



## ISSUES OF ECONOMIC ANALYSIS OF ELECTRIC ENERGY GENERATION IN A FLOATING POWER PLANT

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### Abstract

*This article presents basic dependences for conducting a technical and economic analysis related with investment projects. It describes a combined system of a compression ignition engine and a steam turbine, whose aim, when placed on a floating platform, is to generate electric energy in the so-called distributed generation system. Such a system involves a reciprocating internal combustion engine and a connected steam turbine system that uses the energy contained in the exhaust gas of the combustion engine. Assumptions and restrictions, as well as results of calculations are given in the article. Calculations were conducted only in view of investment and operational costs. The parameters of Wartsila and MAN Diesel & Turbo low-speed combustion engines of the capacity of approximately 54 MW were used for the analysis, and on the basis of them the cost of generating 1 MWh of electric energy was estimated..*

**Keywords:** *electric energy, compression ignition engine, steam turbine, floating power plant*

### 1. Introduction

Business entities to a large degree determine the economic development of a country, as well as the welfare of its society. Each of them produces a part of gross domestic product. The new social and economic system that has been developing in Poland since the beginning of the 90s led to the evaluation of free market economy. Processes taking place in the global economy had a dramatic impact on the changes in the conditions under which Polish enterprises operate. The changes were mostly caused by factors such as globalisation, regionalisation, internationalisation, production and services concentration, development of financial markets, modern technology and logistics development. Furthermore, the increasing importance of environmental protection, as well as knowledge, entrepreneurship and innovativeness also played a role.

Continually changing conditions, increased requirements of customers, as well as growing competition force business entities to take regular actions maximising the efficiency of their operation. These days decision-making without quickly available and reliable technical and economic information is impossible. Nevertheless, sole possession of the information is not sufficient in order to evaluate the efficiency of an enterprise. A reliable assessment may only be performed through a financial analysis involving technical and economic data.

For many years now the solutions to power plant technical systems that would increase their thermodynamic efficiency have been sought. Thermal power stations fuelled with solid and

liquid or gas fuels almost always involve systems with turbines driving power generators (in the case of high capacity power plants).

The issue of a large amount of noxious substances emitted by conventional power plants to the atmosphere and extensive plaster dumps formation led to research on solutions that would prevent these phenomena. Furthermore, there is a demand for increased thermodynamic efficiency of a cycle, while reducing the costs of power generation. For that purpose the use of combined systems is considered that would involve a compression ignition engine and a steam turbine cycle. When placed on a platform, such a solution would provide for the generation of electric energy in the so-called distributed generation system.

Energy generated in a distributed system, also called distributed generation, involves the generation of energy by small units or production plants directly connected to distribution networks or located in the consumer's power system. They usually generate electric energy using renewable or non-conventional energy sources, often combined with heat generation. One of the basic classifications of distributed generation sources is classification in view of the generated power value. We can differentiate:

- small distributed generation (units of capacity between 1 kW and 5 MW);
- medium-sized distributed generation (units of capacity between 5 MW and 50 MW);
- large distributed generation (units of capacity between 50 MW and 150 MW);

The aim of this work is to conduct a technical and economic analysis involving the analysis of investment and operational costs of a power plant. This would enable the determination of the costs of the power plant generating a unit of power depending on the operation of the power unit. Furthermore, the benefits derived from using a combined system and the advantages in an offshore floating power plant in view of environmental friendliness of the plant will be analysed.

## 2. Selected issues of economic analysis

Running a business activity becomes more and more complicated and troublesome, which is why it should be based on a complex economic analysis. Various definitions of an economic analysis can be found in economy publications. An economic analysis is defined as activities related with the evaluation of a business entity operation. It involves the division of economic processes and phenomena into their components, specification of cause and effect dependences between the analysed components and formulation of general conclusions drawn from comparative assessments[2].

Each entity running a business activity performs periodic analyses aimed at verifying whether the goals that were set for it have been met. Consequently, the entity may prepare new, more detailed development plans. An economic analysis is the basic tool used for the verification of an entity's performance. The division of an economic analysis into areas is presented in Figure 1[7].

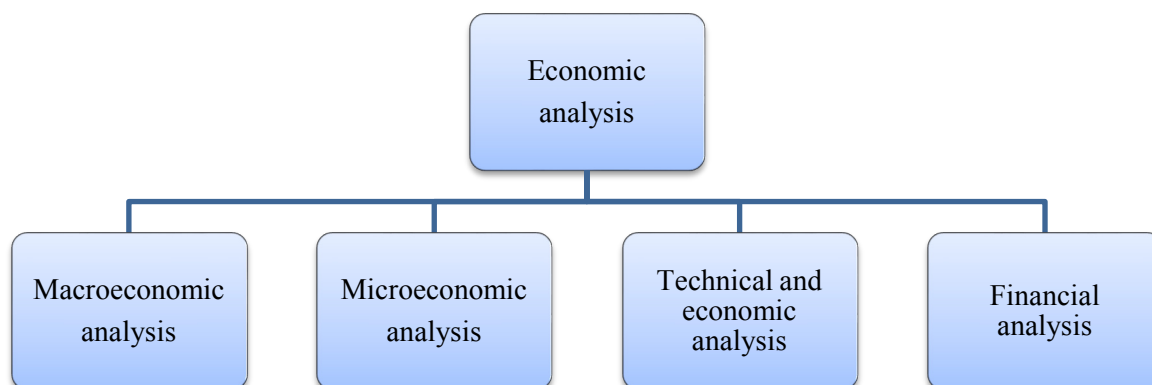


Fig. 1. Types of economic analysis

A technical and economic analysis deals with an accurate representation of an economic situation of an entity using tracer analysis. Various areas of an entity's activity may be the object of analysis, including material performance (products, semi-finished products, services), cost of production or services rendition, human resources management, fixed assets management, technical progress and innovativeness, goodwill, and most of all – property and financial situation.

A financial analysis deals with processing financial performance of an entity on the basis of data included in the income statement and the cash flow statement, as well as other financial statements prepared by the entity[4].

While performing calculations related with the evaluation of an investment project, the following elements must be considered:

- Investment completion time
- Investment operation time.

The investment completion time is the time in which the investor incurs expenditures for the investment launch. The investment completion time may relate only to the baseline period, i.e. the first year, or the investment may be spread over a period of time, e.g. platform construction, engine installation, steam turbine installation. In such a case investment expenditures should be divided into the periods in which they are incurred.

The investment operation time is the time in which the investor benefits from the investment.

Usually, an investment starts generating profits after 1 year, unless the investment completion time is spread over several periods, and the investment starts generating profits after several of the periods are completed.

When performing a technical and economic analysis, the costs structure must be considered:

- investment costs;
- operational costs;
- depreciation;
- interest (financial costs)

Operational costs are all those costs that the project generates after the investment is launched.

Depreciation is a generic type of cost that is not included in operational costs, as it is not a type of expenditure.

If loans (foreign capital) are taken out, then the item called interest, i.e. financial costs, appears.

## 1. Project economic efficiency assessment

The following indexes are used for the economic efficiency assessment of an investment.

1. Net Present Value (NPV) which for the time of the system utilization of N years from the moment the investment is put into operation results from cash flows added to each other that are planned in the subsequent years of operation (including the year zero).

$$NPV = \sum_{t=0}^N \frac{CF_t}{(1+r)^t} \quad (1)$$

where: t - current year of operation, N - total number of years of operation,  $CF_t$  - cash flow in a given year t, r - discount rate

For a technical solution that aims at an economic optimum, the NPV is maximum. This in turn gives the following function of an objective:



$$NPV \rightarrow max \quad (2)$$

2. Net Present Value Ratio (NPVR) involves the ratio of the project net value to the investment expenditures ( $J_0$ ) necessary in order to reach the NPV:

$$NPVR = \frac{NPV}{J_0} \quad (3)$$

NPVR is an auxiliary index that enables the selection of an investment variant when comparing projects that are similar in terms of structure, investment expenditures, operation time, etc.

3. Internal Rate of Return (IRR) specifies the discount rate at which the Net Present Value calculated for the entire period of operation equals zero. An investment is profitable only when the Internal Rate of Return is greater than discount rate  $r$ .
4. Simple Pay Back Period (SPBP) and Discounted Pay Back Period (DPBP) specify the minimum number of years for which the sum of actual cash flows and discounted cash flows for the year in which the investment is put into operation equals zero:

$$\sum_{t=0}^{SPBP} CF_t = \sum_{t=1}^{SPBP} CF_t - J_0 \quad (4)$$

$$\sum_{t=0}^{DBP} \frac{CF_t}{(1+r)^t} = \sum_{t=1}^{DBP} \frac{CF_t}{(1+r)^t} - J_0 \quad (5)$$

Using the definition of pay back periods, this article also introduces the notions of simple and discounted investment value in the subsequent years of its operation. These values are obtained by summing up CF cash flows from the year 0 to the analysed year  $N$ .

As results from dependences from (1) to (5), the basic element of an investment economic efficiency assessment are Net Cash Flows. For the entire period of operation of the analysed power plant net cash flows were calculated using the following formula:

$$CF = -J_0 + J_k + S_n - K - P_d + A - R + L \quad (6)$$

where:

- $J_0$  - total incurred investment expenditure ( $J_0 = J_w + J_k$ ),
- $J_w$  - part of investment expenditures financed using the entity's own funds,
- $J_k$  - part of investment expenditures financed using bank loans,
- $K$  - production costs (including depreciation and bank interest),
- $P_d$  - income tax,
- $A$  - depreciation of fixed assets,
- $R$  - loan instalment,
- $L$  - investment object liquidation value.

#### 4. Calculations and results

The calculations of a floating power plant construction involved the comparison of two low-speed combustion engines – Wartsila 9RTA96C and MAN Diesel & Turbo 9K98MC-C7.1-TII – for the load of 90% CMCR (Contract Maximum Continuous Rating), placed on an offshore platform.

Table 1 Basic parameters of low-speed compression ignition marine engines

Parameter	Unit	9RTA96C [14] WARTSILA	9K98MC-C7.1-TII [12] MAN DIESEL & TURBO
$N_D$	kW	46332	48762
$m_{sD}$	kg/s	104.504	134.25
$m_{fD}$	kg/s	2.146	2.369
$t_4$	°C	271	232.8
$b_{eD}$	g/kWh	166.8	174.9

The calculations were based on the following assumptions:

- Electric energy generation will take place in a combined system including a compression ignition engine and a turbine, as well as a power grid connection.
- Operation time of the plant amounts to 15 years.
- Discount rate amounts to 8%.
- It was assumed that the investment will be financed in full using the investor's resources.
- The calculations do not include prices nor costs increase factors.
- Exchange rates according to the National Bank of Poland as of 18 March 2014 – USD 1 = PLN 3.043 / USD, EUR 1 = PLN 4.2295 / EUR.
- Operation of the power unit amounts to 6500 h per year.
- Heavy fuel, density of 890 – 960 kg/m<sup>3</sup>
- The floating power plant will be placed on a mobile platform weighing approximately 200 t.

In accordance with the obtained information, the estimated cost of 1 kg of the structure amounts to EUR 7. Consequently, the cost related with the platform purchase (KP) will amount to 200 000 kg \* EUR 7 / kg \* PLN 4.2295 / EUR = PLN 5921300.

When calculating a compression ignition engine price it was assumed that 1 kW of power costs USD 200.

Therefore the cost of the Wartsila engine:

CEW - Wartsila compression ignition engine cost (Cost Engine Wartsila)

CEW = 46332 kW \* USD 200 / kW \* PLN 3.043 / USD = PLN 28197655.2

MAN engine cost:

CEM - MAN compression ignition engine cost (Cost Engine MAN)

CEM = 48762 kW \* USD 200 / kW \* PLN 3.043 / USD = PLN 29676553.2

Steam turbine (TP) cost:

TM 1000 – Makila TITurbomeca, applied power: 3 897 kW, cost: PLN 6052000

The team operating the floating marine power plant includes 10 people (WZ)

Team remuneration: 10 people \* average daily rate of USD 200 = USD 2000 / day; Yearly cost of the power plant team remuneration will amount to PLN 2221390

Cable connection to the grid (PK):

PLN 57.55 for 1 kW; connection to the grid at the distance of 200 m

Cost of connecting the Wartsila engine system to the grid:

PLN 57.55 / kW \* 46332 kW = PLN 2666406.6

Cost of connecting the MAN engine system to the grid:

PLN 57.55 / kW \* 48762 kW = PLN 2806253.1

Price of 1 m<sup>3</sup> of heavy fuel is approximately PLN 2200 (KFj)

Wartsila

$m_{fD} = b_e * N_D$



$$m_f = 166.8 \text{ g/kWh} * 46332 \text{ kW} = 7728177.6 \text{ g/h}$$

$$m_{fD} = 7.728 \text{ t/h}$$

Man

$$m_{fD} = 174.9 * 48762 = 852847.8 \text{ g/h}$$

$$m_f = 8.528 \text{ t/h}$$

Let us assume that  $1 \text{ m}^3 = 920 \text{ kg/m}^3$ , i.e.  $0.92 \text{ t/m}^3$

The Wartsila engine uses 7.728 t/h of heavy fuel, i.e. it requires  $8.4 \text{ m}^3/\text{h}$ , so the fuel cost amounts to  $8.4 \text{ m}^3/\text{h} * 6500 \text{ h} * \text{PLN } 2200 / \text{m}^3 = \text{PLN } 120120000$  (KF)

The MAN engine uses 8.528 t/h, i.e. it requires  $9.269 \text{ m}^3/\text{h}$ , so the fuel cost amounts to  $9.269 \text{ m}^3/\text{h} * 6500 \text{ h} * \text{PLN } 2200 / \text{m}^3 = \text{PLN } 132546700$  (KF)

The performed calculations enabled the determination of total investment expenditures as the sum of costs related with the purchase of a floating platform, a compression ignition engine and a steam turbine, and the construction of a cable connection to the grid, which is expressed as:

$$J_0 = CE + TP + KP + PK \quad (7)$$

and operational costs:

$$K = KF + WZ \quad (8)$$

Using dependences (7) and (8) Table 2 was compiled that contains power units calculation results for the two engines, depending on their power capacity and fuel consumption:

Table 2 List of investment and operational costs

Parameter	Unit	9RTA96C [14] WARTSILA	9K98MC-C7.1-TII [12] MAN DIESEL & TURBO
$N_D$	kW	46332	48762
CE	PLN	28197655.2	29676553.2
PK	PLN	2666406.6	2806253.1
$J_0$	PLN	42837361.8	44456106.3
KF	PLN	120120000	132546700
K	PLN	122341390	134768090

The calculation results compiled in Table 2 show the dependence of investment costs on the compression ignition engines power capacity and the operational costs on the unitary wear of the main engine. That is why the selection of proper power units operation parameters during the technical and economic analysis is of such importance.

On the basis of the assumptions and calculations included in part four of the article it was possible to determine the annual generation of electric energy ( $E_{el}$ ):

$$E_{el} = N_D * \text{engine operation time (t)} \quad (9)$$

Using dependence (9) the level of power generation by the analysed engines was calculated: Wartsila

$$E_{el} = 46332 \text{ kW} * 6500 \text{ h} = 301158000 \text{ kWh} = 301158 \text{ MWh} \quad (10)$$

MAN

$$E_{el} = 48762 \text{ kW} * 6500 \text{ h} = 316933000 \text{ kWh} = 316933 \text{ MWh} \quad (11)$$

On the basis of results listed in Table 2 and the level of power generation by the individual power units, the estimated cost of generating 1 MWh of electric energy was calculated ( $KPE_{el}$ ):

$$KPE_{el} = \frac{K}{E_{el}} \text{ PLN/MWh} \quad (12)$$

Wartsila

$$KPE_{el} = \frac{122341390}{301158} = 406.24 \text{ PLN/MWh} \quad (13)$$

MAN

$$KPE_{el} = \frac{134768090}{316933} = 425.23 \text{ PLN/MWh} \quad (14)$$

The obtained costs of electric energy generation by the analysed power units (13), (14) show the direction of future optimization works related with the technical and economic analysis. The possibility of increasing the efficiency of power units and the engines operation time should be considered, as it may result in a reduction of operational costs that have a direct influence on the cost of generating 1 MWh of electric energy. The purchasing price of 1 m<sup>3</sup> of heavy fuel used for the calculations is based on wholesale prices offered by market wholesalers. Preferential conditions for a floating power plant were not analysed. This article presents general information about the practical application of technical and economic analysis tools when evaluating investment projects.

### 3. Summary

The method of presenting information in the article was to describe the issues of an economic analysis of electric energy generation in a floating power plant in a clear and complete manner.

The proposed concept of power generation in floating power plants has the following advantages:

- increased generation of power in the north of Poland,
- diversification of primary energy sources that reduces coal consumption and increases liquid fuels consumption,
- possibility of residual heavy fuels combustion in the engine,
- reduction of the amount of coal transported from the south of Poland or imported on ships,
- lack of slag and ash,
- reduced CO<sub>2</sub>, NO<sub>x</sub> emissions as a result of the increase in the system efficiency and the reduced emission resulting from the engine structure. What is more, the reduction of SO<sub>x</sub> emissions due to the application of sulphur-recovery systems,
- shorter construction time, when compared to a conventional power plant and the possibility of gradual launching. First: the compression ignition engine is put into



operation, then, during its operation, a combined system with a steam turbine is constructed,

- lack of complications related with water cooling the condenser, minor impact on the environment related with water management,
- mobile possibilities – offshore platform

In order to verify the profitability of the construction of a floating power plant it is necessary to perform a complex analysis related with cash flows involving total net sold generation value.

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