PROMOTION OF THE ORGANIC RANKINE CYCLE BASED COGENERATION: OPPORTUNITIES AND CHALLENGES

VORONCA. M.-M.*, VORONCA S.-L.**, CRUCERU M.***
*Romanian Energy Efficiency Fund, Johann Strauss no. 2A, Bucharest,
**C.N.T.E.E. Transelectrica S.A., Olteni no. 2 - 4, Bucharest
***University "Constantin Brâncuşi" Târgu Jiu, Republicii no. 1, Târgu Jiu
mihai.voronca@free.org.ro

Abstract - *Most economic operators are obviously power consumers, but only a few industrial companies report heat consumption for technological purposes. The recent implementation in Romania of modern solutions aiming at a "smarter" use of heat will prove that such companies might become power producers. Challenges still being the need for cost cutting and the competitiveness increase, such kind of 'actors' will be able to face easier the impact of other possible worldwide economic recession events. This paper aims at revealing the opportunities and challenges of promoting cogeneration based on Organic Rankine Cycle. Two relevant cases of investments already implemented by Romanian companies are studied from both the technological and economical points of view.*

Keywords: heat waste, heat recovery, residual power, Organic Rankine Cycle, investment, profitability.

1. INTRODUCTION

At the beginning mankind has accidentally discovered fire and then, the biomass to heat. Rapidly, the heat was used not only for heating but also for food preparation purposes. In consequence heat became useful and helped men to develop themselves. The heat has helped man to get more evolved hunting tools, to manufacture goods for living and to start trading them. During all Ages coming after, heat has helped mankind to evolve.

Obtained from coal and centuries after from oil and gas, the heat we use today i.e. for heating, cooling and power generation is expensive and polluting. Traditionally, for heat and power generation purposes the "friendly" water was the working liquid compared to cooling where "environmental aggressive" refrigerant liquids were used. Facing reinforced environmental constraints, several actions aiming at impact mitigation were put in place in the last decades. These were the ways we have learned to limit heat waste and to promote heat recovery. And more importantly, we have started to explore methods of heating, not only power "greening".

2. WATER V.S. ORGANIC FLUID

The technology used for fossil fuel fired power generation in a classic Rankine Cycle (fig. 1) involves a fuel fired steam boiler which produces a certain amount of superheated steam. The rated pressure may vary between 28 to 36 bars and the temperature between 320°C and 360°C.

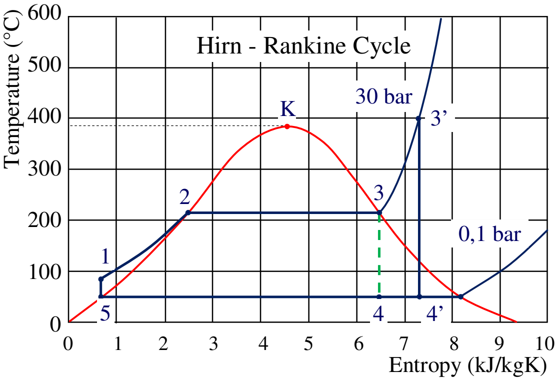

Fig. 1. Hirn - Rankine Cycle:
1-2-3 Boiler Steam Generation; 3-4 Turbine Steam Expansion; 4-5 Condenser Steam Condensation; 5-1 Pressure Increase in Feed Pump
(source: http://www.orcycle.be/)

This steam drives the steam turbine which transfers the energy to the generator via gears and coupling. With the single-stage turbine used in small power plants it is possible to obtain power with an electric efficiency of 12-14% from the energy input.

Steam turbines are generally suitable for CHP plants with an electrical output greater than 2MW. The condenser transforms the turbine outlet low pressure steam into liquid which is fed back to the boiler. In combined heat and power schemes (CHP), the condenser's cooling heat is frequently fed into a heating circuit such as district heating.

For superheated steam generation purposes, important amount of heat as well as fuel are needed. The absence of only nowadays adopted environmental constraints has encouraged the extensive use of fossil fuels, relatively accessible in geographical and financial terms.

Increased efforts aiming at heat recovery and "greening" have oriented the scientific works towards the identification of substitute liquids. First "reported victims" were the substances used for refrigeration. Alternatives to Ammonia and Freon as Chlorofluorocarbons and Hydro-chlorofluorocarbons were identified. Today, the prospect of the previously mentioned fluids phasing out is orienting efforts towards the organic fluids use.

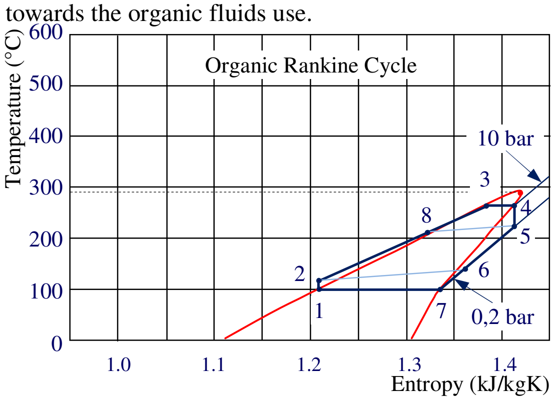

Fig. 2. Organic Rankine Cycle:
2-8-3-4 Evaporator Vapour Generation; 4-5 Turbine Vapour Expansion; 5-6-7-1 Condenser Vapour Condensation; 1-2 Pressure Increase in Feed Pump (source: http://www.orcycle.be/)

When the water is replaced by an organic fluid in a classic Rankine Cycle, this one (fig. 2) is called an Organic Rankine Cycle (ORC). The most modern ORC technology used implies the circulation of the organic fluid in a closed circuit: vaporisation of the high pressure liquid by heat recovered from primary processes or "green" heat exchange within the evaporator, expansion of the vapour within a slow-moving axial turbine based along similar principles to a steam turbine, condensation of low pressure vapour by cooling within the condenser and the increase of liquid pressure with the feed pump. All general thermodynamic laws remain always applicable: the bigger the temperature difference between evaporator and condenser, the higher the cycle efficiency is.

Most of the organic fluids are so called dry fluids. These dry fluids have the advantage that they remain superheated after expansion, so condensation of the fluid in the turbine can be avoided. Some commonly used organic fluids are pentane, propane, toluene, ammonia and some coolants. As these organic fluids have a lower evaporation point than water, the ORC based technology runs properly at a lower temperature of 300°C (in figure 2, the highest temperature of the heat source is about 280°C), and a working pressure of 10.0 bar. Condensation occurs at 100°C (0.2 bars), which makes the cooling heat still usable for heating purposes.

The ORC electric efficiency is around 17% of the total energy input, which is about 3% higher than traditional steam turbines. ORC units are suitable for geothermal and biomass CHP plants with an electric output as small as 200 kW. Single ORC units go up to 2MW in size and multiple units can be installed to increase capacity.

Compared to classic units, the ORC system performs well under partial load because of the low working pressures and temperatures.

The purpose of this paper is to present challenges and opportunities of Organic Rankine Cycle based on cogeneration technologies promotion. The related results and conclusions of a generally recognised methodology based investigation [1] are to be highlighted, too.

2. METHODOLOGY

In Annex III of the Directive 2004/8/EC on the promotion of cogeneration - based solutions on a useful heat demand in the internal energy market [1], the amount of primary energy savings provided by cogeneration production is determined with the formula:

$$\mathrm{PES} = \left(1 - \frac{1}{\frac{\mathrm{CHP\,H\eta}}{\mathrm{Ref\,H\eta}} + \frac{\mathrm{CHP\,E\eta}}{\mathrm{Ref\,E\eta}}} \right) \times 100\% \,, \quad (1)$$

where:

PES - the primary energy savings;

CHP Hη - the heat efficiency of the cogeneration production, defined as an annual useful heat output divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration;

REF Hη - the efficiency reference value for separate heat production;

CHP Eη - the electric efficiency of the cogeneration production defined as annual electricity from cogeneration divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration;

REF Eη - the efficiency reference value for separate electricity production;

The use of this method, the same presented in [2], is motivated by the fact that the" Organic Rankine cycles" is listed in the Annex I of the Directive 2004/8/EC [1]. As indicated in Annex III of the Directive 2004/8/EC [1], such technology could be also classified as high-efficiency cogeneration.

As considered in the precedent paper"Installation of a Cogeneration Unit within a Chemical Company" [2], the purposes of using the previously mentioned method consist in promptly delivering valid data referring to an existing situation analysing the efficiency of the separate production of heat and electricity, while collecting accurate information regarding the efficiency of the Organic Rankine cycle based cogeneration technology. Consequently, in the following chapter authors are proposing a detailed investigation on such ORC technology that facilitates the "power extraction" from waste or recovered heat based on cogeneration premises. Authors propose two theoretical cases which are below considered: geothermal and respectively biomass based cogeneration.

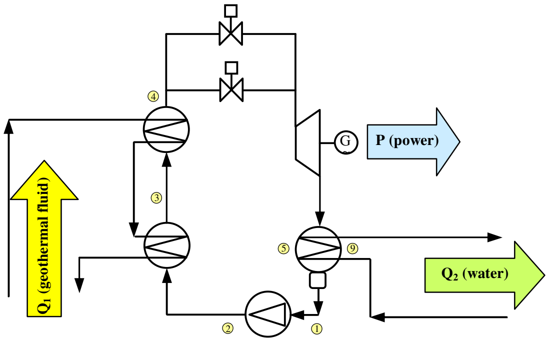

Fig. 3. Geothermal ORC Cogeneration Unit
(source: http://www.electratherm.com/)

The processes depicting the geothermal based thermodynamic cycle of figure 2 implies a high pressure regenerator, an evaporator, a vapour expander coupled to a power generator, a condenser, and a pump (fig. 3). The working liquid is compressed by a feed pump (1→2) and then transferred to the regenerator where the liquid is preheated (2→3) due to second stage geothermal water cooling and then transferred to the evaporator where it is transformed in vapour (3→4). The high pressure organic vapours are expanded into a turbine (4→5). After expansion, the superheated vapours enter the condenser where vapours are transformed into liquid (5→1). Finally, the liquid pressure is then increased with the feed pump (1→2) and circulated back to the regenerator.

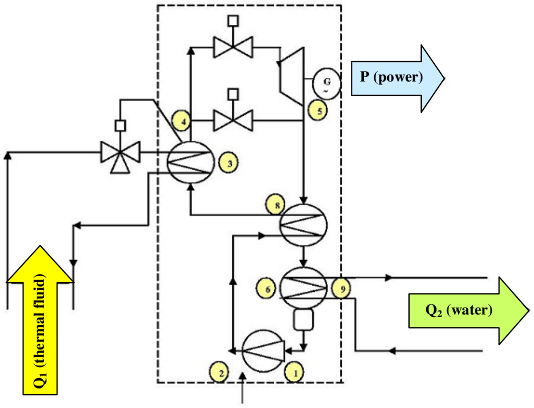

Fig. 4. Biomass fired ORC Cogeneration Unit
(source: 1.2 MW_e High Efficiency Cogeneration Unit, Energy - Serv S.R.L. Bucharest)

The processes depicting the biomass based thermodynamic cycle of figure 2 imply an evaporator, a vapour turbine coupled to a power generator, a condenser, a low pressure regenerator and a pump (fig. 4). The working organic liquid is compressed by a feed pump (1→2) and then transferred to the evaporator where it is transformed in vapour (8→3→4) due to the transfer of heat from high temperature thermal oil to the organic liquid. The thermal oil is initially heated in a biomass fired boiler. The high pressure organic vapours are expanded into a turbine (4→5). As the vapours remain superheated after expansion, a regenerator placed before the condenser is cooling the vapours (5→6) and preheating the liquid before the inlet into evaporator (2→8). From the regenerator outlet the vapours are condensed (6→1) and the liquid pressure is then increased with the feed pump (1→2), sent to the regenerator and circulated back to the evaporator.

3. PROJECT HIGHLIGHTS

3.1. Technical description of a geothermal based ORC cogeneration unit

The considered geothermal based ORC cogeneration unit operates on geothermal water with a temperature of 105ºC (low enthalpy heat source), and transfers the heat to a ”R 245 fa” type fluid which moves from liquid to vapour state (process 3→4 in fig. 2). The process occurs within the evaporator as already indicated (fig. 3), with a rated thermal power from 400 kW_{th} to 860 kW_{th} and for a certain amount of geothermal water flow rate available (i.e. 12.6 l/s), the total annual heat amount recovered from the geothermal water could be of about 5,154 $MW_{th}h$/year.

Fig. 5. Twin Screw Expander
(source: http://www.electratherm.com/)

In correlation with the cooling groundwater average temperature of 10ºC (essential for the amplitude of expansion 4→5 of fig. 2) crossing the condenser (fig. 3), the twin screw expander also known as a Lysholm type motor (fig. 5), coupled to a synchronous power generator with the rated electric power from 30 kW_e to 65 kW_e, leads to a total annual gross amount of generated power of 382 MW_eh/year (i.e. the equivalent of a total annual net amount of 303 MW_eh/year).

Following various manufacturers' technical specifications, the rated power of the considered cogeneration unit may vary in-between 30 and 65 kW at a rated voltage of 380 V and frequency of 50 Hz, the operation being possible for environmental temperatures from -29ºC to 49ºC. The power factor is 97% and distortions due to harmonics are of 2% for voltage and of 10% for intensity. The noise level is 92 dB at 3 m distance. Lysholm type motors operate at low speed without gear box or oil pump and have a 3:1 turn down ratio.

For an adequate groundwater flow rate (i.e. the equivalent of 5.7 l/s), a total annual amount of about 4,747 $MW_{th}h$/year (in addition to the initial energy content of the ground water) is transferred from the condenser with a rated thermal power from 370 kW_{th} to 795 kW_{th} of the considered ORC cogeneration unit and sold to the district heating system for sanitary water preparation purposes.

The thermodynamic net efficiency of power generation for geothermal based ORC cogeneration unit is 7%, value which will be associated to the variable CHP $^{G}E\eta$.

3.2. Technical description of a biomass based ORC cogeneration unit

The considered biomass based ORC cogeneration unit operates on wooden waste from a wood processing factory, along with two other biomass fired boilers for hot water, and respectively warm water production.

The biomass fired boiler integrated to the ORC cogeneration unit has the rated capacity of 8 MW_{th} and transfers the generated heat to a thermal fluid at a rated temperature of 320°C. Facing moderate heat fluxes due to the low caloric value of wooden waste (i.e. 9.000 kJ/kg), the thermal fluid can easier take over heat than the water, the related heat transfer efficiencies being as much as 5% to 8% higher for hot oil systems than conventional steam ones.

Leaving the biomass fired boiler, the thermal fluid enters the evaporator of the ORC cogeneration unit where the transformation (3→4 in fig. 2) of the organic fluid (i.e. silicon oil) occurs from liquid to vapour.

The vapour expansion (4→5 in fig. 2) powers a blades type turbine (fig. 4) with good efficiency (up to 90%), low mechanical stress due to low peripheral speed, low RPM allowing the direct drive of the synchronous generator without reduction gear, no erosion of the turbine blades due to the absence of the moisture in the vapour nozzles and very long operational life of the machine due to the characteristics of the working fluid that, unlike steam, is non eroding and non corroding for valve seats tubing and turbine blades.

The turbo generator has a gross rated electric power of 1,317 kW_e or a net rated electric power of 1.2 MW_e.

To increase the overall efficiency of the ORC cogeneration unit, the regenerator with a rated capacity of 4 MW_{th} placed before the condenser decreases the superheated vapour enthalpy (5→6 in fig. 2) for preheating purposes and the condenser with a rated capacity of 5.4 MW_{th}, transforms the vapours in liquid (6→1 in fig. 2).

For the considered biomass fired ORC cogeneration unit on annual basis operation, the total annual generated ”useful” heat amount for warm water purposes is of about 35,418 $MW_{th}h$, and an additional ”residual” annual generated power amount of 6,450 MW_eh.

The thermodynamic net efficiency of power generation for the biomass fired ORC cogeneration unit is 12%, value which will be associated to the variable CHP $^{B}E\eta$.

3.3. Estimated Primary Energy Savings

Authors are assuming that the projects are implemented by industrial companies which are eligible customers, in line with the definitions from Directive 2003/54/EC [3]. For energy savings calculation reasons, authors have kept the assumption that the electricity market is still dominated by fossil fuel-based electricity producers [2]. Consequently, the efficiency reference value of 31.85% [4] for separate electricity production in Romanian thermal power plants is to be associated to the variable REF Eη from the formula (1).

For the variable CHP Eη from the formula (1), the values CHP $^{G}E\eta$ and CHP $^{B}E\eta$ are to be in each case assigned, in order to determine the estimated primary energy savings for geothermal based and biomass based cogeneration units.

The value associated to the variable REF Hη from the formula (1) is 92%. Authors are deeming that separate heat generation is to be considered as efficient as possible, in order to limit the favourable effect of using renewable energy sources in the analysed cases for power generation.

Annex II of the Directive 2004/8/EC [1] mentions that the overall efficiency for micro-cogeneration units should be calculated based on certified values. Authors have assumed the overall efficiency values provided by manufacturers (i.e. Electratherm USA, Turboden Italy). The considered overall efficiency of the geothermal based ORC cogeneration unit is 98.39% and for biomass based ORC cogeneration unit is 82.72%, respectively. For the already specified CHP $^{G}E\eta$ and CHP $^{B}E\eta$, the thermodynamic efficiencies of condensers integrated to the considered ORC cogeneration units assigned as the values CHP $^{G}H\eta$ and CHP $^{B}H\eta$ of variable CHP Hη in formula (1) are 91.39% and 70.72%.

Based on the methodology from Annex III of the Directive 2004/8/EC [1], the estimated primary energy savings ^{G}PES of the geothermal based ORC cogeneration unit are:

$$^{G}\mathrm{PES}=\left(1-\frac{1}{\dfrac{\mathrm{CHP}\ ^{G}\mathrm{H}\eta}{\mathrm{Ref\ H}\eta}+\dfrac{\mathrm{CHP}\ ^{G}\mathrm{E}\eta}{\mathrm{Ref\ E}\eta}}\right)\times 100\%=$$

$$=\left(1-\frac{1}{\dfrac{91.39}{92.00}+\dfrac{7.00}{31.85}}\right)\times 100\%=17.57\%. \quad (2)$$

Similarly, the estimated primary energy savings ^{B}PES of biomass based ORC cogeneration unit are:

$$^{B}\mathrm{PES}=\left(1-\frac{1}{\dfrac{\mathrm{CHP}\ ^{B}\mathrm{H}\eta}{\mathrm{Ref\ H}\eta}+\dfrac{\mathrm{CHP}\ ^{B}\mathrm{E}\eta}{\mathrm{Ref\ E}\eta}}\right)\times 100\%=$$

$$=\left(1-\frac{1}{\dfrac{70.72}{92.00}+\dfrac{12.00}{31.85}}\right)\times 100\%=12.70\%. \quad (3)$$

Both determined ^{G}PES and ^{B}PES values qualify the ORC cogeneration units as highly efficient, as Annex III stipulates that the ”cogeneration production from cogeneration units shall provide primary energy savings calculated according to point (b) of at least 10% compared with the references for separate production of heat and electricity”.

For primary energy savings calculation purposes, it should be assumed that both annual amounts of heat and electricity from cogeneration are to be considered as separate types of generation, where, on one hand, the heat is produced within modern heat plant with 92% efficiency (a disadvantageous assumption for the intended comparison), and on the other hand power is generated in thermal power plants with 31.85% efficiency [4].

In the case of geothermal based ORC cogeneration unit, the annual amount of heat $^{G}H_{CHP}$ is 1.319 MJ/year. For a thermodynamic efficiency CHP $^{G}H\eta$ of 91.39%, the resulting annual primary energy consumption $^{G}PEC_{CHP}$ is:

$$\begin{aligned} {}^{G}PEC_{CHP} &= \frac{{}^{G}H_{CHP}}{CHP\ {}^{G}H\mu} = \frac{1.319\,\mathrm{MJ/year}}{91.39\,\%} \\ {}^{G}PEC_{CHP} &= 1.443\ \frac{MJ_{PE}}{year} \end{aligned} \quad . \qquad (4)$$

For the separate heat and power generation, considering that the total annual amount of heat $^{G}H_{SEPARATE}$ is 1.319 MJ/year and the total annual amount of electricity $^{G}E_{SEPARATE}$ is 0.084 MJ/year for REF Hη of 92% and REF Eη of 31.85%, %, the resulting annual primary energy consumption $^{G}PEC_{SEPARATE}$ is:

$$\begin{aligned} {}^{G}PEC_{SEPARATE} &= \frac{{}^{G}H_{SEPARATE}}{REF\,H\eta} + \frac{{}^{G}E_{SEPARATE}}{REF\,E\eta}; \\ {}^{G}PEC_{SEPARATE} &= \frac{1.319\,\mathrm{MJ/year}}{92\%} + \frac{0.084\,\mathrm{MJ/year}}{31.85\%}; \qquad (5) \\ {}^{G}PEC_{SEPARATE} &= 1.698\,\frac{MJ_{PE}}{year}. \end{aligned}$$

In conclusion, the resulting annual primary energy savings for the geothermal based ORC cogeneration unit $^{G}PEC_{SAVINGS}$ is

$$\begin{aligned} {}^{G}PEC_{SAVINGS} &= {}^{G}PEC_{SEPARATE} - {}^{G}PEC_{CHP}; \\ {}^{G}PEC_{SAVINGS} &= 1.698\,\frac{MJ_{PE}}{year} - 1.443\,\frac{MJ_{PE}}{year}; \qquad (6) \\ {}^{G}PEC_{SAVINGS} &= 0.255\,\frac{MJ_{PE}}{year}. \end{aligned}$$

In the case of biomass based ORC cogeneration unit, the annual amount of heat $^{B}H_{CHP}$ is 9.838 MJ/year. For a thermodynamic efficiency CHP $^{B}H\eta$ of 70.72%, the resulting annual primary energy consumption $^{B}PEC_{CHP}$ is:

$$\begin{aligned} {}^{B}PEC_{CHP} &= \frac{{}^{B}H_{CHP}}{CHP\ {}^{B}H\mu} = \frac{9.838\,\mathrm{MJ/year}}{70.72\,\%} \\ {}^{B}PEC_{CHP} &= 13.912\ \frac{MJ_{PE}}{year} \end{aligned} \quad . \qquad (7)$$

For the separate heat and power generation, considering that the total annual amount of heat $^{B}H_{SEPARATE}$ is 9.838 MJ/year and the total annual amount of electricity $^{B}E_{SEPARATE}$ is 1.792 MJ/year for REF Hη of 92% and REF Eη of 31.85%, the resulting annual primary energy consumption $^{B}PEC_{SEPARATE}$ is:

$$\begin{aligned} {}^{B}PEC_{SEPARATE} &= \frac{{}^{B}H_{SEPARATE}}{REF\,H\eta} + \frac{{}^{B}E_{SEPARATE}}{REF\,E\eta}; \\ {}^{B}PEC_{SEPARATE} &= \frac{9.838\,\mathrm{MJ/year}}{92\%} + \frac{1.792\,\mathrm{MJ/year}}{31.85\%}; \qquad (8) \\ {}^{B}PEC_{SEPARATE} &= 16.319\,\frac{MJ_{PE}}{year}. \end{aligned}$$

In conclusion, the resulting annual primary energy savings for the geothermal based ORC cogeneration unit $^{B}PEC_{SAVINGS}$ is

$$\begin{aligned} {}^{B}PEC_{SAVINGS} &= {}^{B}PEC_{SEPARATE} - {}^{B}PEC_{CHP}; \\ {}^{B}PEC_{SAVINGS} &= 16.319\,\frac{MJ_{PE}}{year} - 13.912\,\frac{MJ_{PE}}{year}; \qquad (9) \\ {}^{B}PEC_{SAVINGS} &= 2.407\,\frac{MJ_{PE}}{year}. \end{aligned}$$

Considering both the geothermal based and biomass based ORC cogeneration units, the annual amounts of energy saved are significantly greater that those determined with the relations (6) and (9) as long as renewable energy sources are used for power and heat generation against fossil fuels. In conclusion, the total annual amount of energy saved by using geothermal energy is 1.698 MJ_{PE}/year and the total annual amount of energy saved by using biomass is 16.319 MJ_{PE}/year.

3.4. Adequate Financial Prospects

In the case of the geothermal based ORC cogeneration unit, the power extraction from geothermal heat is financially adequate due to avoided costs related to fuel and power purchasing expenditures [2] and to earnings from heat supply. The aggregation of limited financial costs (i.e. royalty of 4% p.a.) for using the underground geothermal water, with free of charge generated power to cover the pumping demand (i.e. power supply price of 107 €/MW_{e}h, VAT excluded) and earnings from heat sold to the district heating system (i.e. heat supply price of 13 €/MW_{th}h, VAT excluded), could represent annual financial benefits amounting to 91,291 €/year. Investment favourable circumstances are created by the opportunity to access such “cheap heat”, authors naming here the geothermal energy, and the possibility to increase the heat supply in the district heating system.

In the case of the biomass based ORC cogeneration unit, the power extraction from waste heat (wooden waste) is financially adequate exclusively due to avoided costs related to fuel and power purchasing expenditures [2]. The annual financial benefits (i.e. power supply price of 68 €/MW_{e}h, VAT excluded) could be evaluated at an amount of 439,917 €/year. Access to “no cost” or “low cost” wooden waste as well as important amounts of heat for drying purposes and power needed in technological processes are opportunities creating a favourable investment environment.

3.5. Favourable Environmental Impact

The use of such ORC technologies for cogeneration purposes is environmentally friendly as long as the heat is generated by using renewable energy sources. As indicated in paragraph 3.3, for a total annual heat amount extracted for geothermal energy is 1.698 MJ_{PE}/year representing the equivalent of 525 toe/year. Based on the records published by the International Energy Agency in 2010 [5], specifying that one toe_{TPES} in Romania would emit 2.28 tonnes of CO_2, it results that the avoided emissions of CO_2 are 1,198 tonnes CO_2/year.

Similarly, the equivalent of the total annual amount of 16.319 MJ_{PE}/year energy saved by using the biomass is 5,052 toe/year. Based on the same records published by the International Energy Agency in 2010 [5], it results that the avoided emissions of CO_2 are11,517 tonnes CO_2/year.

Both cases could justify the authors' opinion that ORC technology based cogeneration is greening the environment.

3.6. Total Investment

The total investment for the geothermal based cogeneration unit (www.electratherm.com) is expected to amount to €193,182 (Table 1). The investment is supposed to rise the annual financial benefits amounting to 91,291 €/year, representing the equivalent of 47% from the total investment.

Table 1

Geothermal Cogeneration Project	**€**
Geothermal based ORC cogeneration unit (evaporator, expander, condenser, pump, preheater etc.)	151,515
Other equipment, raw materials etc.	18,939
Design, Engineering, Erection Works, Commissioning	22,727
Total	**193,182**

Costs in Table 1 do include custom duties (as the manufacturer is from Reno, Nevada, United States of America), storage taxes, transportation fees and authorisation taxes and do not include VAT.

Following the estimations of the Feasibility Study depicting the chosen technical solution, the total investment for the biomass based cogeneration unit is expected to come to €5,227,273 (Table 2). The investment is supposed to rise annual financial benefits amounting to 439,917€/year, representing the equivalent of 8% from the total investment size.

Table 2

Biomass Cogeneration Project	**€**
Biomass based ORC cogeneration unit (thermal oil boiler, evaporator, expander, condenser, pump, regenerator etc.)	4,772,727
Other equipment, raw materials etc.	189,394
Design, Engineering, Erection Works, Commissioning	265,152
Total	**5,227,273**

Costs in Table 2 do not include custom duties (as the manufacturer is an Italian company), storage taxes and VAT, but include transportation fees and authorisation taxes.

4. RESULTS AND DISCUSSIONS

4.1. Performance Indicators Values

To determine the investment performance indicators [6] authors have adopted the notations from [2], respectively a - the discount rate, h - the year of expenditure or earning, d - the duration of erection works, D - the lifetime of investment V_h - the annual revenue in year h, C_h - the annual expenditure in year h, and I_h - the annual investment in year h.

Based on the discounted cash flow CF_h determined with the relation (10):

$$CF_h = [V_h - (I_h + C_h)]\frac{1}{(1+a)^h},\ h = \overline{1, D+d} \quad , (10)$$

the net present value NPV was obtained with the relation (11):

$$NPV = \sum_{h=1}^{d+D}\frac{V_h}{(1+a)^h} - \sum_{h=1}^{d+D}\frac{I_h + C_h}{(1+a)^h} > 0 \quad , (11)$$

the internal rate of return IRR being analytically calculated with the relation (12):

$$IRR = a_{min} + (a_{max} - a_{min})\frac{NPV_+}{NPV_+ + |NPV_-|} \quad . (12)$$

Relations (13) are used for the gross payback time GPT and the discounted payback time DPT:

$$\sum_{h=1}^{GPT}[V_h - (I_h + C_h)] = 0\ ,\sum_{h=1}^{DPT}\frac{V_h - (I_h + C_h)}{(1+a)^h} = 0\ . \quad (13)$$

For the case of geothermal based ORC cogeneration unit, the values associated to the investment performance indicators were obtained with a discount rate of a = 12%, for a duration of erection works d = 1 year, a lifetime of investment D = 20 years, with annual net revenues V_h = €91,291, and annual expenditures C_h = 0, for an investment in the year d of I_h = €193,182 (for any other year h from the interval d, D + d, I_h being null). The values are presented in Table 3.

Table 3

Geothermal based ORC Cogeneration Project

Investment Performance Indicators

a	12	%	**C_h**	0	€
V_h	91,291	€	**I_h**	193,182	€
GPT	2.1	years	**NPV**	488,711	€
DPT	2.6	years	**IRR**	47	%

The values associated to the investment performance indicators for the biomass based ORC cogeneration unit were determined in similar conditions, exception making the annual net revenues V_h = €439,917 and the investment in year d I_h = €5,227,273. Against an initial value of the discount rate of 12% leading to inappropriate values of investment performance indicators, authors have considered a discount rate of 5% as recommended in financial analyses aiming at accessing the financial resources from Structural Instruments. The values for this presumption are presented in Table 4.

Table 4

Biomass based ORC Cogeneration Project

Investment Performance Indicators

a	5	%	**C_h**	0	€
V_h	439,917	€	**I_h**	5,227,273	€
GPT	11.9	years	**NPV**	255,065	€
DPT	18.5	years	**IRR**	6	%

4.4. Financing: decisions to take

Information presented in tables 3 and 4 has been obtained by authors based on cash flow projections in both cases of ORC based cogeneration and without taking into consideration a possible participation to the Tradable Green Certificates Scheme in Romania, financially rewarding investments leading to the power generation based on capitalisation of renewable energy sources. A very predictable rise of the electricity price in 2013 as effect of national power liberalisation has not been taken into account, either.

Both cases of ORC based cogeneration investments are valuable as long as energy savings and CO_2 emission mitigations are obtained. Additionally, the “power extraction” from recovered or waste heat partially transforming initial consumers in power producers represents another challenging advantage.

In the case of the geothermal based ORC cogeneration technologies, the investment is commercially attractive and is to be very rapidly implemented as long as the values associated to the investment performance indicators (in table 3) are good looking even for decision makers of the banking sector. A Romanian company is expected to implement such investment in the very next future.

For the implementation of investments aiming at promoting biomass based ORC cogeneration, the values from table 4 do not encourage a commercial approach but they present adequacy for an action aiming at accessing financial resources from Structural Instruments, which were designed especially for such investments. After a longer than initially considered period for such financial engineering setting up, the first Romanian biomass based ORC cogeneration unit is presently under implementation and is to be commissioned in June 2012 at the latest.

After their commissioning before mid-2012, both investments will generate more than the initially estimated benefits, demonstrating that the ORC based cogeneration technologies are financially viable.

5. CONCLUSIONS

An inventory of end-users reporting basically heat consumption for technological purposes will probably reveal that not so many industrial sectors are involved. But even so, companies generating waste heat or having good prospects for heat recovery do exist and might be targeted to apply for ORC based cogeneration. As this paper shows, the recent implementation in Romania of modern solutions aiming at such “smarter” use of heat will prove that such end-users might become power producers. Two relevant sectors were considered: wooden furniture industry and geothermal based heat generation for district heating purposes. Authors have noted that information about the implementation of such ORC based technologies in petrochemical industry is available too.

As it was presented, in line with low values associated to the thermodynamic efficiency of Organic Rankine Cycle, the related based cogeneration asks for a complete use of condensers’ cooling heat for technological purposes. This is mainly the reason for which the power “leaving” the Cycle is called “residual”, in line with the provisions of the EU relevant pieces of legislation appealing to high efficient cogeneration.

Alternatively, “forcing” the increase of generated power in an ORC based cogeneration unit is possible, if required so. But the operation is less efficient as long as the evacuated heat in excess cannot be used. Consequently, the heat “resource” (wasted or recovered) is inefficiently exploited.

ORC technologies are now mature and results irrefutable. For certain cases, less attractive financial prospects will come to an appropriate end; premises of an already announced 2013 electricity price increase and the operation of Tradable Green Certificates Scheme are solid.

ORC based cogeneration requirements are (i) the “heat resource” being available, accessible and affordable and (ii) steady heat use demand.

The implementation of such applications encourage authors to consider that cogeneration in Romania by using ORC based technologies represents the new investment trend in energy end user behaviour change, with a favourable cost cutting, security of supply improvement and competitiveness increase.

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