SUSTAINABLE SOLUTION TO EXPLOIT THE GEOTHERMAL ENERGY POTENTIAL FOR POWER AND HEAT GENERATION

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Abstract - Nowadays the environmental pollution is one of the main concerns worldwide going next to the preoccupation to ensure the energy consumption of the modern world continuously increasing. One solution to this issue is the energy generation using renewable sources, especially considering the classic energy sources being limited and the unfavourable availability forecast for coal, natural gas and oil.

The paper is structured in five chapters and addresses a topic related to the exploitation of renewable energy sources to generate heat and power using modern and sustainable solutions in order to reduce the environmental impact by facilitating greenhouse emissions savings.

The first chapter presents general considerations related to the solutions to generate heat from geothermal energy providing brief information about an existing geothermal system in Oradea, underlines the importance of the main topic and the current concerns.

In the second chapter are evaluated the geothermal system's performance indicators based on the real energy audit.

The third chapter shows an eco-friendly and financial efficient solution to exploit the geothermal potential for co-generation of heat and power, being presented the optimised energy balance and new performance indicators.

In the fourth chapter are given economical appraisal results of the geothermal co-generation investment and the last chapter indicates the final conclusions.

Keywords: renewable energy, sustainable energy technology, energy efficiency, geothermal energy potential, power, heating

1. INTRODUCTION

Modern world is relying today on electrical energy. The next-generation technologies are built to operate consuming power. It's also notable the significant and continuous growth of world population, determining default steps that should be taken to provide thermal energy in the form of hot water, heating or air conditioning to ensure decent and convenient living conditions. Moreover, the nature needs our help to conserve the appropriate environment for living conditions.

Thus, the green house emission level should be considerable decreased immediately by introducing clean modern technologies with high energy performance. Significant reduction of green house emissions level is accessible by power generation using renewable energy sources.

Romania is one of those countries having access to a wide range of renewable energy sources, from wind to solar, geothermal or biomass. The West side of Romania is enriched with geothermal deposits and several local commercial operators are providing surveys, explorations for geothermal waters by drilling deep wells. The geothermal deposits in the Romanian West Plane are located at depths of 2500 ... 3000 m, in fissured rocks of chalk and dolomite, with average temperature of water ranging between 70... 115°C. [1]

Considering these water temperatures, the geothermal waters can be successfully used into a heating centralised system (HCS) to generate heat for residential buildings, social objectives, administrative and commercial buildings, placed in the vicinity of the geothermal water extractions. Such projects are already in place in Bihor county where the heating centralised systems are using the geothermal water as source of primary energy, Beius and Oradea heating systems being representative projects.

The structure of a heating centralized system including the geothermal station and three thermal substations is schematically represented in figure 1. [2]

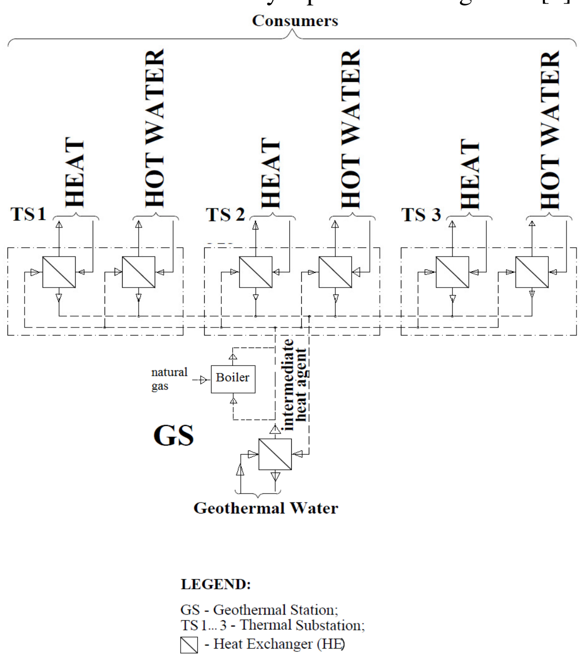

Fig.1. Schematic representation of the heating and hot water production system

The geothermal water, extracted from drilling, is transferring the energy within a heat exchanger to the intermediate agent which is delivered through the intermediate agent network to three thermal substations. For the seasons when the need for heat is exceeding the potential of the geothermal water, a boiler using natural gas is providing the missing energy.

The geothermal station analyzed here is defined by main parameters, [2] as follow:

- maximum thermal power: 10,5 MW
- geothermal water thermal power: 8 MW
- thermal power from boilers on natural gas: 2,5 MW

1. GEOTHERMAL SYSTEM'S PERFORMANCE INDICATORS

The energy audit performed for the system formed by the geothermal station and the intermediate agent network is based on the following measured parameters [3]:

- geothermal water flow: 117 m^3/h
- geothermal water inlet temperature: 106 ^oC
- geothermal water outlet temperature: 52,3 ^oC
- natural gas was flow: 270 Nm^3/h
- Inferior calorific power: 35800 kJ/Nm^3

The complex energy balance, on a yearly basis, for the system gathering the geothermal station and the intermediate agent network is presented in table 1 and schematically represented in the Sankey diagram shown in figure 2.

Table 1. Complex energy balance for the system gathering the geothermal station and the intermediate agent network [3]

Inlet Energies		**MWh**	**%**
Q_{at}	heat transferred by the geothermal water	30278,1	91,74
Q_{gn}	heat produced by burning natural gas	2372,9	7,19
Q_{ac}	heat combustion air	18,9	0,06
E	power consumed	333,2	1,01
W_i	total inlet energies	33003,1	100
Outlet Energies		**MWh**	**%**
ΔQ_{SCP}	plates heat exchanger's lost heat by convection and radiation	25	0,08
ΔQ_{caz}	Boiler's lost heat by convection and radiation	3,9	0,01
ΔQ_{ga}	lost heat via flue gases, discharged into the chimney	189,8	0,58
ΔQ_{RAI}	lost heat through intermediate agent network	1458,7	4,42
Q_u	useful heat, ceded in thermal substation	30818,7	93,38
ΔE_c	power lost in cables	4,8	0,01
ΔE_m	power lost in engines	46	0,14
E_u	useful power (to the engines trees)	282,4	0,86
w_e	total outlet energies	32829,3	98,47
w_Σ	the energy balance error	173,8	0,53

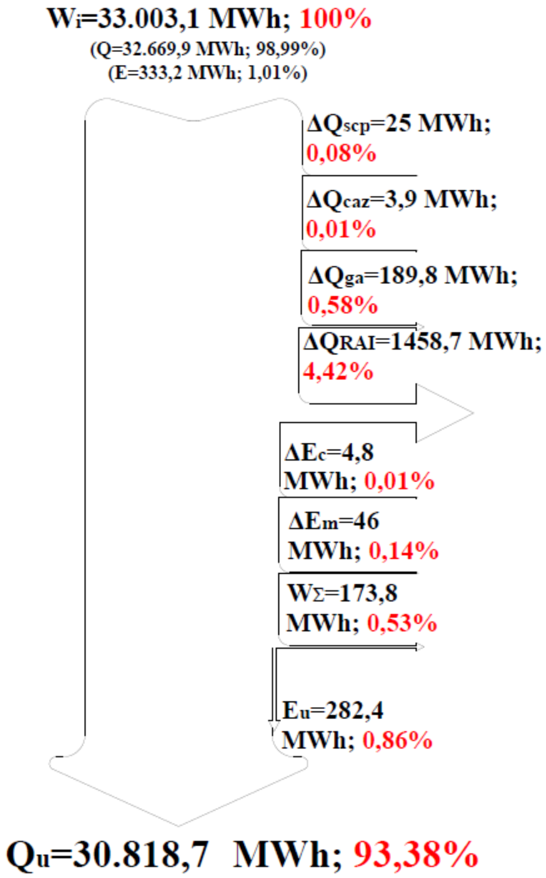

Fig. 2. Sankey Diagram representing the energy balance of geothermal station and intermediate agent network

Based on the complex energy audit, shall be determined the following performance indicators:

- system's thermal performance:

$$\eta_{te} = \frac{Q_u}{Q} x100 = 94.33\% \qquad (1)$$

- system's electrical performance:

$$\eta_{ee} = \frac{E_u}{E} x100 = 84.75\% \qquad (2)$$

- geothermal station thermal performance:

$$\eta_{etSTG} = \frac{Q_u + \Delta Q_{RAI}}{Q} x100 = 98.8\% \qquad (3)$$

- intermediate agent network thermal performance:

$$\eta_{etRAI} = \frac{Q_u}{Q_u + \Delta Q_{RAI}} x100 = 95.48\% \qquad (4)$$

- green-house gases emissions (GES) level [4]:

$$GES = Qgn * Fgn + E * Fpower = 712{,}90 \text{ t } CO2 \qquad (5)$$

The real energy balance results analysis shows that the solution of using the geothermal water energy to produce hot water and heating within a heating centralised systems supplying residential and industrial heat consumers has a very good performance ($\eta_e = 94{,}24\,\%$) and an appreciable social impact based on the competitive price for hot water and heat, much lower than the average prices paid by the consumers across country.

The price competitiveness derives from the lower price of the energy obtained from geothermal water ($\sim 0{,}07\ lei/kWh$) [2] compared with the natural gas price burned in the boiler ($\sim 0{,}12\ lei/kWh$) to produce the similar amount of energy. [5]

2. CO-GENERATION OF HEAT AND POWER SOLUTION FOR A SUPERIOR USE OF GEOTHERMAL ENERGY

The investigations addressed the technical possibilities for a superior exploitation of the geothermal energy potential, without generating a significant negative impact on the operation performance of heating centralized system, neither on the environment or affecting prices competitiveness.

The solution identified proposes the use of a power generation installation using as primary energy a part of the energy potential of geothermal water.

The proposed power generation installation is based on Organic Rankine Cycle module (ORC) having penta-fluor-propane (HFC-245fa) as working fluid. The technical advantages resulted by the use of an organic fluid in a Rankine cycle consists in high efficiency, reduced mechanical stress on turbine due to low speed, elimination of the mechanical losses in speed reducer due to the direct coupled turbine-generator, lack of erosion to turbine's blades due to the lack of liquid droplets in the fluid vapours. [6, 7]

In addition to the technical benefits there are benefits in the field of operation and maintenance mentioning simple start/stop procedures, no need for supervisory staff, low noise in operation, high availability (> 98 %), high efficiency operation at partial loads, reduced costs of operation/ maintenance (3 - 5 hours/week), long life cycle. [6, 7]

The principles of Organic Rankine Cycle installation is presented schematically in the figure 3.

It is important to note that T expander is not a turbine but a unit of two blades, similar with the gas compression system from helix compressors.

The main parameters of an ORC power generation installation suitable to be used within a geothermal station to co-generate heat and power, consist in:

- installed power: 30 ... 65 kW;
- source of warm: geothermal water with inlet temperature range of 88... 116 °C; inlet heat range 400 ... 860 kW and flow range 27,4 to 45,4 m^3/h;
- source of cold: cold water or air with outlet heat range 370... 795kW;

Considering the data above the average electrical efficiency is $\mu \cong 7.5$ %.

The installation is characterised by the following basic parameters:

- thermal power on entry: Qi =725 kW (flow 45 m^3/h)
- electrical power: P_e=50 kW
- thermal power to condensation (air-cooling): Q_e=670 kW
- average own power consumption: $P_p \cong 8.5$ kW (power for operation of circulation pump, fans condenser).

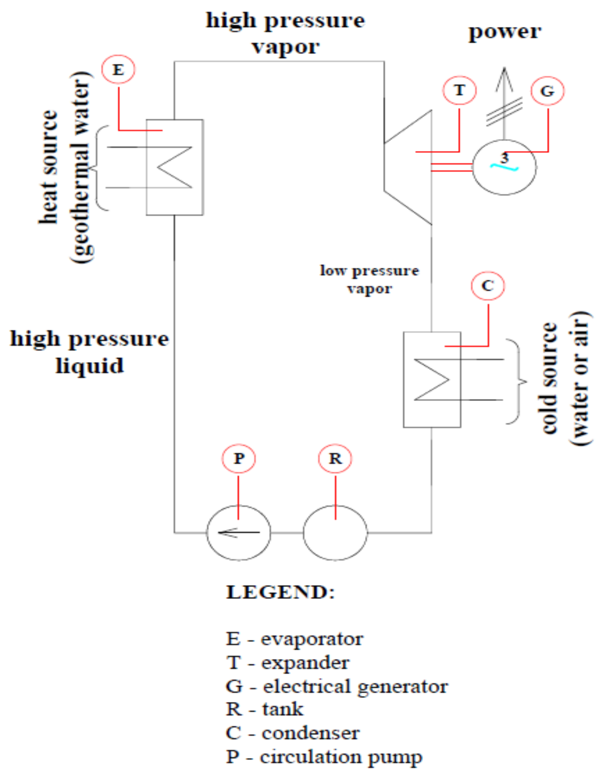

Fig. 3. Schematic representation of the Organic Rankine Cycle installation. [8]

The suggested option to insert the ORC power generation module inside the heating centralized system is represented in figure 4.

The ORC module is placed upstream the geothermal station within a secondary circuit where a part of the geothermal waters flow directed to the geothermal station is used to provide the primary energy for the ORC installation. The ORC module generates power, to be delivered into national power grid, and heat delivered in the geothermal station.

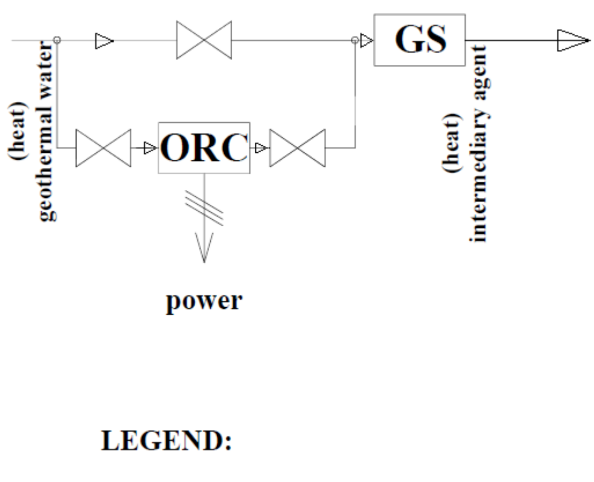

Fig. 4. Schematic representation of the proposed option to insert the ORC power generation module inside the heating centralised system

On the basis of energy calculations was estimated that the proposed installation will produce yearly 378 MWh of power, of which 64 MWh represents own power consumption and 314 MWh represents the electricity to be delivered to national power grid.

Starting with the energy baseline audit presented in table 1 and considering the influence of the operation of ORC module on the geothermal centralised heating system it was calculated the new energy balance on yearly basis in order to appreciate how the operation of ORC module influence the performance of the geothermal system.

The results of the complex energy audit performed for the centralized geothermal heating systems including the geothermal station and intermediary agent network, in the condition of ORC module in operation, is presented in the Table 2 and schematically represented in Figure 5.

Table 2. Complex energy balance for the system gathering geothermal station and the intermediate agent network with ORC module in operation. [3]

Inlet Energies		**MWh**	**%**
Q_{at}	heat transferred by the geothermal water	30010,9	90,78
Q_{gn}	heat produced by burning natural gas	2686,4	8,13
Q_{ac}	heat combustion air	21,4	0,06
E	electrical energy consumed	338,5	1,02
W_i	total inlet energies	33057,2	100
Outlet Energies		**MWh**	**%**
ΔQ_{SCP}	plates heat exchanger's lost heat by convection and radiation	25,7	0,08
ΔQ_{caz}	boilers lost heat by convection and radiation	5,2	0,02
ΔQ_{ga}	lost heat via flue gases, discharged into the chimney	250,7	0,76
ΔQ_{RAI}	lost heat through intermediate agent network	1458,7	4,41
Q_u	useful heat, ceded in thermal substation	30818,7	93,23
ΔE_c	power lost in cables	4,9	0,01
ΔE_m	power lost in engines	46,7	0,14
E_u	useful power (to the engines trees)	286,9	0,87
w_e	total outlet energies	32897,5	99,52
w_Σ	the energy balance error	159,7	0,48

Based on the complex energy audit for the system formed by the geothermal station and intermediate agent network, with ORC module in operation, shall be determined the new performance indicators:

- system's general performance:

$$\eta_e = \frac{Q_u + E_u}{W_i} x100 == 94.1\% \qquad (6)$$

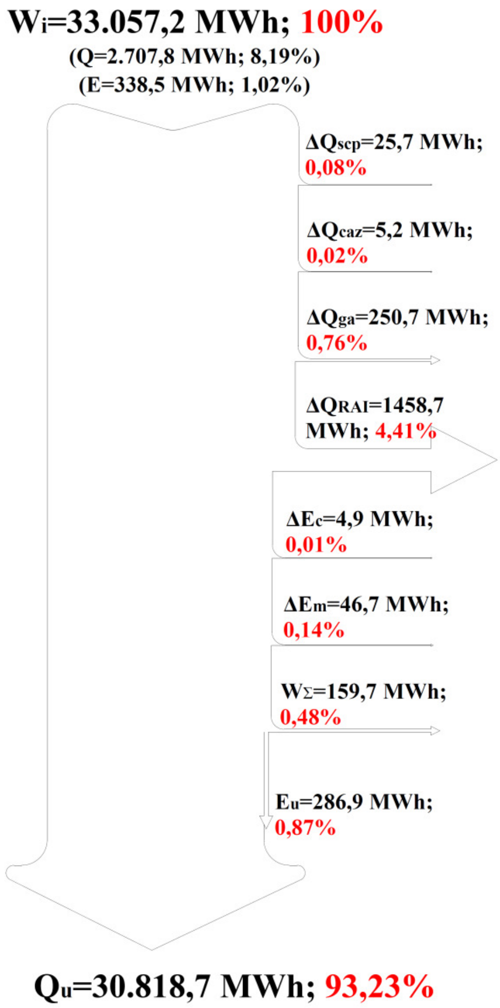

Fig. 5. Sankey Diagram representing the energy balance for the system formed by geothermal station and intermediate agent network with ORC module in operation.

- system's thermal performance:

$$\eta_{te} = \frac{Q_u}{Q} x100 = 94.19\% \qquad (7)$$

- system's electrical performance:

$$\eta_{ee} = \frac{E_u}{E} x100 = 84.76\% \qquad (8)$$

- geothermal station thermal performance:

$$\eta_{etSTG} = \frac{Q_u + \Delta Q_{RAI}}{Q} x100 = 98.65\% \qquad (9)$$

- intermediate agent network thermal performance:

$$\eta_{etRAI} = \frac{Q_u}{Q_u + \Delta Q_{RAI}} x100 = 95.48\% \qquad (10)$$

- green-house gases emissions (GES) level [4]:

$$GES = Q_{gn} * F_{gn} + E * F_{power} = 779{,}94 \text{ t } CO_2 \qquad (11)$$

The performance indicators calculations shows that the operation of the ORC module installed upstream the geothermal station has no significant influence on the heating centralized systems performance, observation that incourage the development of such power generation projects where consitions are suitable.

Analysing the performance of the ORC installation the calculations started with the yearly complex audit. The complex energy balance, on a yearly basis, only for the ORC module has been drawn up based of the information presented in the technical sheet of ORC module type S400-ET. The resuts are presented in table 3 and schematically represented in a Sankey diagram in fig. 6.

Table 3. Energy balance for the ORC module installed upstream the geothermal station

Inlet Energies		**MWh**	**%**
Q_{at}	received heat from geothermal water	5481	100
W_i	total inlet energies	*5481*	*100*
Outlet energies		**MWh**	**%**
ΔQ_e	heat transferred to cold source (evacuated in condenser)	5065,2	92,41
ΔE_g	power lost in generator and internal network	37,8	0,69
ΔE_{CP}	power for own consumption	64,3	1,17
E_u	useful power (to be delivered in national power grid)	313,7	5,72
W_e	total outlet energies	5481	100

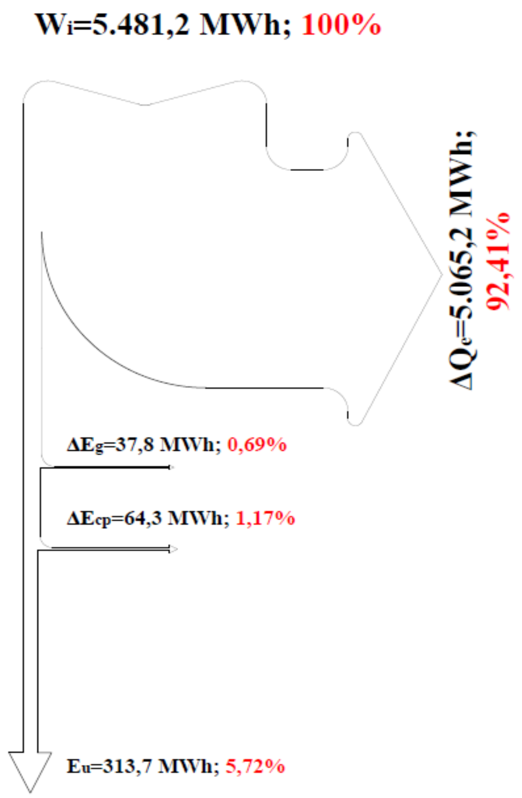

Fig. 6. Sankey Diagram representing the energy balance of the ORC module.

Considering the energy balance presented above it was calculated the performance indicators of the ORC module:

- ORC module's electrical performance:

$$\eta_{ee} = \frac{E_u}{W_i} x100 = 5.72\% \quad (12)$$

- green-house gases emissions (GES) savings [4]:

$$dGES = E_u * F_p = 219,9 \text{ t } CO_2 \quad (13)$$

The power generated by the ORC installation using geothermal water energy as primary energy is clean energy with zero green house emissions. The green house emissions savings corresponds to the clean power generated by the ORC module and delivered into the national grid which replaces the same amount of power generated by classic power generation installation.

3. ECONOMIC SUSTAINABILITY

The technical evaluation confirmed the utility, the realistic and achievable approach of using ORC module to generate power and heat exploiting the geothermal water as primary energy. The environmental benefits and minimum costs of operation are strong arguments when the opportunity of such investments is promoted. The economic reality is extremely important for creating the sufficient conditions to implement such projects and the financial sustainability is decisive. Thus, it was therefore necessary an economic evaluation of the project, calculating the financial performance indicators in order to confirm the project's financial feasibility complementary with the technical feasibility. For the financial performance indicators calculation the economic evaluation treats the initial investment versus revenues and expenses generated after implementation.

For the amount of power generation calculations is considered that the ORC module will be in operation 8000 hours/year, the rest of the yearly hours being used for revisions, preventive and corrective maintenance works.

The ORC module generates 400 MWh/year power, of which 68 MWh/year represents the own consumption and the rest of 332 MWh/year constituting net power production delivered to the national power grid.

The value of the net power generated and delivered into the national grid, considering the price of power and the corresponding green certificates [9] is estimated at:

$$Vp = Q_E \text{ x } (P_E + 2 \text{ x } P_{CV}) = 49468 \text{ euro/year}$$

where:

P_E = 49 euro/MWh – average power price sold in national grid

P_{CV} = 50 euro/MWh – average green certificates price

Q_E = 332 MWh/year - power generated and sold

The revenues obtained from selling the power, generated and delivered into national grid, are formed by the value of the power sold and the value corresponding the sell of green certificates distributed according the regulations, two green certificates for each MWh of power generated and delivered into national grid.

The economical appraisal is based on the following hypothesis:

- total investment value: 205850 euro
- depreciation period: 20 years
- service and monitoring costs: 944 euro/year
- other operational costs: 1749 euro/year
- bank loan level for 5 years: 150000 euro
- loan interest: 10293 euro/year

The resulting financial performance indicators show a feasible investment [10]:

- Payback period = 5,6 years
- IRR= 22%
- NPV= 192372 euro
- Benefit/Cots ratio = 1,93

The financial indicators calculated confirm the feasibility of a project implementing ORC module upstream a geothermal station in order to generate power to be delivered into national power grid.

4. CONCLUSIONS

Prior to making use of a part of the geothermal water energy to produce power, the centralized geothermal heating system‘s performance indicators shows a high performance level:

- general performance: $\eta_e = 94,24\%$
- thermal performance: $\eta_{te} = 94,22$ %,
- electrical performance: $\eta_{ee} = 84,75$ %.

Introducing the ORC module upstream the geothermal station change slightly in the sense of reducing the performance as follow:

- general performance: $\eta_e = 94,1$ %,
- thermal performance: $\eta_{te} = 94,19$ %,
- electrical performance: $\eta_{ee} = 84,76$ %.

The performance reduction level is very small, 0,14% for general performance and for thermal performance, but the electric performance is remaining the same.

The performance of the ORC module generating power to be delivered in national power grid, evaluated at $\eta_e=5,72\%$ is low due to the relatively low temperature of geothermal water (~100-106 ^{O}C). But, from economic considerations, were confirmed the opportunity and feasibility of the superior exploitation of geothermal water potential by co-generating power and heat with ORC module installed upstream the geothermal station in the conditions when the power is delivered in the national power grid and benefits of the receipt of green certificate.

A parallel technical and financial evaluation was performed for technical and financial feasibility appraisal in the conditions when the power generated by ORC module is used for the own consumption and not being delivered into national power grid. The evaluation aware that if the power generated by the ORC module will be used for the own consumption of the geothermal heating centralized system, the complex energy balance calculations shows a general performance significantly reduced of ηe= 81,38 %, meaning 12,86 % less that in baseline situation without ORC module installed.

As a result of present solutions analysis it was identified the opportunity to exploit the geothermal water's energy potential to generate power using an ORC module optimizing the use of power by direct delivery in national power grid and not for self-consumption.

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