Design of a geothermal plant to heat a waterpark swimming pool: Case study of tramutola (Basilicata, Italy)

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ABSTRACT. *Geothermal energy is the renewable characterized by the most secure base-load and low greenhouse gas emissions. It supplies both heat for direct use and energy for power production. In particular, it could give a significant contribution in the heat production, that accounts for more than half of the world final energy consumption, by considering also that three quarters of this heat demand is currently met by fossil fuels, thus causing a significant impact on climate and environment. The aim of this paper is to present a case study where the thermal potential of the geothermal resource is exploited. Specifically, a technical study, coupled with an appropriate economic analysis, is presented. This study is finalized to design a geothermal plant that can guarantee the heating of a swimming pool of the waterpark of Tramutola, in Basilicata region.*

RÉSUMÉ. *L'énergie géothermique est une énergie renouvelable caractérisée par la charge de base la plus sécurisée et la réduction des émissions de gaz à effet de serre. Il fournit à la fois de la chaleur pour une utilisation directe et de l'énergie pour la production d'énergie. En particulier, il pourrait apporter une contribution significative à la production de chaleur, qui représente plus de la moitié de la consommation d'énergie finale dans le monde. en considérant également que les trois quarts de cette demande de chaleur sont actuellement couverts par des combustibles fossiles, ce qui aurait un impact significatif sur le climat et de l'environnement. L'objectif de cet article est de présenter une étude de cas où le potentiel thermique de la ressource géothermique est exploité. En particulier, une étude technique, associée à une analyse économique appropriée, est présentée. Cette étude est finalisée pour concevoir une centrale géothermique pouvant garantir le chauffage d'une piscine du parc aquatique de Tramutola, dans la région de Basilicate.*

KEYWORDS: *geothermal, heating, design.*

MOTS-CLÉS: *géothermie, chauffage, design.*

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1. Introduction

Economic development is strongly correlated with the energy use whose increase, however, induces a rise of greenhouse gas emissions. The production of renewable energy can help to decouple this correlation by reducing the emissions and, as a consequence, by contributing to a sustainable development.

To meet the emissions' targets defined by the Kyoto Protocol in 2005 and by the Kigali amendment in 2016, many international organizations and governments are promoting a wide use of renewable energy in the private and public sectors (Trumpy *et al.*, 2016).

Geothermal energy is defined as heat stored in the subsurface, it is a renewable, sustainable, independent of features weather, stable, operational reliable, and environmentally friendly energy source that can be sustainably exploited by playing a significant role in the abatement of greenhouse gas emissions, yielding up to 4% of future energy consumption (power and heat). It has been extensively investigated to mitigate global warming, reduce air pollution and, as a consequence, reduce the global energy consumption (Limberger *et al.*, 2018; Wang *et al.*, 2018; Barbato *et al.*, 2017).

Actually, it is used both for the production of electricity, with an estimate of about 73.5 TWh/yr of supplied energy and directly for heating and cooling, by generating about 163.2 TWh/yr of thermal energy (Trumpy *et al.*, 2016).

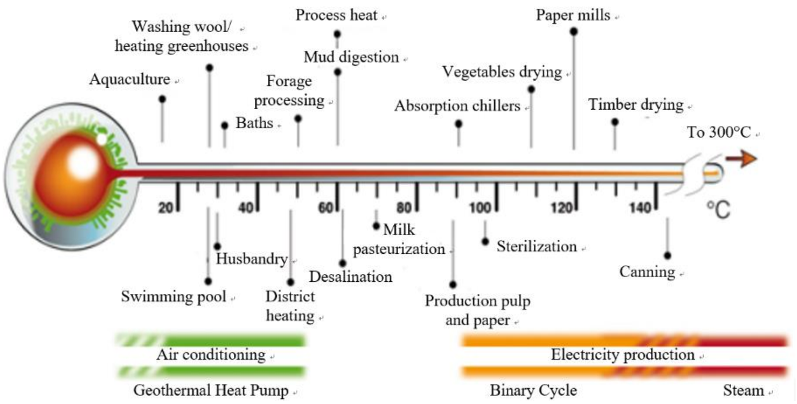

Figure 1. Lindal diagram

High-temperature hydrothermal resources, with temperatures above 220 °C, that allow mainly to commercially produce electricity, are only in few places in the world (i.e. Lardarello in Tuscany). However, the optimization of technologies able to co-produce power and heat from more abundant hydrothermal systems of medium temperature (usually 110-180 °C) has produced an increase of geothermal plants in other areas of the world. Specifically, far most of the work focused on evaluating the

Organic Rankine Cycles (i.e. Unterhaching in Germany), in order to determine their capacity to extract energy from low temperature sources. By regarding the structure of the cycle, there are different alternatives: i.e., either single- or double-flash geothermal power plants, dry-steam power plants and binary cycle power plants (Peña-Lamas *et al*., 2018). Moreover, there has been an increase also of the exploitation of low temperature geothermal resources for the direct use of the heat in many applications as evidenced in the Lindal diagram of Figure 1.

Typical geothermal systems for direct heat are made of two or more wells: hot water is produced by production wells, whereas injection wells are used to re-inject the water after heat extraction. Re-injection is applied to preserve aquifer pressure by allowing sustainable production and to prevent any environmental contamination at the surface due to geothermal fluids (Limberger *et al*., 2018).

Specifically, in this work a low temperature hydrothermal source has been investigated in order to verify the possibility to use its heat for heating a swimming pool of the Waterpark of Tramutola, in Basilicata region (Italy).

The aim is both to demonstrate the techno-economic feasibility of the geothermal plant in place of traditional and more pollutant systems and to present a work methodology where the design of a renewable energy source system is based on a territory planning that allows us to well know all the energy opportunity.

2. Methodology

The aim of the work is to develop a technical-economic feasibility study for the realization of a geothermal plant that exploits a low temperature source for heating a swimming pool.

Firstly, a preliminary territorial, climatic and energetic analysis was performed in order to know all the boundary conditions that can affect the efficiency of the systems (Evola *et al.*, 2018).

Secondly, the intervention site (i.e. Waterpark of Tramutola) and the geothermal source (heat water well) were investigated.

Thirdly, a general design of the geothermal plant was defined in order to identify the main technical characteristics and, as a consequence, to estimate the costs.

Finally, an economic study was carried out in order to verify the convenience to realize the plant.

3. Preliminary analysis

3.1. Territorial analysis

Tramutola (Figure 2) is a village and municipality in the province of Potenza, in the Southern Italian region of Basilicata (Figure 3).

The town lies on wooded hill slopes and overlooks a fertile valley due to the abundance of water.

Figure 2. Panorama of the inhabited center of Tramutola

Figure 3. Localization of Tramutola

Table 1 shows the main information that characterizes the territorial context of the Municipality of Tramutola.

Figure 4 and Figure 5 show the photos, respectively, with the definition of the boundaries of the Municipality of Tramutola and with the entire territory.

Figure 4. Boundaries of the municipality of Tramutola

Figure 5. Territory of Tramutola

Table 1. Main information of Tramutola

Territorial information	
Coordinates	40°19′N - 15°47′E
Altitude	660 m
Surface	36.65 km^2
Inhabitants	3061 (01/01/2017)
Density	83.52 ab./km^2
Neighbouring Municipalities	Marsicovetere, Moliterno, Montesano sulla Marcellana, Padula, Paterno
Other information	
Seismic Class	Zone 1 (high seismicity)
Climatic Class	Zone D, 2091 GG

3.2. Climatic analysis

In order to locally evaluate the climatic characteristics of the territory in terms of temperatures (Table 2), rainfall (Table 3a) and windiness (Table 3b), the data collected by the weather station of Pergola di Marsico Nuovo, located at 908 meters above sea level and about 15 km from the Municipality of Tramutola, were taken as a reference.

Table 2. Temperatures (i.e. max mean, min mean, mean and degrees days in heating and cooling) for year 2017

Month	$\bar{T}$max [°C]	$\bar{T}$min [°C]	$\bar{T}$ [°C]	Heating DD	Cooling DD
1	3.2	-3.2	0.2	1023.3	0.0
2	10.9	2.6	6.0	584.8	0.0
3	13.7	3.4	7.9	547.4	0.0
4	15.5	5.0	9.7	435.2	0.0
5	20.4	8.8	14.1	212.8	4.6
6	27.3	14.2	20.1	7.0	138.2
7	29.3	15.8	22.0	6.0	240.8
8	31.2	17.1	23.5	2.2	326.8
9	21.1	10.8	15.2	151.4	21.0
10	17.9	7.8	12.1	305.5	0.0
11	10.9	3.9	7.0	588.0	0.0
12	4.4	-0.8	1.7	922.8	0.0

Table 3. Rainfall (a) and windiness (b) for year 2017

a)	Month	Total [mm]	b)	$\bar{v}$ [m/s]
	1	78.2		2.2
	2	50.8		2.1
	3	73.0		1.9
	4	31.1		1.8
	5	74.1		1.4
	6	10.9		1.0
	7	42.2		1.4
	8	2.6		1.2
	9	102.1		1.4
	10	51.3		1.2
	11	121.2		1.4
	12	128.0		1.9

In particular, the territory is characterised by a significant thermal excursion between day and night and this can affect the temperature of a swimming pool water.

3.3. Energetic analysis

In order to get a complete vision of the energy renewable sources' situation, this analysis was carried out not only in terms of geothermal resources, but also in terms of solar, wind and hydrological resources.

3.3.1. Solar resource

Table 4. Monthly average daily global radiation

	Horizontal Surface kWh/m^2	Tilted Surface (30° South) kWh/m^2
January	1.93	2.94
February	2.72	3.62
March	3.74	4.36
April	4.90	5.10
May	5.91	5.65
June	6.60	6.07
July	6.46	6.03
August	5.56	5.55
September	4.27	4.72
October	3.20	4.05
November	2.11	3.03
December	1.68	2.61

Table 4 reports the monthly average daily global radiation, calculated at the coordinates of the site. The yearly global radiation is equal, respectively, to 1496 kWh/m^2 and 1636 kWh/m^2 (Chabane *et al*., 2018).

3.3.2. Wind resource

The wind potential of the territory was evaluated by analysing the maps of Italian Wind Atlas. In particular, Figure 6 reports, for a wind generator high of 25 m, the yearly average velocity of the wind, that changes between 4 m/s and 6 m/s, whereas Figure 7 reports the yearly specific production that changes between 1000 MWh/MW and 2000 MWh/MW.

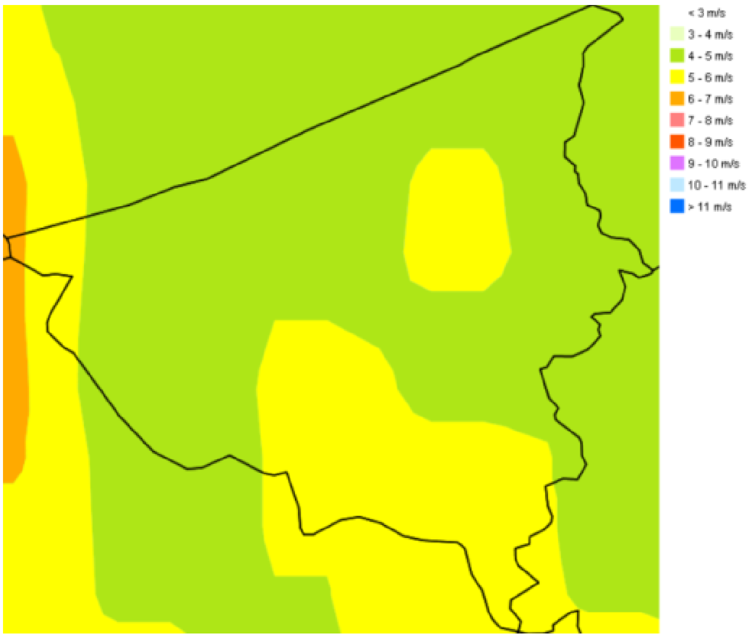

Figure 6. Yearly average velocity of the wind [m/s]

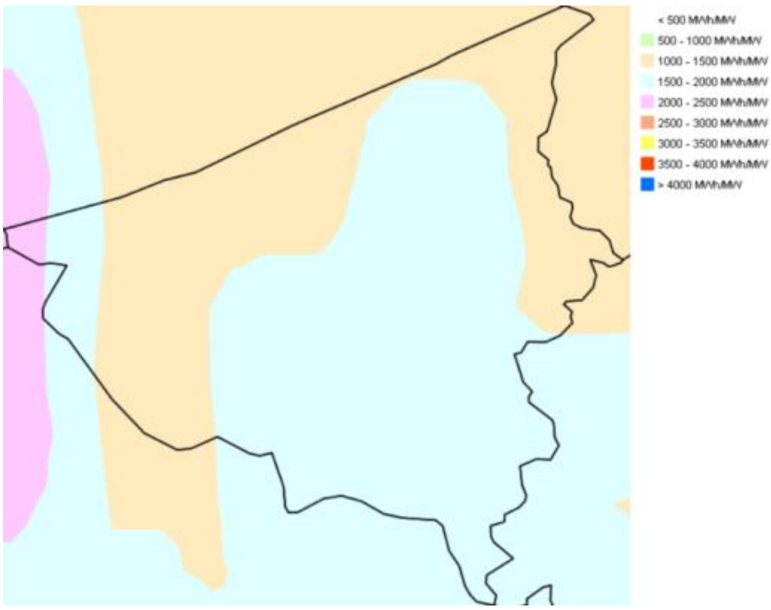

Figure 7. Yearly specific production [MWh/MW]

3.3.3. Hydrological resource

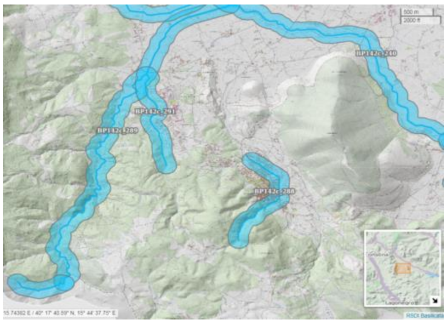

Figure 8. Hydrography of territory of Tramutola

The Municipality of Tramutola falls within the water basin of the river Agri, that springs from the sources of the Piano del Lago between Mount Maruggio and Mount Lama, at an altitude of 1300 m, and flows into the Ionian Sea, in the Municipality of Policoro. It develops for 132 km, and its basin has an extension of 1715 Km^2.

Its hydrography is represented in Figure 8.

3.3.4. Geothermal resource

The growing interest in geothermal energy and its exploitation has led to the definition of new tools for the assessment of the energy potential of the subsoil both for the production of electricity, exploiting high and medium enthalpy resources, and for the production of thermal for use in industrial or thermal processes and for heating/cooling of buildings with closed or open cycle systems that directly use groundwater, using, respectively, medium and low enthalpy resources.

Figure 9 shows the theoretical capacity of the territory of Basilicata to produce geothermal electricity. This map, although not detailed, shows how the entire region is characterized by a medium-low capacity.

Since there are no detailed studies, to draw some consideration on the specific geothermal potential of the territory of Tramutola, reference is made to the potential of the neighbouring territory of Campania, object of study within the VIGOR project, by using the maps implemented in a dedicated geothermal webgis. In particular, this allowed to evidence that:

(1) The thermal conductivity assumes medium-high values, equal to 3-3.5 W/mK;

(2) The suitability of the area for the use of open-loop geothermal systems is discrete;

(3) The specific energy exchanged with the ground, which is useful for the use of closed-loop geothermal systems, assumes variable values between 70 kWh/m^2 and 100 kWh/m^2.

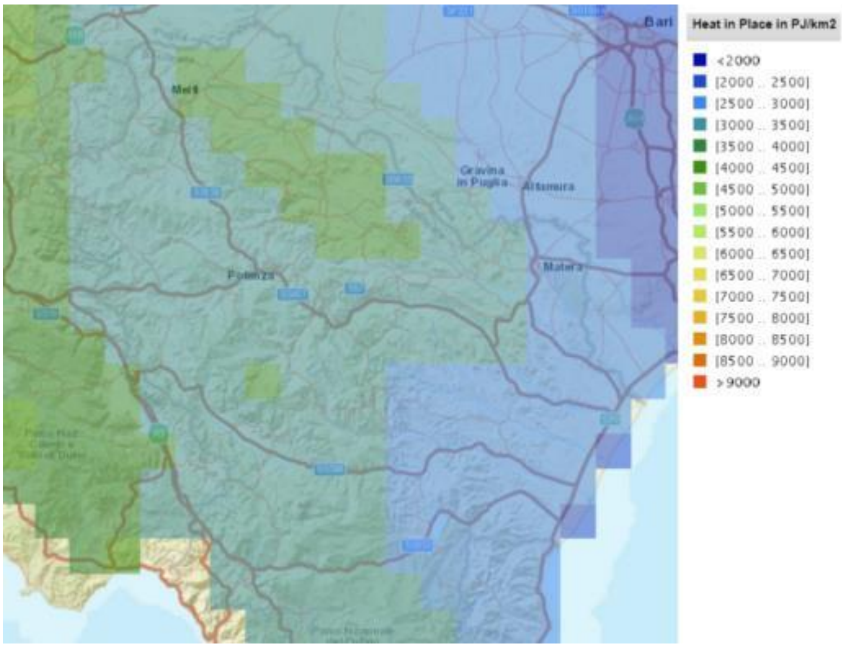

Figure 9. Theoretical capacity [PJ/km^2]

4. SITE

The "Rocco Scotellaro" Waterpark of Tramutola (Figure 10) is one of the most popular waterparks in Basilicata.

Figure 10. Localization of waterpark

The structure is surrounded by nature, within the sub-river basin identified in Figure 10 by the code BP142c_289, and it occupies a large area, by offering a wide range of services and attractions.

It is located in Contrada Caranna n. 2 and it is open from 24 June to 31 August, from 9:00 to 20:00.

Currently the pools are naturally heated using only the solar irradiation of the opening periods. This is a limitation because the water temperature is influenced by both atmospheric conditions (variability between one day and the next, presence of wind, etc.) and by the significant temperature excursion between day and night that characterizes the summer months, as evident in Table 2.

Generally, a mass of water contained in a pool tends to disperse heat through three different modes:

(1) Dispersions by convection and conduction: they occur due to the contact between water and air above the surface, between water and walls of the pool, through the materials of the walls, and between the walls and the land or other romms located around the swimming pool;

(2) Dispersions by irradiation: they occur due to the propagation of heat in the form of electromagnetic waves between the surface of the water and the cold bodies that the surface of the water "sees": typically the ceiling, the windows or walls, or the sky;

(3) Evaporation dispersions: a certain quantity of water, depending on different environmental conditions, passes from the liquid state to the gaseous state, subtracting energy from the mass of liquid contained in the pool.

Moreover, it is necessary to take into account also the decrease of temperature due to the introduction of new water, reintegrated every day into a variable quota, that has to be almost equal to 5% (reduced to 2.5% as a function of the bathers' daily number) of the water volume of the pool.

Typical values of temperature are:

Pools for swimmers: ≥24°C (preferably 26-28°C);

Pools for non-swimmers (i.e. for children): ≥26°C (preferably 28-29°C).

Figure 11 shows the swimming pool, object of the present study. In August, it is frequented daily by about 500 people. Its characteristics are:

Shape: Rectangular;

Length: 30 m;

Width: 20 m;

Depth: Variable;

Water volume: 1500 m3.

Figure 11. Swimming pool

At about 300 m from the waterpark (Figure 12) there is a well whose water has the following geothermal characteristics:

Temperature: 28°C;

Flow: 10 l/s.

This is a low-enthalpy resource that can be taken and transported, via an appropriate insulated pipe, to a heat exchanger.

Figure 12. Localization of the geothermal source

Figure 12 shows the photo with the location of the well respect to the waterpark. The pipeline for the transport of the fluid could follow the road, thus facilitating the works of geothermal plant installation.

Table 5 reports the energy needs of the swimming pool by considering that, thanks to the contribution of an external energy source, this can be opened also in other periods of the year and, in particular, by April 1 to October 31, with a temperature that is at most at 26°C and does not fall below 24°C.

Table 5 evidences that the major energy demand is mainly due to the maintenance of the temperature of the free water surface (64%) and, secondly, to the daily water renewal (23%).

Table 5. Energy needs

USE PROFILE		
Period	Apr-Oct	
Hours/day	11	
SIZES OF POOL		
S (m^2)	600	Free water surface
V (m^3)	1500	Water volume
Sl (m^3)	250	Side surface
Sb (m^2)	600	Bottom surface
THERMOIGROMETRIC DATA		
u	0.9	Water emission factor
R (kcal/h)	68	Irradiation of the black body
Tp (°C)	26	Pool temperature
Ta (°C)	18.5	Air average temperature
Th (°C)	15	Water temperature of the aqueduct
hca (kcal/h m^2 °C)	4	Convective exchange coefficient
Pp (kg/m^2)	325	Vapor pressure at eq. with pool water
Pa (kg/m^2)	250	Vapor pressure of the ambient air
t (h)	72	First heating period
Cover	No	Application of the cover pool
% ren	2.5%	Percentage of daily water renewal
Esc	0%	Efficiency of recovery heat exchanger
POWER		
Power required for initial heating	267	kW
Power required for maintenance (free water surface)	123	kW
Power required for maintenance (side and bottom)	7	kW
Power required for water renewal	44	kW
CONSUMPTIONS		
Energy required for initial heating	19190	kWht

Energy required for maintenance (free water surface)	259020	kWht
Energy required for maintenance (side and bottom)	14840	kWht
Energy required for water renewal	92400	kWht
Energy required for pumping	20630	kWhe
Yearly energy consumption	385450	kWht
	20630	kWhe

5. Geothermal plant

5.1. Plant scheme

Figure 13 depicts the scheme of the geothermal plant.

This consists of two main sections:

(1) The section with the pipeline that transfers the geothermal fluid from the well to the exchangers and vice versa;

(2) The section constituted:

(a) From the pipeline that transfers the water from the pool to the heat exchanger for maintaining the temperature at 26°C,

(b) From the pipeline that transfers the aqueduct water to the heat exchanger, in cascade with the heat exchanger for maintaining the temperature, for heating at 24 °C,

(c) From the pipeline that transfers the aqueduct water to the heat exchanger for initial heating. This exchanger will operates only during the start of the waterpark and it will be activated by appropriate valves.

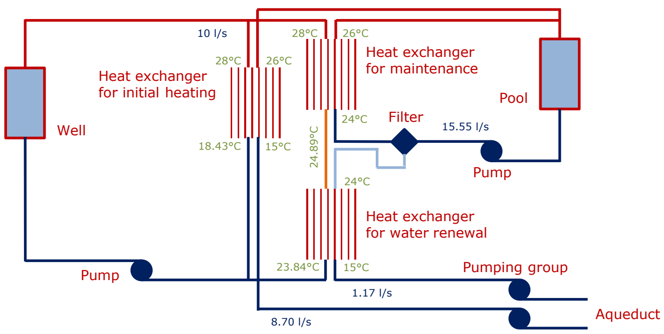

Figure 13. Geothermal plant scheme

The diagram shows both the flow of the fluids at the inlet to the exchangers and the temperatures of the inlet and outlet fluids. These data were assessed on the basis of the powers identified in Table 5.

It is a complex plant designed to enter filtered water in the pool whose temperature is not less than 26°C.

5.2. Pipeline and pumps

In order to minimize heat losses during the transport of water from the well to the exchangers installed in a dedicated area near the swimming pool, an insulated steel pipe suitable for district heating networks will be used.

Figure 14. Section of pipe

In particular, the pipe, in pre-insulated steel, supplied in 6/12 m bars and able to withstand a maximum temperature of 140°C, is composed of:

a welded or seamless black steel pipe, grade P235 GH;

a rigid polyurethane foam insulation, thermal conductivity <0.03 W/mK at 50°C;

a high density polyethylene sheath tube.

In Table 6 are reported the technical characteristics of the pipe.

The transfer of water between the well and the waterpark inside the pipeline will occur by fall because a slight difference in height has been found, quantified in about 10 m, on the basis on the analysis of some level curves provided by the Basilicata Region. The return for the groundwater re-emission will take place thanks to the help of an electric pump, characterized by a power of 1.7 kW.

Table 6. Technical characteristics of the pipe

DN mm	ϕ est. PE mm	Insulating thickness mm	Weight kg	Cost €/m
100	200	39	12.6	59.50

5.3. Heat exchangers

Three plate heat exchangers will be used, as shown in Figure 13. Table 7 report their main technical characteristics.

Table 7. Technical characteristics of the heat exchangers

Use	Power [kW]	U [W/m2K]	A [m2]
Maintenance at 26°C	130		74
Heating water renewal	44	1275	10
Initial heating	267		54

6. Economic analysis

In order to validate the design of geothermal plant, presented in the previous section, in terms both energy saving and economic analysis, a comparison with a traditional gas plant was carried out.

6.1. Energy saving

In Table 8 is reported the energetic comparison in order to evaluate the energy saving.

Table 8. Yearly energy saving

	produced MWh/y	Eff.	consumed MWh/y	TEP/y
Consumptions standard gas plant				
Thermal energy of heat boiler	385	90.0%	428	36.8
Electrical energy of pool pumping group	21	50.0%	42	3.9
Consumptions geothermal plant				
Electrical energy of pump	4	50.0%	8	0.7
Electrical energy of pool pumping group	21	50.0%	42	3.9
Energy saving				36.1

6.2. Economic analysis

The economic feasibility analysis was performed with Matlab by using the discounted cash flow (i.e. DCF) method generated by the project. The DCF valuation leads to the determination of synthetic valuation indices (i.e. indices of profitability of the investment), calculated on the basis of discounted cash flow. The discounting rate was assumed to be 5%.

6.2.1. Investment

In Table 9 is reported an estimate of the costs of the whole geothermal plant.

Table 9. Estimate of the costs

Description	Cost [€]
Heat exchanger 130 KW	€ 13’400.00
Heat exchanger 44 KW	€ 9’200.00
Heat exchanger 267 KW	€ 9’200.00
Pipeline	€ 35’700.00
Works	€ 5’000.00
Pumping group 9,7 kW	€ 4’000.00
Geothermal pipeline pump 2 KW	€ 1’000.00
Total	€ 77’500.00

6.2.2. Operating overruns

The only operating extra costs introduced with the geothermal plant derive from the purchase of electricity required for pumping the geothermal fluid from the sampling well to the heat exchange point. These are equal to 574 €/y, by considering an electricity sales price equal to 0.16 €/kWh.

6.2.3. Operating savings

The use of the geothermal resource allows to zero the operating costs related to the purchase of the fuel necessary for the pool heating; this saving was calculated by referring to a value for the purchase of natural gas equal to 0.06 €/kWh. In the period of use (i.e. April-October), the global saving is equal to € 25’667.00.

6.2.4. Operating revenues

The revenues due to the realization of the plant consist in the application of Energy Efficiency Certificates or White Certificates. The value of a White

Certificate is estimated to 210 €/TEP. The relative revenue is expected for 10 years and it is equal to 7’726.00 €/y.

6.2.5. Indices of profitability of the investment

After estimating the extra investment costs and the net operating savings introduced by the proposed plant, the investment profitability ratios were calculated, determined by hypothesizing a technical life of the plant of 20 years and a discounting rate equal to 5 %. They are thus obtained the following results:

Discounted Payback Period (DPP): 3.61 years;

Net present value (NPV): 287 k€;

Internal Yield Rate: 41.2%.

7. Conclusions

This study has evidenced the technical and economic feasibility of a geothermal plant that exploits the groundwater temperature of 28°C for heating the water of a swimming pool into the waterpark of Tramutola by allowing a higher and better use of the structure.

References

Barbato M., Cirillo L., Menditto L., Moretti R., Nardini S. (2017). Geothermal energy application in Campi Flegrei Area: The case study of a swimming pool building, *International Journal of Heat and Technology*, Vol. 35, Special Issue 1, pp. S102-S107. http://doi.org/10.18280/ijht.35Sp0114

Chabane F., Laznek I., Bensahal D. (2018). Prediction of global solar radiation on the horizontal area with the effect of relative humidity part: I. *Italian Journal of Engineering Science*, Vol. 61+1, No. 2, pp. 115-118. http://doi.org/10.18280/IJES.620109

Evola G., Marletta L., Cimino D. (2018). Weather data morphing to improve building energy modeling in an urban context, *Mathematical Modelling of Engineering Problems*, Vol. 5, No. 3, pp. 211-216. http://doi.org/10.18280/mmep.050312

Limberger J., Boxem T., Pluymaekers M., Bruhn D., Manzella A., Calcagno P., Beekman F., Cloetingh S., van Wees J. D. (2018). Geothermal energy in deep aquifers: A global assessment of the resource base for direct heat utilization. *Renew Sust Energ Rev*, Vol. 82, No. 1, pp. 961-975. http://doi.org/10.1016/j.rser.2017.09.084

Limberger J., Boxem T., Pluymaekers M., Bruhn D., Manzella A., Calcagno P., Beekman F., Cloetingh S., Wees J. D. (2018). Geothermal energy in deep aquifers: A global assessment of the resource base for direct heat utilization. *Renew Sust Energ Rev*, Vol. 82, pp. 961-975. http://doi.org/10.1016/j.rser.2017.09.084

Peña-Lamas J., Martinez-Gomez J., Martín M., Ponce-Ortega J. M. (2018). Optimal production of power from mid-temperature geothermal sources: Scale and safety issues. *Energ Convers Manage*, Vol. 165, pp. 172-182. http://doi.org/10.1016/j.enconman.2018.03.048

Trumpy E., Botteghi S., Caiozzi F., Donato A., Gola G., Montanari D., Pluymaekers M. P. D., Santilano A., van Wees J. D., Manzella A. (2016). Geothermal potential assessment for a low carbon strategy: A new systematic approach applied in southern Italy. *Energy*, Vol. 103, pp. 167-181. http://doi.org/10.1016/j.energy.2016.02.144

Wang K., Yuan B., Ji G., Wu X. (2018). A comprehensive review of geothermal energy extraction and utilization in oilfields. *J Petrol Scie Eng*, Vol. 68, pp. 465-477. http://doi.org/10.1016/j.petrol.2018.05.012