity market

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Abstract. This paper reports the results of the investment strategy analysis in different electricity sources. New methodology and theory of calculating the market value of the power plant and value of the electricity market supplied by it are presented. The financial gain forms the most important criteria in the assessment of an investment by an investor. An investment strategy has to involve a careful analysis of each considered project in order that the right decision and selection will be made while various components of the projects will be considered. The latter primarily includes the aspects of risk and uncertainty. Profitability of an investment in the electricity sources (as well as others) is offered by the measures applicable for the assessment of the economic effectiveness of an investment based on calculations e.g. power plant market value and the value of the electricity that is supplied by a power plant. The values of such measures decide on an investment strategy in the energy sources. This paper contains analysis of exemplary calculations results of power plant market value and the electricity market value supplied by it.

1. Introduction

The principal objective of running a business is to gain a profit. This goal of making a profit involves a need of following an investment strategy.

Investment strategies are decisions which play a fundamental role on the financial condition of the investors. Such strategies mean that an expense needs to be made, funds designed for an investment are frozen for a long period, an effect is obtained with a certain delay and they carry some degree of risk. An investment strategy has to involve a careful analysis of each considered project in order that the right decision and selection will be made while various components of the projects will be considered. The latter primarily includes the aspects of risk and insecurity, particularly in variable economic conditions. Financial gain forms the most important criterion in the assessment of an investment by an investor. Before making a decision about the investment of financial resources, an investor needs to ensure that the internal return rate on an investment will be high enough. If this is not the case, the investor will not make any decision. The answer to the question about the profitability of an investment in the electricity sources (as well as others) is offered by the measures applicable for the assessment of the economic effectiveness of an investment based on calculations. They include e.g. the market value of a power plant and the value of the electricity that is supplied by a power plant [1,2]. The values of such measures decide on an investment strategy in the energy sources.

The market value of a power plant $J_{pw}$ is the price at which it can be sold/purchased by the owner/buyer, for which both the owner and the buyer can gain a profit that is satisfactory for them.
The value of the electricity market (and not only this) is expressed by the value of $NPV$ in terms of financial resources, which can be gained from investing funds in it. The basic criterion applied for the assessment of the value of all enterprises (as well as energy sources) is associated with the Internal Rate of Return ($IRR$) obtained on the invested capital [1, 2]. A satisfactory profit for the investor who purchases or builds a power plant (further called the IPP – Independent Power Producer) is expressed by the adequate value of the interest rate $IRR_{rw}$ on the capital $J_{rw}$ that is intended to be invested in it. This interest rate has to be higher than the profit that could be gained as a result of investing financial resources $J_{rw}$ on the capital market. A satisfactory profit for the one who sells a power plant is represented by the adequately high share $v_m$ (i.e. relative value of the market) in the joint ownership of a power plant which is preserved by them. The values of $IRR_{rw}$ and $v_m$ are very closely related. By purchasing a power plant, IPP also takes on the financial obligations arising from the loan that was obtained to finance the construction of the power according to the ratio of their stakes in the ownership $(1 - v_m)$.

2. Methodology of calculating the market value of the power plant and value of the electricity market supplied by it

The methodology applied to calculate the market value of the power plant and the value of the electricity market supplied by electricity production in it are presented in [1]. The formula applied to express the production cost of electricity $k_{el, av}$, which determines these values, as well as the formulae to calculate the market value of a power plant $J_{rw}$ and the value of the market $NPV$ supplied by it [1], are found below:

- mean specific cost $k_{el, av}$ of electricity production in a power plant

$$k_{el, av} = \left\{ (1 + x_{st,naw}) \frac{e^{\epsilon_{fuel}}}{a_{fuel} - r} e^{(a_{CO} - r)T} - 1] + \frac{\rho_{CO} e^{\epsilon_{CO}}}{a_{CO} - r} e^{(a_{CO} - r)T} - 1] + \frac{\rho_{NOx} e^{\epsilon_{NOx}}}{a_{NOx} - r} e^{(a_{NOx} - r)T} - 1] + \frac{\rho_{SOx} e^{\epsilon_{SOx}}}{a_{SOx} - r} e^{(a_{SOx} - r)T} - 1] + \frac{\rho_{fuel} e^{\epsilon_{fuel}}}{a_{fuel} - r} e^{(a_{fuel} - r)T} - 1] + (1 - u) \frac{\rho_{CO} e^{\epsilon_{CO}}}{b_{CO} - r} e^{(b_{CO} - r)T} - 1] + \frac{\eta_{el}}{r_{el}} \frac{J}{N} (1 - e^{-T}) \delta_{serv} + \frac{rzJ}{N} \left( 1 - e^{-T} + 1 \right) \right\}^{r} \frac{r}{\eta_{el} (1 - e^{-T})(1 - e^{-T})}$$

- market value of a power plant $J_{rw}$
\[ J_{nn} = \left\{ N_{el}(1 - e^{-a_{el}a_{el}^0})e_{el}^{i0} a_{el} - r \left[ \frac{1}{a_{el} - r} \right] \left[ e^{(a_{el} - r)T} - 1 \right] \right\} + \frac{1}{a_{el} - r} \left[ \frac{1}{a_{el} - r} \right] \left[ e^{(a_{el} - r)T} - 1 \right] \]
power plant construction, \( e \) – internal electrical load of a power plant, \( \delta_{serv} \) – annual rate of fixed cost relative to the value of the investment (cost of maintenance and overhaul of equipment), \( \eta_{el} \) – energy efficiency of a power plant, \( \rho_{CO}, \rho_{NO}, \rho_{SO}, \rho_{dust} \) – emission of CO, CO, NO, SO, particulate matter per specific unit of chemical energy of the coal.

The market value of a power plant \( J_{rw} \) is represented by the function of the relative value of the market \( v_m \), rates: \( r \) and \( IRR_{app} \), prices of energy sources and environmental costs.

If we substitute the actual investment \( J \) associated in the construction of a power plant in the place of \( J_{rw} \) in formula (2) (according to the definition, i.e. under the assumption that no profit is obtained from the operation of a power plant and the rate of the income tax is equal to zero, \( p = 0 \), for \( v_m = 0 \) we obtain the total value of the interest rate \( IRR \), which is obtained on the capital \( J \).

The formula expressing the total value of the \( NPV \) market is derived from (4) for \( v_m = 0 \). For the seller of a power plant, the value of the market is equal to \( NPV v_m \).

3. Discussion and analysis of results of exemplary calculations
The analysis reported here involves a newly built supercritical steam power plant unit as shown in figure 1.

![Figure 1](image)

**Figure 1.** Schematic diagram of a supercritical pressure unit.

\( Ech_w \) – chemical energy of coal, \( POW \) – flow rate of air, \( CFB \) – fluidized boiler, \( MP \) – inter-stage steam reheater, \( WP \) – HP stage in the main turbine, \( SP \) – IP stage in the main turbine, \( NP \) – LP stage in the main turbine, \( U1-U8 \) – respective steam extractions from the main turbine, \( G \) – electricity generator, \( N_{el} \) – generator’s active power, \( SK1 \) – main condenser, \( P1 \) – condensate pump, \( CHPD \) – cooler of steam from labyrinth seals, \( NP1 \) – \( NP4 \) – LP regeneration reheaters, \( TP \) – auxiliary turbine, \( SK2 \) – condenser in auxiliary turbine, \( ODG \) – deaerator, \( ZWZ \) – feedwater tank, \( P2 \) – feedwater pump, \( WP1 \) – \( WP3 \) – HP regeneration reheaters, \( SCH \) – extraction steam cooler.

Table 1 contains a summary of input data used for calculations.

**Table 1.** Summary of input data for the analyzed supercritical pressure power unit.

|   |   |
|---|---|
| 1. | Gross capacity of steam power unit \( N_{el} = 460 \text{ MW} \) |
| 2. | Investment per power unit \( J = 747.5 \text{ mln USD} \) |
| 3. | Annual exploitation time of power unit \( t_d = 7500 \text{ h} \) |
| 4. | Internal electrical load of power unit: \( e = 7.6\% \) |
| 5. | Discount rate \( r = 7\% \), rate of income tax \( p = 19\% \) |
| 6. | Construction period of power unit \( b = 5 \text{ years} \) |
7. Exploitation time $T = 20$ years
8. Annual rate of maintenance and overhaul $\delta_{\text{serv}} = 3\%$.
9. Total cost $x_{\text{sal,ins}} = 0.25$, total cost $x_{\text{sw,was}} = 0.02$.
10. Specific coal price $e_{\text{fuel}} = 2.85$ USD/GJ
11. Price per CO$_2$ emissions: $e_{\text{CO}_2} = 7.35$ USD/Mg
12. Tariff rates per emissions of: $p_{\text{CO}_2} = 0.0725$ USD/Mg, $p_{\text{NO}_x} = 3.164$ USD/Mg, $p_{\text{SO}_2} = 0.056$ USD/Mg, $p_{\text{dust}} = 0.007$ USD/Mg.
13. Ratio of chemical energy of coal in its total use for which the purchase of CO$_2$ allowances is not required $u = 0$.

3.1. Market value of critical parameter power plant and value of the electricity market supplied by it

In the calculations, we adopted zero values of the exponents: $a_d = 0$, $a_{\text{fuel}} = 0$, $a_{\text{CO}_2} = 0$, $a_{\text{CO}} = 0$, $a_{\text{SO}_2} = 0$, $a_{\text{NO}_x} = 0$, $a_{\text{dust}} = 0$, $b_{\text{CO}_2} = 0$. Therefore, it was assumed that all prices remain at a constant level throughout the $T$ number of years over which a power plant is exploited. The results of exemplary calculations are presented in figures 2-7. The specific cost of electricity production in a power unit derived on the basis of formula (1) is equal to $k_{el,av} = 66.88$ USD/MWh.

Figure 2. Market value of a power plant $J_{rw}$ in the function of the relative value of the market $v_m$ and the interest rate $IRR_{rw}$ on capital $J_{rw}$ demanded by IPP as a parameter.

1 – $e_{el} = 80$ USD/MWh, $IRR_{rw} = 0.08$; 1’ – $e_{el} = 75$ USD/MWh, $IRR_{rw} = 0.08$; 1” – $e_{el} = 70$ USD/MWh, $IRR_{rw} = 0.08$; 2 – $e_{el} = 80$ USD/MWh, $IRR_{rw} = 0.1$; 2’ – $e_{el} = 75$ USD/MWh, $IRR_{rw} = 0.1$; 2” – $e_{el} = 70$ USD/MWh, $IRR_{rw} = 0.1$; 3 – $e_{el} = 80$ USD/MWh, $IRR_{rw} = 0.08$; 3’ – $e_{el} = 75$ USD/MWh, $IRR_{rw} = 0.08$; 3” – $e_{el} = 70$ USD/MWh, $IRR_{rw} = 0.08$. 
Figure 3. Ratio of the market value of a power plant $J_{rw}$ in relation to the actual investment $J$ made in its construction in the function of the relative value of the market $v_m$ and the interest rate $IRR_{rw}^{PP}$ on capital $J_{rw}$ demanded by IPP as a parameter.

1 – $e_{el}$=80 USD/MWh, $IRR_{rw}^{PP} = 0.08$; 1’ – $e_{el}$=75 USD/MWh, $IRR_{rw}^{PP} = 0.08$; 1” – $e_{el}$=70 USD/MWh, $IRR_{rw}^{PP} = 0.08$; 2 – $e_{el}$=80 USD/MWh, $IRR_{rw}^{PP} = 0.1$; 2’ – $e_{el}$=75 USD/MWh, $IRR_{rw}^{PP} = 0.1$; 2” – $e_{el}$=70 USD/MWh, $IRR_{rw}^{PP} = 0.1$; 3 – $e_{el}$=80 USD/MWh, $IRR_{rw}^{PP} = 0.12$; 3’ – $e_{el}$=75 USD/MWh, $IRR_{rw}^{PP} = 0.12$; 3” – $e_{el}$=70 USD/MWh, $IRR_{rw}^{PP} = 0.12$. 
Figure 4. Market value of a power plant $J_{rw,p}$ in the function of the relative value of the market $v_m$ and the interest rate $IRR_{p, rw}^{pp}$ on capital $J_{rw,p}$ demanded by the investor (IPP) as a parameter.

1 – $e_d = 80$ USD/MWh, $IRR_{p, rw}^{pp} = 0.08$; 1’ – $e_d = 75$ USD/MWh, $IRR_{p, rw}^{pp} = 0.08$; 1” – $e_d = 70$ USD/MWh, $IRR_{p, rw}^{pp} = 0.08$; 2 – $e_d = 80$ USD/MWh, $IRR_{p, rw}^{pp} = 0.1$; 2’ – $e_d = 75$ USD/MWh, $IRR_{p, rw}^{pp} = 0.1$; 3 – $e_d = 80$ USD/MWh, $IRR_{p, rw}^{pp} = 0.12$; 3’ – $e_d = 75$ USD/MWh, $IRR_{p, rw}^{pp} = 0.12$; 3” – $e_d = 70$ USD/MWh, $IRR_{p, rw}^{pp} = 0.12$

Figure 5. Ratio of the market value of a power plant $J_{rw,p}$ in relation to the actual investment $J$ made in its construction in the function of the value of the market $v_m$ and the interest rate $IRR_{p, rw}^{pp}$ on capital $J_{rw}$ demanded by the investor (IPP) as a parameter.

1 – $e_d = 80$ USD/MWh, $IRR_{p, rw}^{pp} = 0.08$; 1’ – $e_d = 75$ USD/MWh, $IRR_{p, rw}^{pp} = 0.08$; 1” – $e_d = 70$ USD/MWh, $IRR_{p, rw}^{pp} = 0.08$; 2 – $e_d = 80$ USD/MWh, $IRR_{p, rw}^{pp} = 0.1$; 2’ – $e_d = 75$ USD/MWh, $IRR_{p, rw}^{pp} = 0.1$; 3 – $e_d = 80$ USD/MWh, $IRR_{p, rw}^{pp} = 0.12$; 3’ – $e_d = 75$ USD/MWh, $IRR_{p, rw}^{pp} = 0.12$; 3” – $e_d = 70$ USD/MWh, $IRR_{p, rw}^{pp} = 0.12$
Figure 6. Interest rate $\text{IRR}$ on capital $J$.
1 – price of electricity $e_{el} = 80 \text{ USD/MWh}$; 2 – $e_{el} = 75 \text{ USD/MWh}$; 3 – $e_{el} = 70 \text{ USD/MWh}$; ($\text{IRR} \leq r$ for $e_{el} \leq k_{el}$).

Figure 7. Discounted net profits $\text{NPV}$, $\text{NPV}_{\text{IPP}}$, $\text{NPV}_{\text{V_m}}$ gained from exploitation of a power plant in the function of the relative value of the market $v_{\text{m}}$.
1 – data regarding $\text{NPV}$ for $e_{el} = 80 \text{ USD/MWh}$; 1’ – data regarding $\text{NPV}_{\text{IPP}}$ for $e_{el} = 80 \text{ USD/MWh}$; 2 – data regarding $\text{NPV}$ for $e_{el} = 75 \text{ USD/MWh}$; 2’ – data regarding $\text{NPV}_{\text{IPP}}$ for $e_{el} = 75 \text{ USD/MWh}$; 3 – data regarding $\text{NPV}$ for $e_{el} = 70 \text{ USD/MWh}$; 3’ – data regarding $\text{NPV}_{\text{IPP}}$ for $e_{el} = 70 \text{ USD/MWh}$.
The value $J_{rw}$ is relative to the value $IRR_{rw}^{IPP}$ demanded by $IPP$ and the value $v_m$ demanded by the seller (rate $IRR_{rw}^{IPP}$ is applied in the case when we substitute zero, $p = 0$ in the place of the income tax in the formula in (2)). Figure 2 presents the market value of the power plant $J_{rw}$ for various values of $IRR_{rw}^{IPP}$ given the value of the rate $p = 0$ (as already mentioned before). Figure 3 illustrates the ratio $J_{rw} / J$, which demonstrates to what extent the market value $J_{rw}$ is smaller or higher from the actual investment $J$ incurred in the construction of the power plant.

The profit $NPV^{IPP}$ (formula (4)) that is obtained by the investor ($IPP$) represents the profit without tax is deducted, $IPP$ can demand that the price $J_{rw}$ should be calculated in relation to this net profit as shown in figures 4 and 5. By accounting for the value of the income tax on the gross profit, the value $J_{rw,p}$ for $IPP$ should be derivable based on the relation in (2), which already accounts for this tax. Under such circumstances, the price of the power plant decreases from $J_{rw}$ to the value $J_{rw,p}$ for the value $IRR_{p,rw}^{IPP}$ demanded by the investor, equal to $IRR_{rw}^{IPP}$ and the same relative value of the market $v_m$.

Whereas, for $J_{rw} = J_{rw,p}$ and $IRR_{rw}^{IPP} = IRR_{p, rw}^{IPP}$, the relative value of the market $v_m$ decreases while the profit expressed as $NPV^{IPP}$ for $IPP$ increases as shown in figures 2-5 and 7.

The values $J_{rw}$, $J_{rw,p}$ are very sensitive to the variability of the value of the rates $IRR_{rw}^{IPP}$, $IRR_{p, rw}^{IPP}$. The variability in these values by one or two percentage points results in the change of the values $J_{rw}$, $J_{rw,p}$ by a dozen and even a few dozen percentage points.

The fundamental value, which decides on the market value of a power plant $J_{rw}$, $J_{rw,p}$ and values of the profit $NPV$ and $NPV^{IPP}$ gained on the electricity market supplied by a power plant is given by the difference between the sales price that can be obtained on this market and the specific cost associated with its generation. The greater the difference, the bigger the values of $J_{rw}$, $J_{rw,p}$, $NPV$, $NPV^{IPP}$. In addition, the lower the values $IRR_{rw}^{IPP}$, $IRR_{p, rw}^{IPP}$, the greater the market values $J_{rw}$, $J_{rw,p}$.

For example, for the price of $e_{el} = 80$ USD/MWh, and the interest rate on the capital demanded by the investor ($IPP$) equal to $IRR_{p, rw}^{IPP} = 8\%$, the market value of a power plant $J_{rw,p}$ that has to be paid by IPP to the seller should be equal to $J_{rw,p} = 747.5$ million USD under the assumption of the demanded stake in the ownership of a power plant equal to $v_m = 76\%$. Hence, it is equal to the actual investment $J$ made in its construction. For the values of $v_m$ lower than 76\%, the price $J_{rw,p}$ is higher from the actual investment. This price is also higher for the electricity price of $e_{el} = 75$ USD/MWh and $IRR_{p, rw}^{IPP} = 8\%$ for $v_m < 58\%$ and for $e_{el} = 80$ USD/MWh and $IRR_{p, rw}^{IPP} = 10\%$ for $v_m < 14\%$ as shown in figures 4 and 5.

In these conditions, it would be more beneficial for $IPP$ to build a new power plant instead of buying stakes in an existing one ($1 - v_m$). In this case, an answer that would have to be sought regards the question whether there would be a sufficient demand for the production of electricity in it in the already developed market. For the lower electricity prices, e.g. for $e_{el} = 70$ USD/MWh and $IRR_{p, rw}^{IPP} = 12\%$ and the exemplary value $v_m = 30\%$, the market value of a power plant is only equal to $J_{rw,p} = 405$ m USD and the ratio is equal to $J_{rw,p} / J = 0.54$. In this case, the market value of the power plant is equal to only a half of the initial investment. If the sales price of electricity were to fall below the specific cost $k_{el,av} = 66.88$ USD/MWh, the purchase of a power plant by the $IPP$ is out of the question. In this case, the investor would make a loss.
Figure 6 illustrates the interest rate \( IRR \) on the capital \( J \) invested in the construction of a power plant.

As mentioned above, the value of interest \( IRR \) that is gained on the capital \( J \) is derived from the formula (2) for the income tax rate equal to zero, \( p = 0 \), and for \( v_m = 0 \) (since \( IRR \) is not relative to \( v_m \)). The revenues gained from the sales of electricity play a decisive role on the value of \( IRR \) (i.e. the first term of the formula in (2)), as it depends on its price and volume of production and the specific cost of its generation (formula (1)). If the difference in the price and, consequently, the specific cost is greater, the value of \( IRR \) increases as well. In this case, for the already set values of \( IRR_{IPP}^{pp} \), \( IRR_{p, rw}^{pp} \), the market value \( J_{rw}, J_{rw,p} \) increases as well. When the values of the demanded rates: \( IRR_{rw}^{pp}, IRR_{p, rw}^{pp} \) exceed the value of \( IRR \), the prices \( J_{rw}, J_{rw,p} \) drop considerably below the investment \( J \) made in the construction of a power plant.

Figure 7 Illustrates the total value of \( NPV \) market, value of the market for \( IPP \) equal to \( NPV_{IPP}^{pp} = NPV (1 - v_m) \) and the value of the market for the seller of a power plant \( NPV_{v_m} \).

A comprehensive analysis of the market value of a power plant and value of electricity market (based on formulas (1)–(4)) needs to be conducted with the use of differential calculus. Such calculations can provide a number of additional, important information that could not be gathered without it or would be difficult to capture.

4. Summary and conclusions

An investment in energy sources requires the analysis of economic effectiveness of exploiting them. Prior to a strategic decision regarding the involvement of capital in an energy source, \( IPP \) needs to make sure that the interest rates: \( IRR_{rw}^{pp}, IRR_{p, rw}^{pp} \) associated with the investment and the profit \( NPV_{IPP}^{pp} \) from its exploitation will be sufficiently high to satisfy them.

The investment in a power plant is justified only on condition that the sales price that can be potentially gained from the generated electricity is higher from the specific cost of its production. For instance, in case of a supercritical power unit, this cost is equal to around \( k_{el, av} = 67.5 \) USD/MWh. At present, the sales price of electricity is considerably lower. When this price is exceeded, the production would bring a sufficient profit as shown in figure 7. Hence, the investment in a supercritical coal-fired power unit and coal fired units retrofitted by CCS installations, for which the value of the specific cost of electricity production is even greater [3], is not justified on the basis of economic calculation and would bring a loss to \( IPP \) unless the electricity from such sources was subsidized. The construction of wind turbines and photovoltaic installations renders the process particularly unviable from the economic perspective. The volume of electricity that can be derived from such sources is particularly small due to their short operating times. In particular, this applies to photovoltaics, which is coupled with the great investment in them and makes the electricity generated in them an expensive and luxury commodity [3].

The most rational investment strategy for electricity sector, i.e. one that could ensure energy security as well as stability, certainty and continuity of power supply, should be based on building nuclear power units and modernizing the existing coal-fired power plants. The necessary investment, even including the installation of new boilers and steam turbines with better thermal parameters of the fresh steam, is small compared with the investment needed to build supercritical steam units. In the latter case it would be necessary to build the infrastructure for the power plants, which in the retrofitted power units is already in place. At most, it would be necessary to modernize it. The cost of electricity production in such retrofitted units would be considerably smaller compared to new power units; hence, the price increases will be marginal. If they are coupled with the electricity cost in new nuclear power plants, the increases will be small. Another possibility associated with the modernization of the existing coal-fired units is associated with repowering them by a gas turbo generator. The energy efficiency of such retrofitted units will increase to around 50 %, whereas the
emission of carbon dioxide per MWh of electricity will drop by a half; consequently, the cost of electricity production will also be small and equal to around 47.5 USD/MWh [4].

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