STOCHASTIC ANALYSIS UPON THE FEASIBILITY OF THE GEOTHERMAL ENERGY EXPLOITATION

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Abstract - Geothermal resources are included in the category of regenerative energetic resources, which through a real exploitation can assure the satisfying desideratum of long living development under energetic aspect. Considering the fact that the measurements used for evaluating the feasibility indicators of the geothermal energy efficiency have a random character, the stochastic treatment of these evaluations is legitimate. In the paper, after a short justification on the utility of the concern, there is presented the evaluation methodology in stochastic way upon the GEES feasibility and a case study. The final part comprises the conclusions of the analysis.

Keywords: geothermal energy, exploitation, feasibility, stochastic analysis.

1. INTRODUCTION

The long lasting energetic resources rationally exploited [1, 2] can be enclosed in the category of the regenerative energetic resources and are vised by the E.U Directive 2009/28/CE through which the following fundamental acomplisments are to be reached until 2020:

- ✓ Through use reduction of the fosil combustible, to assure the decrease with 20% of the greenhouse gases emissions;
- ✓ The increase with 20% of regenerable energies sources (RES) within the total energetic consumption of the E.U., as well as a 10% target of biofuel in the energetic consumption for transportation;
- ✓ Through the improvement of energetic efficiency, a reduction with 20% of the primary energy consumption up against the level at which the consumption might have reached without these measurements. Furthermore E.U proposes that the level of emissions to be reduced up to 30%, with the condition that the other developed states would adopt similar objectives, these being included in a future global environment agreement post 2012. Negotiations in this direction within the United Nations are still in progress.

The exploitation systems of hidrogeothermal resources are oriented on the following main directions, applied according to the energetic potential of the deposit:

- Direct exploitation ≡ thermic energy extraction ;
- Indirect exploitation ≡ thermo – mechano – electric conversion;
- Combined exploitation (thermic and electric energy);
- Complex exploitation (energy with balneology and biologic purpose);

Applied solutions, nowadays, for the geothermal energy exploitation systems (GEES) are various [3÷7]. The projects for geothermal energy exploitation are analysed in comparison with other regenerative energetic resources, on the basis of some established feasibility criteria [2,8] in which is often operated with fixed values of the operand: investment expenses, exploitation and incomes from produced energy exploitation expenses. In the present paper it is justified the use of random variable values for the operand, the methodology being named and also exemplified the method of work for this case.

2. THE ANALYSIS METHODOLOGY

The criteria and feasibility indicators applied for GEES are [8,9]:

a. The simple way of reclaiming the investment

It is an indicator that compares the value of the necessary investments for GEES accomplishment with the annual registered incomes for detaining GEES. The analytical expression is:

$$\mathrm{DR} = \frac{\sum_{t=1}^{Tr} I_t}{H_m} \tag{1}$$

where:

- I_t [UM] – the investments made in the „t” year, necessary for the GEES accomplishment;
- Tr – the duration of GEES accomplishment (investment);
- H_{tm} [UM] – the annual medium economic effect obtained by detaining GEES;

- UM – monetary units (EURO, USD, LEI).

For countries under development, such is the case of Romania, in the energetic domain , the actuality rate is considered at the value (a=10%). Consequently, the feasability condition becomes:

$$DR \leq 10 \text{ years} \tag{2}$$

b. The actual net profit

Is to be obtained through the comparison of the economic effect, obtained by making GEES, with economic effort, associated to its making and exploiting.

$$VNA = \sum_{t=1}^{T} \frac{H_t - G_t}{(1+a)^t} \tag{3}$$

where:

- H_t – the economic effect obtained in „t"year, [U.M.];
- Gt [UM] – the economic effort realised in „t" year, [U.M.];
- T – the analysed period of time [years];
- a – the actual rate;

For the energetic objectives, such is GEES the analysed period of time is considered T = 20 years. The investment is considered to be feasible if :

$$VNA \succ 0 \tag{4}$$

c. The profitability index

It is an economical efficiency indicator which reports the registered economic effect to the realised economic effort, updated during the usage life of GEES:

$$IP = \frac{\sum_{t=1}^{T} \frac{H_t}{(1+a)^t}}{\sum_{t=1}^{T} \frac{G_t}{(1+a)^t}} \tag{5}$$

The feasability condition of the solution is :

$$IP \succ 1 \tag{6}$$

Furthermore we will refere to :

- Structure and way of calculating the components consisting of expenses and incomes which form the feasability indicators;
- Ways of applying the feasability criteria.

For GEES, the costs, incomes and savings components which enter in the calculating ratios of feasability indicators can be determined as it follows:

Investment expenses (I) with GEES are [10] of the categories: directs (I_d), colaterals (I_{CL}), connexes (I_{CO}). The investments for variety equivalents, such as those for major energetic objectives, concerning the production capacity, transport and loss of power, are not justified to be considered for calculating GEES which have small and medium powers.

The direct investments are those necessary for (I_E) equipments, (I_{IN}) installations and (I_{AP}) machines from the GEES structure, projecting expenses (C_P) and the execution(C_{EX}) GEES . Hence, one can write:

$$\begin{cases} I = I_d + I_{CL} + I_{CO} \\ I_d = I_E + I_{IN} + I_{AP} + C_P + C_{EX} \end{cases} \tag{7}$$

Considering the GEES specific equipments, one can write:

$$I_E = C_{PR} + C_V + C_{GR} + C_{CD} + C_{PP} \tag{8}$$

The expenses subcomponents for equipments represent the aquisition cost for: preheater (C_{PR}), vaporizer (C_V), the engine-generator group(C_{GR}), condensor (C_{CD}) and pomps (C_{PP}). Frequently, in the analysis phase of the GEES feasability the components (I_{IN}, I_{AP}, C_P, C_{PP}) of the direct investment are estimated as a part of the equipment expenses (I_E), as follows:

$$\begin{cases} I_{IN} + I_{AP} + C_P + C_{PP} = b \cdot I_E \\ I_d = (1+b) \cdot I_E = [1{,}15 \div 1{,}3] \cdot I_E \end{cases} \tag{9}$$

The I_{CL} and I_{CO} components of the investment expenses (I) refere to supplimentary jobs that must be undertaken (access, connection to utilities, organisation of the ground, etc) in order to realise GEES. Because of the fact that these components are often at the same value level for all the various credible energetic systems and one of which is compulsory for the vised aria, these components are frequently evaluated. „I_t" is constructed out of parts of the total investment (I), realised in the „t" year.

The economic effort annualy undertaken with GEES (G_t) comprises, besides the investment effort (I_t) and the annual exploiting expenses (C_t) which inclose: personnel expenses for maintainance and supervision(C_{mt}), material expences (C_{Mt}) and energetic type expenses (the proper technological consumption) – C_{Et}. Hence, one can write:

$$G_t = I_t + C_t = I_t + C_{Mt} + C_{mt} + C_{Et} \tag{10}$$

The value of economic effort (G_t) is high in the period of GEES accomplishment when the investment component is high and relatively reduced in the exploiting period of GEES.

The economic effect annualy obtained anual for using GEES, (H_t) becomes operational after entering in function of GEES and can have two components: the countervalue of the produced and sold energy (C_{wt}) and countervalue of the economical stimulents which the state decided to pay to the detainer of GEES for the produced energy out of regenerative energetic resources (C_{SEt}).

$$H_t = C_{wt} + C_{SEt} \tag{11}$$

In Romania the economic stimulus used nowadays is called „green certificate" and has the value of 53 EUR for a MWh produced out of regenerative energetic resources.

Having the annual estimated values (H_t), one can determine the medium value (Htm) on the analysis duration:

$$H_{mt} = \sum_{t=1}^{T} \frac{H_t}{N_T} \qquad (12)$$

N_T – number of values on analysed duration (T).

To assess the feasibility indicators, in the GEES case are possible two types of approach:

- **Determinist**, case in which the measurements which enter into the calculation of feasability indicators have unique values, given by the producer or determined as medium values on the basis of exploiting experience. Consequently, for the feasability indicators, we will have unique values.
- **Stochastic**, when the measurements on the basis of which the feasability indicators are calculated are considered random fluctuant, characterized by definition domains and distribution functions. As a consequence the feasability indicators, will also be random variables. The stochastic character of the (I,H,G) components and its subcomponents it's justified for the following considerations:
  - The prediction regarding the evolution in time of the (a,r) rates has a stochastic character;
  - The prices of equipments have the character of some probabilistic measures;
  - The exploitation expenses (operation, maintainance) have stochastic character, both due to the unitary evolution of prices and the stochastic character of the feasability indicatords of the equipments (implicitly of GEES) as well as the stochastic character of the damage indicators;
  - Because of the random character of the charge curves of the consumers supplied by GEES, which can be reflected on the expenses of the exploitation costs (C), on damages and the incomes registered out of selling the GEES generated energy.

In the case of operating with fluctuant variables, the measurements that enter into the calculating ratios of the feasability indicators are characterized through distribution functions and are composed out of specific rules [11, 12], obtaining thus the feasability indicators. Considering the expressions of the feasability indicators rendered above, in fig. 1, we present the rough results which could be obtained through the operations undertaken in the feasability indicators (FI) ratios.

Considering the fact that the measurements, which enter in the calculating ratios of the feasability indicators have variable degrees (discreet), we will operate with discreet fluctuant variables.

For evaluations, we admit a fluctuation in degrees for the components in the feasability indicators structure in the interval [-15%; 30%], around medium. The evaluations are to be made in two ways: with or without the so called „green certifictes" – the established means [13] for stimulating the development of exploitation of regenerative energetic resources, including GEES.

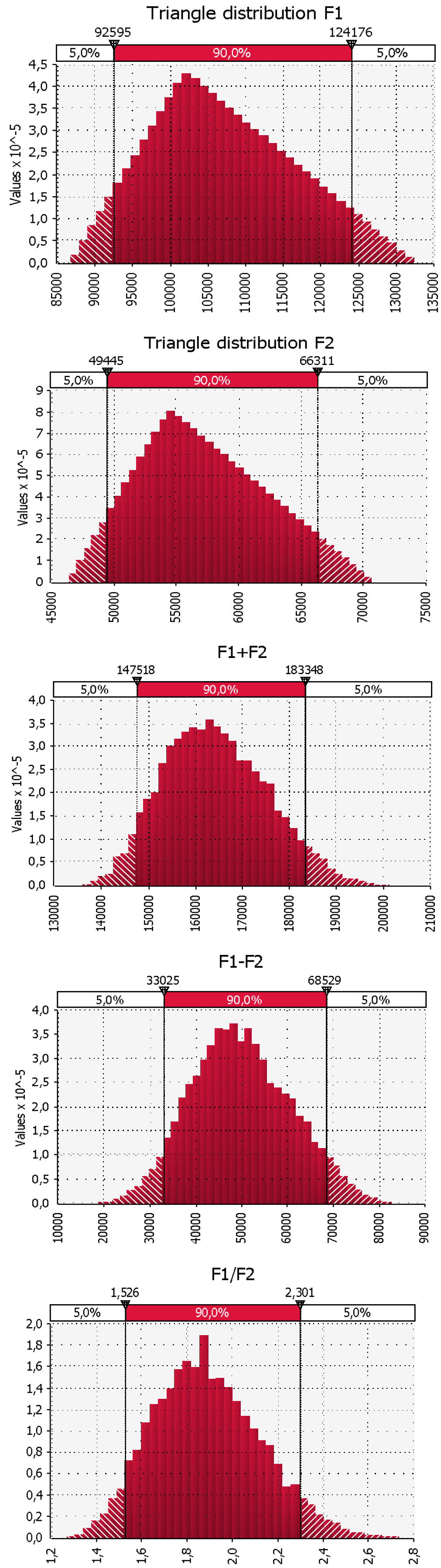

Fig. 1. Rough results obtained through the composition of two distribution functions by specific operations FI evaluated for GEES Studii de caz

3. CASE STUDIES

In the present paper, we will exemplify the methodology for making a feasability study with reference to electro-geothermal plant with binary cycle (EGPB), represented graphically in fig. 2.
In the analysis only the main elements of EGPB are considered, while the price for drilling lead is ignored, considering the fact that the plant uses an already existing drill. For the stochastic analysis of feasability we use the @Risk programme [14].

Forward we will present , two examples of the EGPB feasability analysis, one without the value of green certificates, and the second one considering the grant received under the form of green certificates, taking into consideration the triangle distribution components of the investment expenses.

In table 1 there are presented the actual medium prices (for start) of each equipment at once, on the basis of which the total cost of EGPB was calculated, and in tabel 2 an estimation of the prices for the 5 components, with the inferior limit lower costs with 15%, and superior limit, that is „maxim costs” with an exceeding of medium cost with 30 %, is made for each component.

The medium costs for each equipment are taken from [3, 4, 15] and in [9] we find the medium price on kW installed for the ORC plants which has as a primary source the geothermal energy . This price is of 2259 USD/kW.

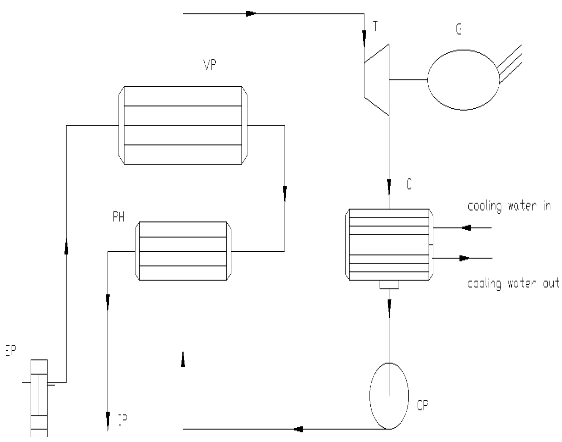

Fig. 2. Simplified diagram of the EGPB

Tabel 1. Average costs equipment for CEGB

No	Components of power plant	Cost [EUR]	Size [kW] or [m^2]	Cost/equipment [EUR]
1	Vaporizer (VP)	330	309	101970
2	Preheater (PH)	330	165	54450
3	Turbine-Generator (T-G)	500	500	250000
4	Condenser (C)	330	790	260700
5	Pump (CP)	500	5,5	2750
6.	**Total**			**669870**

In fig 2 the abreviation means:
EP – extraction pump; IP – injection pump;
PH – preheater; VP – vaporizer; T – turbine;
G – generator; C – condenser; CP – circulation pump;

Tabel 2. Cost values for triangle distribution

No	Components	Minimum [EUR]	Most likely [EUR]	Maximum [EUR]
1.	Vaporizer	86674,5	101970	132561
2.	Preheater	46282,5	54450	70785
3.	Turbine-Generator	212500	250000	325000
4.	Condenser	221595	260700	338910
5.	Pump	2337,5	2750	3575

After introducing the value of equipment costs in the working sheet, we generted for each the triangle distribution. Also, there is calculated the risk in such a manner that the value of the project should exceed with 10%, 50% şi 90% , the result of the distributions. In fig. 3 there is presented an image of the screen during evaluation, during executing the programmed number of iterations, and in fig.4 there is presented the triangle distribution for the total cost.

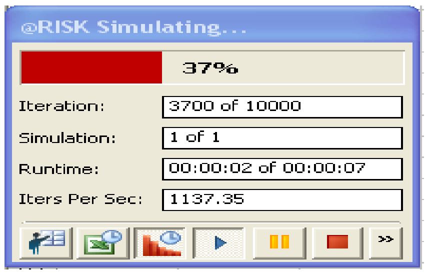

Fig. 3.The screen image with the evaluation process

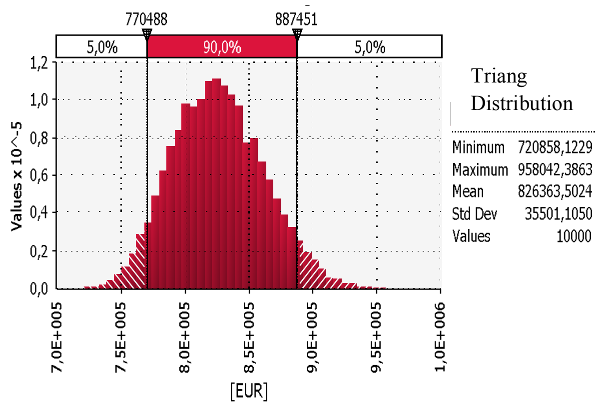

Fig. 4. The triangle distribution for the total cost estimation

The probability that the value of the project would exceed the estimated budget is of 49%, thus justifying the determination of the feasability indicators. The estimated cost for attendance (maintainance) and for the employees wages, for an year is of 50.000 EUR, and the medium production of the plant is 403 kW, thus in a whole year the plant produces supplies of 3,53 GWh. The price received for the supplied energy is of 45 Euro/MWh according to [13].

The above undertaken simulation includes only the costs for the main components of the plant, which is not enough, because the cost of the entire plant is different , according to [9], to the components price one shoul add (auxilliary components, execution manufacturing, s.o.) 300 \$/kW for determining the cost of the whole plant, and the rate Euro/Dollar is: 1 EUR =1,22 USD. Considering this aspect to the total cost of the components, one shoul add (300 \$/kW=246 EUR/kW).

a.) Results without „green certificates" (scenary1)

The price encashed for the sold energy in a year is:

$$Cw = 3530 \cdot 45 = 158.850 \text{ EUR}$$

In fig. 5 – fig. 7. are represented the distributions of the feasibility indicators : the necessary time for recovering the investment, the actual net earning and the profit index.

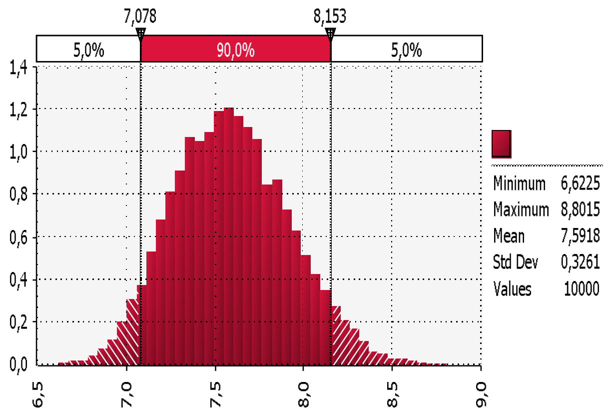

Fig. 5. The distribution of „DR" indicator

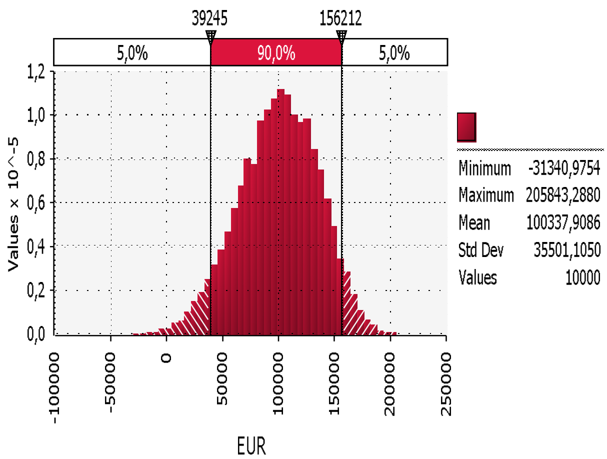

Fig.6. The distribution of „VNA" indicator

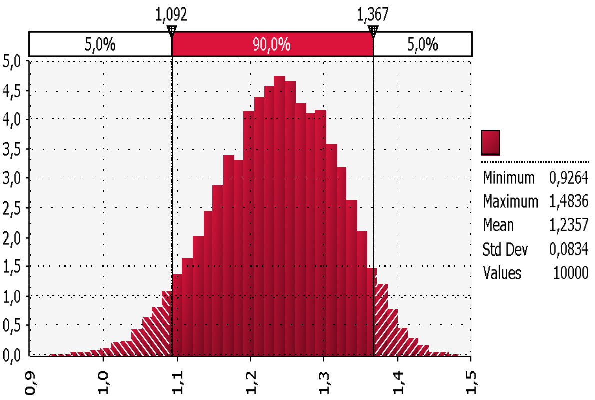

Fig. 7. The distribution of „IP"indicator

b*.) Results with „green certificates" (scenary 2)*

According to Law no. 220/2008 [13] for each MW of raw power supplied in the electric network one can get 2 green certificates , the price for one green certificate being of 53 EUR/MWh. Taking into consideration the efficiency of the generator (96%), the raw power of the plant is of 420 kW.

The total price of the green certificates for an entire year is : $420 \cdot 2 \cdot 53 \cdot 8{,}760 = 389.995$ EUR/year.

In the hypotesis of possible incomes out of green certificates the feasiblity indicators are changed as in fig.8 – fig. 10.

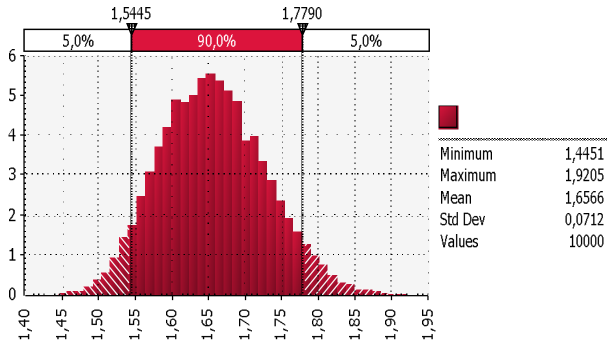

Fig. 8. The distribution of „DR" indicator with green certificates

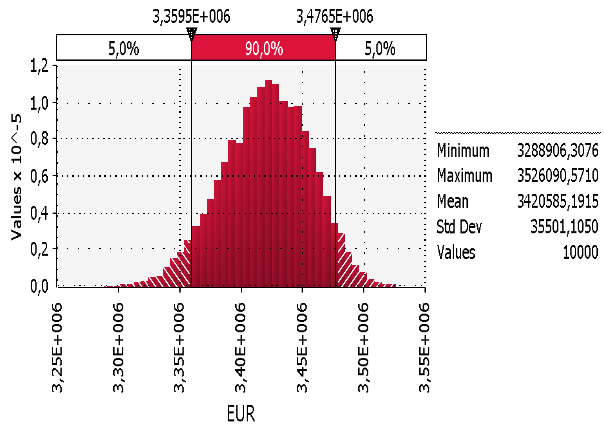

Fig. 9. The distribution of „VNA" indicator with green certificates

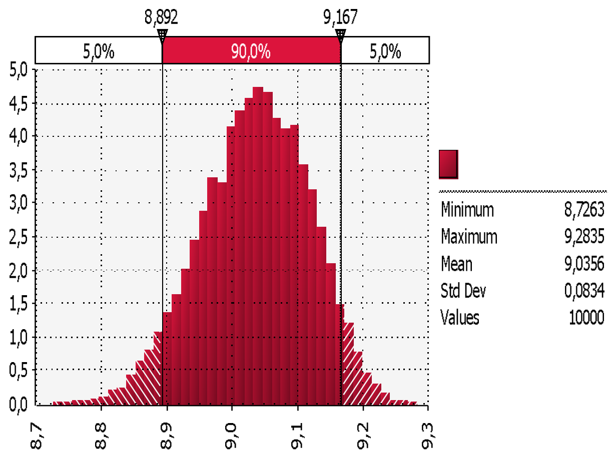

Fig. 10. The distribution of „IP"indicator with green certificates

The results of the evaluation made in the hypotesis of normal distribution of the random variable subcomponents „I" and other details are presented in [16].

4. CONCLUSIONS

- For the feasibility analysis of EGPB one can use the following feasibility indicators: the time for recovering the investment, the actual net earning and the profit index
- In case of EGPB for calculating the feasibility indicators one should know the following values: the investment (I), the economic effect(H_t), the economic effort (G_t), the time for analysis (T).
- Taking into consideration the stochastic charcater of the values which enter into the ratio which calculates the feasibility indicators, it is recommended in order to increase the accuracy of EGPB feasibility analysis, to operate with random variables, characterized through distribution functions and definition domains.

Following the operation of triangle and normal distributions for EGPB feasibility analysis, one can notice:

- ✓ In case of scenary 2, due to the grants received from the state (green certificates) the time for recovering the investment is considerably reduced with values up to 6 years, in comparison with scenary 1 ;
- ✓ The values of feasibility indicators for the two tested distributions (triangle and normal) are closed;
- ✓ In case of scenary 2, the time for recovering the investment is under 2 years, which means that the project is feasible;
- ✓ The equipments which influence considerably the costs of the plant are: the condenser and the engine-generator assembly.

REFERENCES

[1] ** Directiva 2009/28/CE a Parlamentului European şi a Consiliului din 23 aprilie 2009 privind promovarea utilizării energiei din surse regenerabile, de modificare şi ulterior de abrogare a directivelor 2001/77/CE şi 2003/30/CE.
[2] Cleveland C.J., Encyclopedia of Energy, Vol 1÷6 Elsevier Academic Press, 2004.
[3] Schuster A, Karellas S, Kakaras E, Spliethoff H. - Energetic And Economic Investigation Of Organic Rankine Cycle Applications, Applied Thermal Engineering, 2008.
[4] Tchanche B., Quoilin S., Declaye S., Papadakis G., Lemort V. - Economic Optimization Of Small Scaleorganic Rankine Cycles, 2010, pdf.
[5] Ruggero B. - Geothermal Power Generation in the World 2005–2010 Update Report, Proceedings World Geothermal Congress 2010, WGC2010;
[6] Rosca M. - Geotermalism şi centrale geotermale, Editura Universităţii din Oradea, 1999
[7] Felea I., ManolescuM.J. - Applying the Reability Theory to the Investigation and Optimization of the Complex Geothermal Uses, Proceedings of the World Geothermal Congress, vol 4/1995.
[8] Carabulea A., Felea I. - Managementul Riscului Energetic, Partea II, Universitatea Politehnica Bucuresti, Facultatea de Energetica, Catedra Management Industrial, 2000.
[9] Baz González E. - Feasibility Study of Geothermal Utilization of Remoteness Areas, Design an Optimization of a Small Standard Power Plant", University of Iceland & University of Akureyri, February 2011
[10] Felea I. - Ingineria Fiabilităţii în Electroenergetică, Editura Didactică şi pedagogică, Bucureşti, 1996.
[11] Mihoc Gh., et.a., - Bazele Matematice ale Teoriei Fiabilităţii, Ed. Dacia, Cluj-Napoca, 1976.
[12] Panaite V., Munteanu R., - Control Statistic şi Fiabilitate, EDP, Bucureşti, 1982.
[13] ***www.anre.ro;
[14] Sun Caixia, - Feasibility Study of Geothermal Utilization of Yangbajain Field in Tibet Autonomous Region, P.R.China, Msc Thesis, UNU-GTP, 2008.
[15] Panea C. - Studii Şi Cercetări Privind Performanţele Energetice Şi De Disponibilitate Ale Sistemelor De Valorificare A Resurselor Geotermale Cu Entalpie Scăzută, Teza de doctorat, Universitatea din Oradea, 2012.