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Assessment of economic effectiveness in the sources of renewable energy

Abstract
Economic efficiency of a small unconventional source of distributed generation is calculated by comparison of the source's costs for heat and/or electricity with the costs of conventional generation. This paper describes the incremental cost method (MKN), which resembles the long-known LLC method.

Keywords: cost components, investment grant, investment expenditures, incremental cost method, NPV.

1. Introduction

Small energy sources, including unconventional sources, are categorised as distributed sources that supply minor recipients. Often they must cooperate with conventional sources, thereby creating hybrid sources. Various investment economic efficiency evaluation methods have been employed, out of which the following discount methods deserve particular attention: the annual cost method (Kopecki, 1960; Bojarski 1979), which has been practised in the power sector for years, as well as NPV and IRR methods (Ratajczak, 1993; Górzyński, 2002). The above-mentioned methods can be assessed as complete in theoretical terms. The NPV (net present value) method as applied to capital expense projects in the power sector takes into account the annual income from sale of heat and/or electricity, and annual costs associated with their generation. These current annual balances of cash flows from subsequent years of a project's operation are discounted to the year zero – preceding the year of the project's commissioning. As regards small distributed energy resources (fuel cell, biomass, photovoltaic plant, solar heating system, heat pump, etc.), which supply small individual recipients, usually no electricity and/or heat is sold, and the income can be interpreted as a reduction in the annual maintenance expenses of the conventional plant, mainly for the purchase of fuel and electricity. This leads to a modification of the classical NPV method. The cost of energy generated in a conventional plant is compared here as the reference cost with the generation cost of a new proposed source.

In the NPV method the aforementioned generation costs of energy, which constitute a component thereof, are discounted sums of annual current costs from a period of K years, where $K = 1, 2, \ldots, N$ (N – expected/assumed duration of the new source operation). Such conceived streams of annual costs for each period of K years are used to formulate the incremental cost method, which in its form is very visual and the algorithm of which resembles the LLC method.

The name "incremental cost method" (MKN) has been proposed by this authors. It illustrates the discount accumulation of expenses incurred in subsequent years of a proposed project procurement and operation.

2. Cost components

The basis for the development of the MKN method is classical principles of economic calculation, and it assumes the project user's viewpoint in its cost calculation formula. As in the NPV method, the following factors may be thereby considered:
– variation annual of revenues and operating costs,
– variation of annual repayments of bank loans, incl. interest and commission,
– variation of borrowing, discount, and inflation rates,
– variation of interest on income.

In individual years in the subject period of N years of the project's operation the user will incur expenses. "Expenses" mean here fixed and variable operating costs, bank loan repayment, income taxes, and loan servicing costs (interest, bank commission) and return of the capital expenditure portion covered with own contribution.

The annual expense sum discounted to the year zero (SWD) constitutes for a period of K years ($K = 1, 2, \ldots, N$) the incremental cost and is the basis for development of the modified annual cost method not described here.

Because of calculation convenience the discounted expenses and revenues (revenues in the NPV method) are as a rule aggregated to the year zero. This is not an absolutely necessary condition. They may be aggregated to any year without compromising the calculation accuracy and precision.

The discounted sums (SD, SWD) are calculated using a discount factor $(1 + d)^{-i}$ (compound interest, $j = 1, 2, \ldots, N$), where: d is the discount rate, which usually takes a constant value in the calculation period of the operation N years.

The annual cash flow in the j-th year is the sum of all expenses W_j, which is called the new plant's current costs $W_j = K_{rhj}$:

$$W_j = K_{rhj} = K_{r\,ni\,j} + K_{rk\,j} + P_{dochj}, \quad \text{PLN/a} \tag{1}$$

– new unconventional plant:

$$K_{r\,ni\,j} = K_{est\,ni\,j} + K_{ezm\,ni\,j} + Z_{kr\,ni\,j} + P_{kr\,ni\,j} + A_{mw\,ni\,j} + K_{dod\,ni\,j}, \quad \text{PLN/a} \tag{2}$$

– conventional element of hybrid plant (where hybrid source is necessary):

$$\mathrm{K}_{\mathrm{rk\,j}} = \mathrm{K}_{\mathrm{est\,k\,j}} + \mathrm{K}_{\mathrm{ezm\,k\,j}} + \mathrm{Z}_{\mathrm{kr\,k\,j}} + \mathrm{P}_{\mathrm{kr\,k\,j}} + \mathrm{A}_{\mathrm{mw\,k\,j}} + \mathrm{K}_{\mathrm{dod\,k\,j}}, \quad \text{PLN/a} \tag{3}$$

$$j = 1, 2, 3, \ldots, N$$

where:
$K_{r\,ni\,j.}$ — annual current costs of the new plant in the j-th year,
K_{rkj} — current costs of the interoperable conventional plant in the j-th year,
$K_{est\,x\,j}$ — fixed operating costs in the j-th year, inclusive of personnel, overhaul, and current rep air,
$K_{ezm\,x\,j}$ — variable operating costs in the j-th year,

$Z_{kr\,j}$ — loan repayment installment in the *j*-th year ($Z_{kryj} = 0$, where a bank loan was not contracted or is repaid),
$P_{kr\,x\,j}$ — tax on the unpaid part of the loan in the year together with banking services (commission) ($P_{kr\,x\,j} = 0$ where a bank loan was not contracted or is repaid),
$P_{doch\,j}$ — tax on income from the sale of energy generated in the hybrid/co-generation system in the *j*-th year,
$A_{mw\,x\,j}$ — annual installment of return on own contribution to the investment in the *j*-th year,
$K_{dod\,j}$ — additional costs, if any, incurred in the *j*-th year of the project's operation,
indexes x:
ni — for the new plant,
k — for the conventional plant interoperable with the new plant in the hybrid regime.

Total expenditure of funds in the year zero is the investment expenditure incurred, which may consist of own contribution of the proposed plant's future user and of a bank loan. It may happen that the user receives a grant for the project, owing to which it may feel an (apparent) reduction in the investment expenditure:

$$B_0 = (K_{inwc} - D_{ot}) = [(K_{inww} + K_{inwb}) - D_{ot}], \quad \text{PLN} \tag{4}$$

where:
K_{inwc} — total investment expenditure on the project balanced to the year zero,
K_{inww} — user's own contribution to the investment expenditure on the project balanced to the year zero,
K_{inwb} — bank loan to cover the investment expenditure on the project balanced to the year zero,
D_{ot} — investment grant.

The total own contribution K_{inww} and the loan K_{inwb} may be divided between the new plant and the conventional plant interoperable with the new one in hybrid regime:

$$K_{inww} = K_{inwwni} + K_{inwwk}, \quad \text{PLN} \tag{5}$$

$$K_{inwb} = K_{inwbni} + K_{inwbk}, \quad \text{PLN.} \tag{6}$$

2.1. Investment grant

The grant can take different forms, but it may ultimately be presented as a one-off amount lodged in the year zero. The problem of subsidies and justification for their amounts has been repeatedly discussed by this author in assessing the costs of electricity generation in wind turbines (Soliński, & Solińska, 2000; Kusto, 2001). One of the arguments presented to justify a subsidy for renewable and unconventional energy sources are so-called external costs associated with conventional power generation, which were calculated after many years of research conducted in the last decades of the previous century by an international team of experts Extern-E (Malko, 2004; Radovic, 2005). Avoidance of at least some of these additional costs might be grounds for granting a subsidy.

A particular form of investment grant may be the use of effects of international or inter-regional cooperation between countries/regions in which the investment expenditures on a project (solar heating system, heat pump, wind farm, biogas system, etc.), as well as the generation/manufacture costs of energy or other products, vary. This problem has been long known to economists, and it was also analysed by this author with regard to wind farms with showing a very high potential efficiency of such co-operation clearly beneficial for the both parties concerned (Kusto, 2002). his concept, addressed to wind generation, may also be adopted for other distributed sources.

2.2. Investment expenditures

Capital expenditures for a new plant are usually incurred in a period not longer than one year, during the year zero. If the investment expenditures are incurred over several years, as is the case with a plant with high installed power (at least a few megawatts), their individual components from formula (4) will be the sums discounted to the year zero. Where the discount rate is fixed, the total expenditure may be calculated according to (7). Where the discount rate is variable over time (a generalized case), the total investment costs (K_{inwcd}) are calculated after formula (8):

$$K_{inwcd} = \sum_{j=N1}^{0} K_{inwc\,j} \cdot (1+d)^{j} + \sum_{j=1}^{N2} K_{inwc\,j} \cdot (1+d)^{-j}, \quad \text{PLN} \qquad (7)$$

$$K_{inwcd} = \sum_{j=N1}^{0} K_{inwc\,j} \cdot \prod_{k=1}^{j} (1+d_k) + \sum_{j=1}^{N2} \frac{K_{inwc\,j}}{\prod_{k=1}^{j} (1+d_k)}, \quad \text{PLN} \qquad (8)$$

where:

$K_{inwc\,j}$ — total investment expenditures incurred on the plant in the j-th year, $j = 1, 2, \ldots, N$, PLN/a,

d_k — discount rate in the k-th year, $k = 1, 2, \ldots, N$,

$N1$ — number of years of the investment expenditure's incurrence, prior to the year of the project's commissioning,

$N2$ — number of years of the investment expenditure's incurrence, after the year of the project's commissioning.

In a similar way the discount sums of the total expenditure's components may be calculated. The total expenditure's components include the future project user's own contribution and bank loans. The following formulas are presented in their generalized form, which takes into account the investment expenditures' incurrence in the years prior the year zero and in the year zero (prior to the project's commissioning), and during the project's operation (so-called phased capex project).

1. Own contribution:

$$K_{inwwd} = \sum_{j=N1}^{0} K_{inww\,j} \cdot \prod_{k=1}^{j} (1+d_k) + \sum_{j=1}^{N2} \frac{K_{inww\,j}}{\prod_{k=1}^{j} (1+d_k)}, \quad \text{PLN} \qquad (9)$$

where $K_{inww\,j}$ — own investment expenditures incurred in the j-th year, $j = 1, 2, \ldots, N$, PLN/a.

2. A bank loan:

$$K_{inwbd} = \sum_{j=N1}^{0} K_{inwb\,j} \cdot \prod_{k=1}^{j} (1+d_k) + \sum_{j=1}^{N2} \frac{K_{inwb\,j}}{\prod_{k=1}^{j} (1+d_k)}, \quad \text{PLN} \qquad (10)$$

where $K_{inwb\,j}$ — bank loan for the plant project drawn in the j-th year, $j = 1, 2, \ldots, N$, PLN/a.

2.3. Operating costs

There are two kinds of operating costs. **Variable operating costs** are the costs of energy and operating supplies consumed in subsequent years of the N-year period. For a new plant that may be calculated after formula (11, 13), for a conventional plant — after equation (12, 14), considering that these costs may vary in subsequent years due to changing electricity and fuel prices:

– for hybrid sources with heat pumps:

$$K_{ezm\,ni\,j} = c_{el\,j} \cdot \left(k_{mrpc\,j} \cdot \frac{\dot{Q}_{pc} \cdot T_{ipc}}{\phi \cdot \eta_{sil}} + E_{elruch} \right), \quad \text{PLN/a} \qquad (11)$$

$$K_{ezmk\,j} = c_{pal\,j} \cdot k_{mrk\,j} \cdot B_{ka} = c_{pal\,j} \cdot k_{mrk\,j} \cdot \frac{\dot{Q}_{ik} \cdot T_{ik}}{W_d \cdot \eta_k}, \quad \text{PLN/a} \qquad (12)$$

– for other hybrid source types:

$$K_{ezm\,ni\,j} = c_{el\,j} \cdot k_{mrni\,j} \cdot E_{el\,a}, \quad \text{PLN/a} \qquad (13)$$

$$K_{ezmk\,j} = c_{pal\,j} \cdot k_{mrk\,j} \cdot B_{ka} = c_{pal\,j} \cdot k_{mrk\,j} \cdot \frac{\dot{Q}_{ik} \cdot T_{ik}}{W_d \cdot \eta_k}, \quad \text{PLN/a} \qquad (14)$$

where:

$c_{el\,j}$ — expected electricity price in the j-th year, PLN/kWh,
$c_{pal\,j}$ — expected fuel price in the j-th year, PLN/kg,
E_{elruch} — annual consumption of electricity for operating purposes, kWh/a,
$k_{mk\,ni\,j}$ — operating supplies cost coefficient in the j-th year,
$k_{mrk\,j}$ — operating supplies cost coefficient for conventional plant in the j-th year,
$k_{mr\,pc\,j}$ — operating supplies cost coefficient for heat pump in the j-th year,
$\dot{Q}_{ik}$ — installed power of the boiler, kW,
$\dot{Q}_{ni}$ — installed power of the new plant, kW,
$\dot{Q}_{pc}$ — installed power of the heat pump, kW,
T_{ini} — installed power time of the new plant, h/a,
T_{ik} — installed power time of the boiler, h/a,
T_{ipc} — installed power time of the heat pump, h/a,
W_d — calorific value of the fuel, kJ/kg or kJ/m^3,
φ — coefficient of performance of the heat pump,
η_k — boiler efficiency, annual average,
η_{sil} — efficiency of the motor driven by the heat pump.

Fixed operating costs may be calculated as fixed amounts in subsequent years, using the fixed operating costs rate (Kopecki, 1960). It must be clearly underlined that these costs may change in subsequent years. Anticipating these changes is a forecasting issue.

$$K_{est\,ni\,j} = K_{estni} = r_{ce} \cdot \sum_{j=-N1}^{N2} K_{inwni\ j} \quad , \quad \text{PLN/a} \tag{15}$$

$$K_{estkj} = K_{estk} = r_{ce} \cdot \sum_{j=-N1}^{N2} K_{inwk\ j} \quad , \quad \text{PLN/a.} \tag{16}$$

3. Incremental Cost Method (MKN)

As mentioned above, the incremental cost method is part of the NPV method. The MKN method calculates the stream of annual current costs (S_{KLh}) discounted to the year zero (!) for a hybrid plant for the period of L years, while the L number is counted incrementally, successively, up to the value of N. The incremental costs for the whole plant are the sum of individual incremental costs of the new facility's systems and the incremental cost of the conventional plant:

$$S_{KLh} = \sum_{j=1}^{L} \frac{K_{rpc\ j}}{\prod_{t=1}^{j}(1+p_{pct})} + \sum_{j=1}^{L} \frac{K_{rk\ j}}{\prod_{t=1}^{j}(1+p_{kt})} \quad , \quad \text{PLN} \tag{17}$$

$$L = 1, 2, 3, \ldots, N.$$

The incremental cost method is particularly useful in comparing investment options. It has the following major advantages:

– it is a discount method, it is theoretically complete,
– it provides a clear visual representation of all costs — investment expenditures and current costs.

The method's disadvantage is its computational complexity that requires good preparation, and it is difficult to verify forecasting of numerical data (e.g. discount rates, changes in fuel and electricity prices, etc.), as in the annual cost (NPV) method or other discounting approaches. The MKN method's graphic presentation is demonstratively shown in Fig. 1, which illustrates the comparison of three investment options.

Under option 1 the initial costs are small in the first year of operation, which may originate from the relatively low investment expenditure, but the current costs are high. In period L_1 the aggregate costs (discounted streams) are the lowest, but after a period of L_2 they are already the highest. Option 2 features very high initial costs (high investment expenditure), but also the lowest annual current costs and already after L_2 is better than option 1, and after period L_3 it is the cheapest option. It may be noted that if an investment project's time horizon is shorter than L_1, then option 1 is absolutely the most advantageous, but if this period is longer than L_3, then option 1 should be implemented.

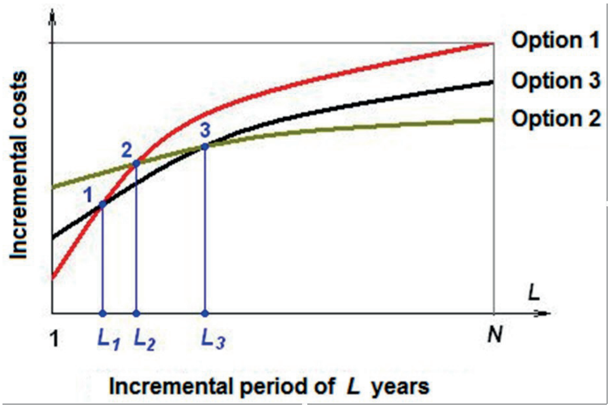

Fig. 1. Graphic illustration of the incremental cost method

Cost-effectiveness comparison of several investment options imposes the condition of meeting the basic requirement of equality of the final results for all options. With respect to plant variants the final results' equality boils down to: the same annual energy output, the same peak heat/electric power and the variation thereof in time (equality of the time-ordered charts). Failure to meet the above requirements makes the options comparison difficult. Where the final results differ, they have to be additionally equalised by computation.

4. Conclusion

All known calculation methods require bringing all investment options to the same final results. When the effectiveness of the investment in a project is assessed from the project user's viewpoint, then the initial costs include only those expenses that are directly incurred by the user, but no bank loan. During a heating system's operation its user repays the whole debt, and this is included in the current costs of the heat and/or electricity generation, which also include the return of own investment contribution deducted in subsequent years. The discussed calculations include all cost items, therefore they are substantially complete.

The incremental cost method can distinguish a special case, whereby the investment expenditure allocated to the year zero is reassigned to the first year of operation, which theoretically means the repayment of all bank loan installments (if granted) and return of the own investment contribution within this first year.

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