GEOTHERMAL POWER GENERATION THROUGH APPLICATION OF LOW TEMPERATURE TURBINE (LTT) POWER GENERATION TECHNOLOGY

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KEY WORDS

Power generation, turbine, rock, well

ABSTRACT

Western Georgia has abundant geothermal energy resources retained in aquifer waters of Lower Cretaceous fractured and karstified limestones and dolomites located at depths between 2,500-4,000 m (GL). Flowing wellhead temperatures are reported in the range 85°-110°C, the installed geothermal capacity amounts to 312 MW_t. Application of the currently developed low temperature turbine (LTT) power generation process would suggest the potentially available annual geothermal power supply to the tune of 530 GWh, enough to power more than 100,000 households. The LTT power generation process is applicable at geothermal water temperatures from 85°C and higher with a postulated efficiency up to 23%. This paper provides a) an assessment of the Georgian geothermal power reserve, b) a brief description of the LTT power generation process, and c) a summary of the general conditions and salient parameters attributed to a tentative geothermal power pilot project located in the Zugdidi-Tsaishi area, western Georgia. Preliminary calculations reveal a financial rate of return (FRR) for this project at 17%.

1. INTRODUCTION

The total Georgian geothermal heat resources in terms of heat-in-place and heat reserves have been assessed at 260 and 60 EJ, respectively. Approximately 85% of the heat-in-place is bound in the aquifer rock matrix, the remaining 15% of the geothermal heat energy is confined in geothermal and hydrothermal formation waters contained in secondary porosity systems comprising fissures, fractures, vugs and karstified rock, - a primary porosity system is entirely absent.
The Georgian geothermal energy resource is of the low enthalpy type, producing wellhead temperatures range between 40°-110°C. Maximum geothermal temperatures as induced from isothermal maps occur in western-central Georgia adjacent to the town of P'oti where the temperature at top aquifer level reaches 150°C and higher, however located at depths ranging between 4,000-6,000 m (MSL).
Geologically Georgia can be subdivided into two provinces, i.e. eastern and western Georgia. These two geological provinces are separated by a prominent northeast-southwest trending basement high, referred to as the Dziruli High (Ref. Tsertsvadze *et al.*, 2002 [1], and Tallbacka, 2002 [2]). It is believed that the western Georgian province reflects the subsidence and structural development of the Black Sea Basin, the geological conditions of eastern Georgia are principally related to the Caspian Sea Basin development. A map showing the distribution of the Georgian geothermal energy resources is shown in Fig. 1.

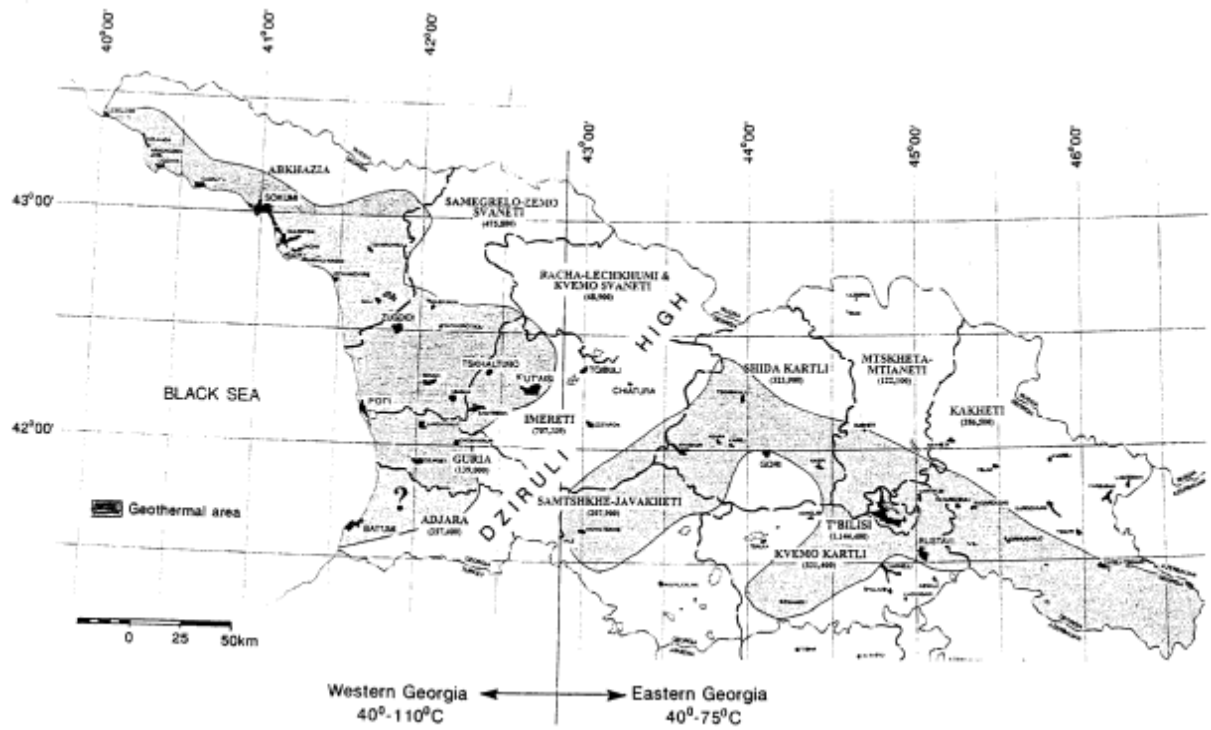


Fig. 1. Distribution of Georgian geothermal energy resources (after Tallbacka, 2002 [2])

Superior geothermal energy conditions are confined within western Georgia whereas the major part of the Georgian population, hence the major Georgian energy demand, is confined in eastern Georgia. Climatic conditions accentuate the differences in energy demand and utilisation. In a future perspective major residential energy demand would focus on the sustainable provision of power, hot tap water and air condition in the subtropical western Georgia, the more temperate conditions in eastern Georgia carries the substantial supply of district heat in addition to hot tap water and power. Whereas there is ample opportunity for the provision of geothermally geneated heat, air conditioning and hot tap water within both eastern and western Georgia, the opportunity for the production of geothermal power is limited to western Georgia in an area covering aproximately 3,500 square kilometres and with the geothermal aquifer zone located between 3,000-4,000 m (GL). Proven geothermal water wellhead temperatures range between 85°-110°C.
The recently developed low temperature turbine (LTT) power generation process allows the conversion of heat to power at geothermal wellhead temperatures ranging from 85°C and higher. The process is based on a newly invented energy carrier substance and turbine design carrying an efficiency postulated at 20% and higher. This paper summarises the evaluation of the geothermal resource in terms of heat-in-place and power reserves and furthermore highlights the opportunity to establish a geothermal power pilot project in western Georgia. Preliminary financial and economical analyses indicate rates of return at 17% and 19%, respectively.
Based on volumetric calculations the Georgian geothermal power reserves were assessed at 66 million MWh_e, hypothetically more than sufficient to cover the entire Georgian energy demand. The importance of Georgia's indigenous geothermal energy resource becomes apparent. In this context Tallbacka, 2002 [2] stressed the requirements for conservation, regulation and legislation with regard to the Georgian geothermal energy resource. Such requirements are not restricted to Georgia alone.

2. GEORGIAN GEOTHERMAL ENERGY RESOURCE

The Georgian geothermal energy resource was assessed by Tallbacka in 2002 [2] based on the predominantly information by Buachidze *et al.* [3] in 1998 and Tsertzvadze *et al.* in 2002 [1].

2.1. Georgian geothermal heat-in-place

The above assessment reveals a total geothermal energy resource in terms of heat-in-place to correspond to 260 EJ (260 x 10^{18}J) or 72 PWh_t (72 x $10^9 MWh_t$). Approximately 85% of this heat-in-place is bound in the rock matrix, the remaining 15% is confined in the geothermal aquifer water contained in secondary porosity comprising fracture, fissure and karstified systems of the aquifer rock. There is no evidence of primary porosity in the Georgian aquifer zones of interest. The allocation of the heat-in-place between western and eastern Georgia as well as salient parameters used in the underlying calculations are shown in TABLE 1. Useful energy conversions are shown in TABLE 2.

Table 1. Geothermal Heat-In-Place

PARAMETER	WESTERN GEORGIA	EASTERN GEORGIA
Net rock volume, $10^9 m^3$	2,435	309
Water volume, $10^9 m^3$	75	6
Heat capacity $_{rock,}$ $MJ/m^3/°C$	0.84	0.84
Heat capacity $_{water,}$ $MJ/m^3/°C$	4.20	4.20
Heat-in-place $_{rock,}$ EJ	205	20
Heat-in-place $_{water,}$ EJ	32	2
Total heat-in-place, EJ	237	22

The heat capacity value for the rock matrix was taken from Tsertsvadze *et al.*, 2002 [1] reporting a value at 0.2 cal/g/°C. Based on the above the total Georgian geothermal heat-in-place is assessed at 260 EJ.

Table 2 : Useful Energy Conversions

TO / FROM	Btu	Cal	Joule	kWh
Btu	1	252.0	1,055	2.93×10^{-4}
Cal	0.00397	1	4.186	1.16×10^{-6}
Joule	9.48×10^{-4}	0.2389	1	2.78×10^{-7}
kWh	3,413	8.60×10^5	3.60×10^6	1

kilo (k) = 10^3, mega (M) =10^6, giga (G) = 10^9, tera (T) = 10^{12}, peta (P) = 10^{15}, exa (E) = 10^{18}

2.2. Georgian geothermal heat reserves

The total Georgian geothermal heat energy reserves were assessed at 60 Exajoules (60 x 10^{18}J), i.e. corresponding to approximately 24% of the heat-in-place. The geothermal heat reserves and allocation into matrix and water bound heat as expressed in Gigajoules (GJ), Gigacalories (Gcal) and Megawatt hours (MWh) are summarised in TABLE 3 below.

Table 3 : Georgian Geothermal Heat Reserves

	GJ	Gcal	MWh_t
Total heat reserves	60.0×10^9	14.3×10^9	16.7×10^9
Water bound reserves	16.1×10^9	3.9×10^9	4.5×10^9
Matrix bound reserves	43.9×10^9	10.4×10^9	12.2×10^9

Approximately 90% of the geothermal energy reserves are confined within Western Georgia in an area covering approximately 8,000 square kilometres, i.e. 12% of the total Georgian territory. In terms of population it is estimated that 30% of the population is located within this area, the remaining 70% is confined in Eastern Georgia and in areas outside geothermal energy potential. The dilemma, i.e. comprising the presence of superior geothermal energy potential situated in areas of limited energy demand and vice versa is not an unique Georgian problem, although referred to as the "Georgian Dilemma" in the following. Overcoming the constraints related to the Georgian Dilemma is a main objective pursuant to the geothermal development strategy presented by Schreiber *et al.* in 2002 [4]. The introduction of the low temperature turbine (LTT) power generation process would appear an important contribution in the context of this strategy.

2.3. Georgian installed geothermal heat capacity and power reserve

Currently there exist 66 constructed geothermal wells in Georgia with a combined installed capacity reported at 358.8 MW_t (Ref. Gzirishvili *et al.*, 2000 [5]).
The allocation of this heat capacity as well as related pertinent production information are shown in TABLE 4 below. The location of the various areas is shown in Fig. 2,

Table 4 : Georgian Installed Geothermal Heat Capacity And Related Production Data

AREA	EXISTING WELLS	FLOW RATE, m^3/hr	DEPTH, m GL	$T_{aver.}$ °C	CAPACITY, MW_t	SALINITY, g/l
T'bilisi	6	400	1,800-2,800	67	23.8	0.2-0.3
Zugdidi	16	1,000	1,200-2,800	85	74.4	0.9-2.4
Kvaloni	4	400	3,100-3,400	90	32.5	8.0-9.0
Dranda	2	60	1,700-3,300	96	5.2	2.0-3.0
Kindgi	14	1,170	3,100-3,900	104	113.5	1.2-2.4
Mokvi	11	550	3,600-3,800	95	48.0	1.0-2.5
Okhurei	3	450	3,300-3,900	103	37.9	1.0-2.0
Tskhaltubo	5	800	500-1,000	30	14.0	0.5-1.0
Samtredia	1	125	1,200-1,700	61	5.9	2.5-3.0
Vardzia	4	80	300-1,400	60	3.6	10.0-13.0
Total	**66**	**5,035**	**-**	**-**	**358.8**	**-**

Modified after Gzirishvili *et al.*, 2000 [5].

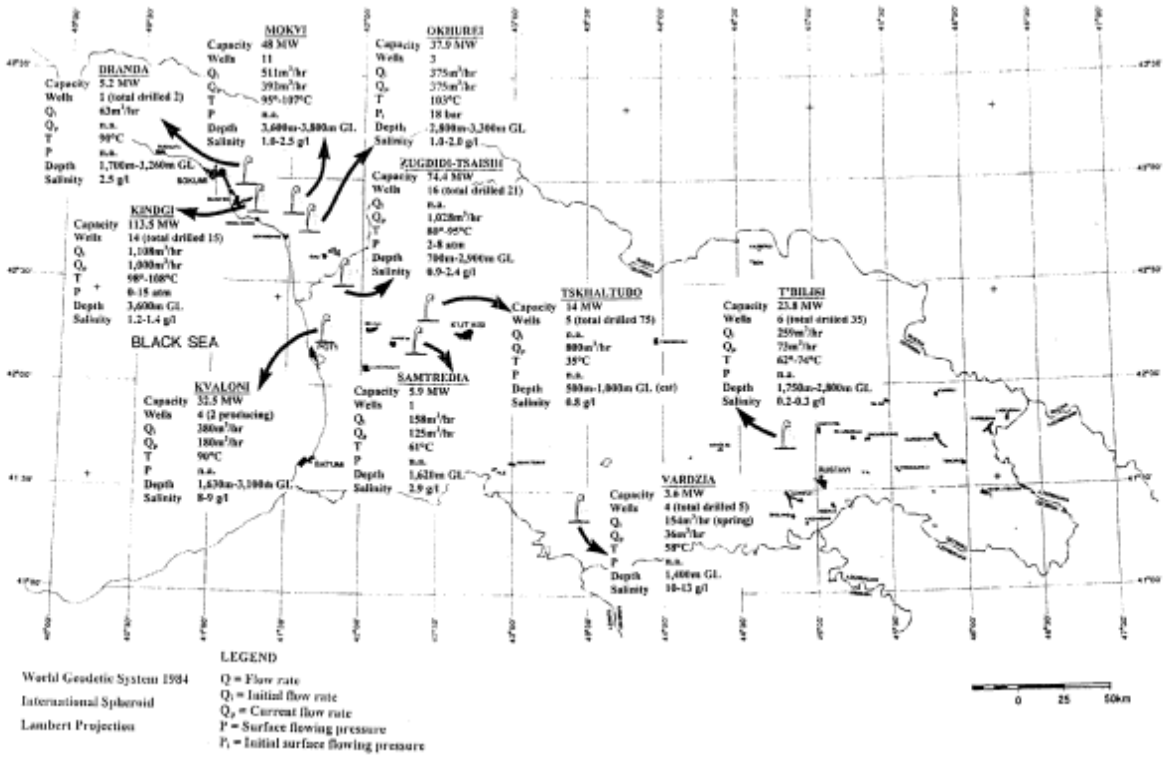


Fig. 2. Georgian installed geothermal heat capacity and salient parameters (Ref. Tallbacka, 2002 [2])

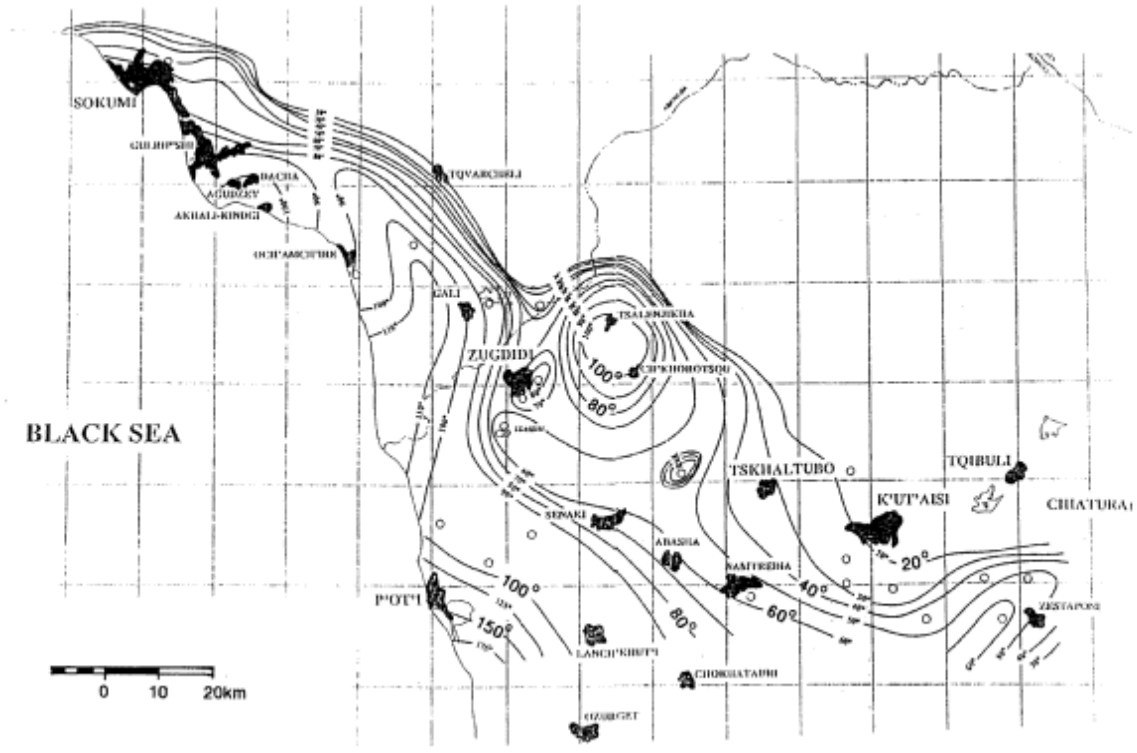


Fig. 3. Isothermal map at top aquifer level, western Georgia (contour interval 10°C) (Ref. Tallbacka, 2002 [2])

Based on Tsertsvadze *et al.*, 2002 [1] an isothermal map at top aquifer level was prepared for western Georgia by Tallbacka, 2002 [2], shown in Fig. 3. The related area versus temperature plot is shown in Fig. 4, also indicating the allocation of main energy utilisation.

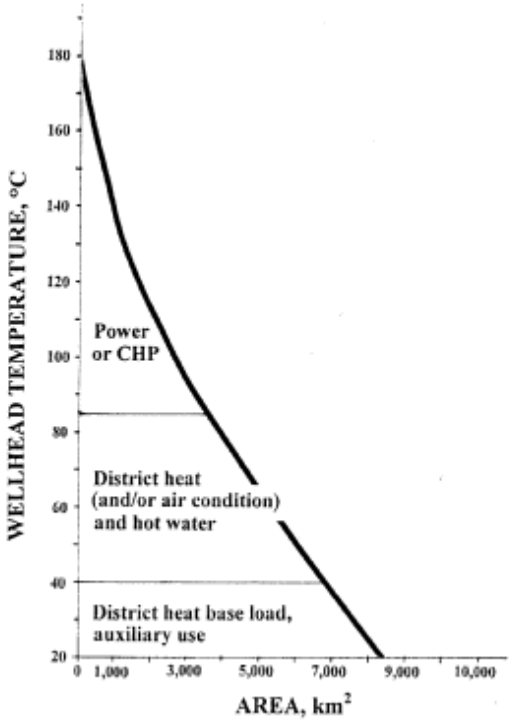


Fig. 4. Area versus wellhead temperature, western Georgia

The plot reveals an area of 3,500 square kilometres with flowing wellhead temperatures at 85°C and higher. Fifty geothermal water wells are located within this area with a total installed capacity of approximately 312 MW_t. The conversion of heat energy to power using the LTT power generation process carries a postulated efficiency at 20%. This would imply potentially available geothermal power reserves to the tune of 62 MW, enough to power approximately 100,000 homes in western Georgia and adjacent areas. The opportunity to convert low enthalpy geothermal energy resources to power would extend areas for geothermal prospective interest beyond urban and denser populated rural areas, hence limiting the influence of the Georgian Dilemma.
Assuming an equal aquifer zone thickness of 500 metres would imply a gross aquifer volume amounting to 1,750 cubic kilometres (1,750 x $10^9 m^3$). Using an average flowing wellhead temperature at 100°C and heat retrieval through heat exchange down to 25°C would imply a geothermal heat energy reserve comprising 330 TWh_t, i.e. based on an aquifer porosity of 0.25% and surface recovery at 85% of the heat contained in the available heat carrier (the geothermal water). The conversion of 330 TWh_t to power using the LTT process at 20% efficiency would imply a geothermal power reserve of 66 TWh_e (66 million MWh_e).

3. THE LTT POWER GENERATION PROCESS

The low temperature turbine (LTT) power generation process is currently being developed by a Swedish energy development company. The LTT process that has originally been designed with a view to the conversion of heat energy contained in industrial process waste water into electricity appears suitable for application in connection with the development of low enthalpy geothermal resources. The opportunity to generate power from low enthalpy geothermal resources would considerably increase areas for prospective geothermal development, in particular in areas

of low heat demand or in areas where the geothermal resources are too remotely located for practical utilisation for district heat (or air condition) supply. The power generation loop of the LTT process appears quite conventional, however carrying postulated high efficiency due to a newly invented energy carrier substance (b.p. at 65°C) and related modifications in turbine design. The efficiency of the LTT process has been postulated at approximately 20%. A basic design schematic of the LTT power generation loop is shown in Fig. 5.

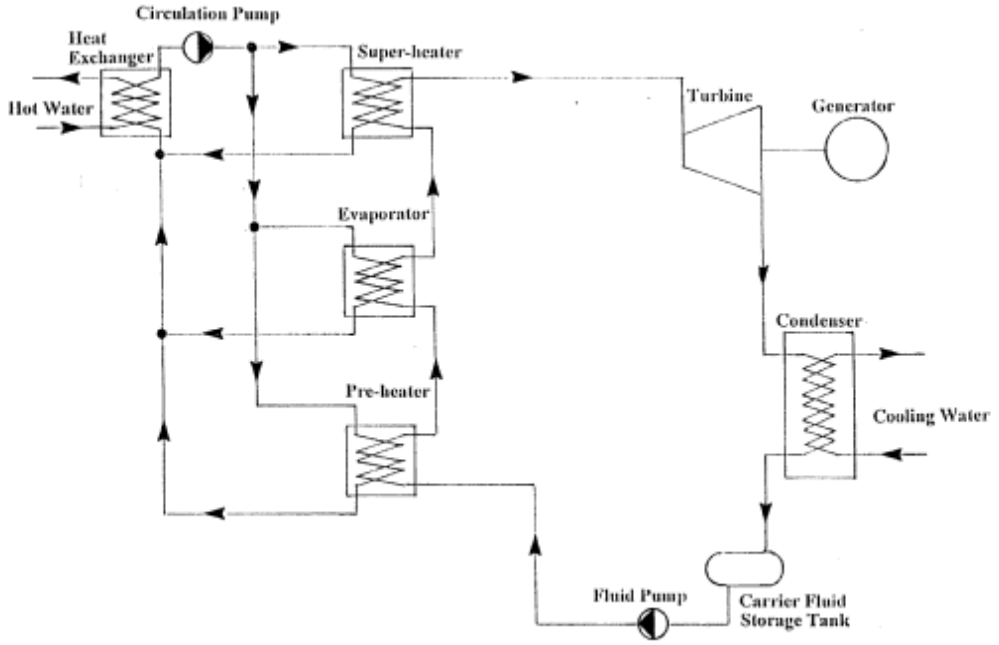


Fig. 5. The LTT power generation loop, basic design schematic

The LTT power generation process provides the opportunity to supply low cost electricity from geothermal heat contained and produced from geothermal water wells with flowing wellhead temperatures from 85°C and higher. Geothermal heat is retrieved through heat exchange and transferred into a closed loop comprising a newly invented carrier fluid that expands and drives a turbine which in turn drives a generator. The generator normally provides power at 400 V, 50 Hz.

Planned standard capacity (1.5 MW) LTT power plant units are container mounted (length 12.2 metres, width 2.3 metres, height 3.0 metres) with a gross weight of six tons. The containers are equipped for readily connection to heat exchanger(s) as well as connections for cooling water. The containers furthermore house the required appliances for hook-up to existing power distribution grids. Larger plants can be constructed on site or alternatively be established through the required number of LTT units connected in parallel.

The LTT power generation process is environmentally friendly and carries no greenhouse gas or other types of emissions. The process is sustainable and operationally safe, modest capital expenditures coupled with low operating costs result in a highly competitive power production cost, currently assessed at US cents 1.4/kWh (EU cents 1.2/kWh).

4. THE ZUGDIDI-TSAISHI GEOTHERMAL POWER PILOT PROJECT

A tentatively suitable location for a geothermal power pilot project has been considered in the Zugdidi-Tsaishi area, located approximately 250 kilometres northwest of T'bilisi and 40 kilome-

tres north-northwest of the harbour town of P'oti on the Black Sea Coast. The pilot project area revealing the locations of existing geothermal wells in the Tsaishi area is shown in Fig. 6. The wells designated "N-10" (producer), "N-18" (producer) and "N-17" (injector) are currently being considered for the pilot power project. Pertinent parameters with regard to the power pilot project are summarised in Table 5.

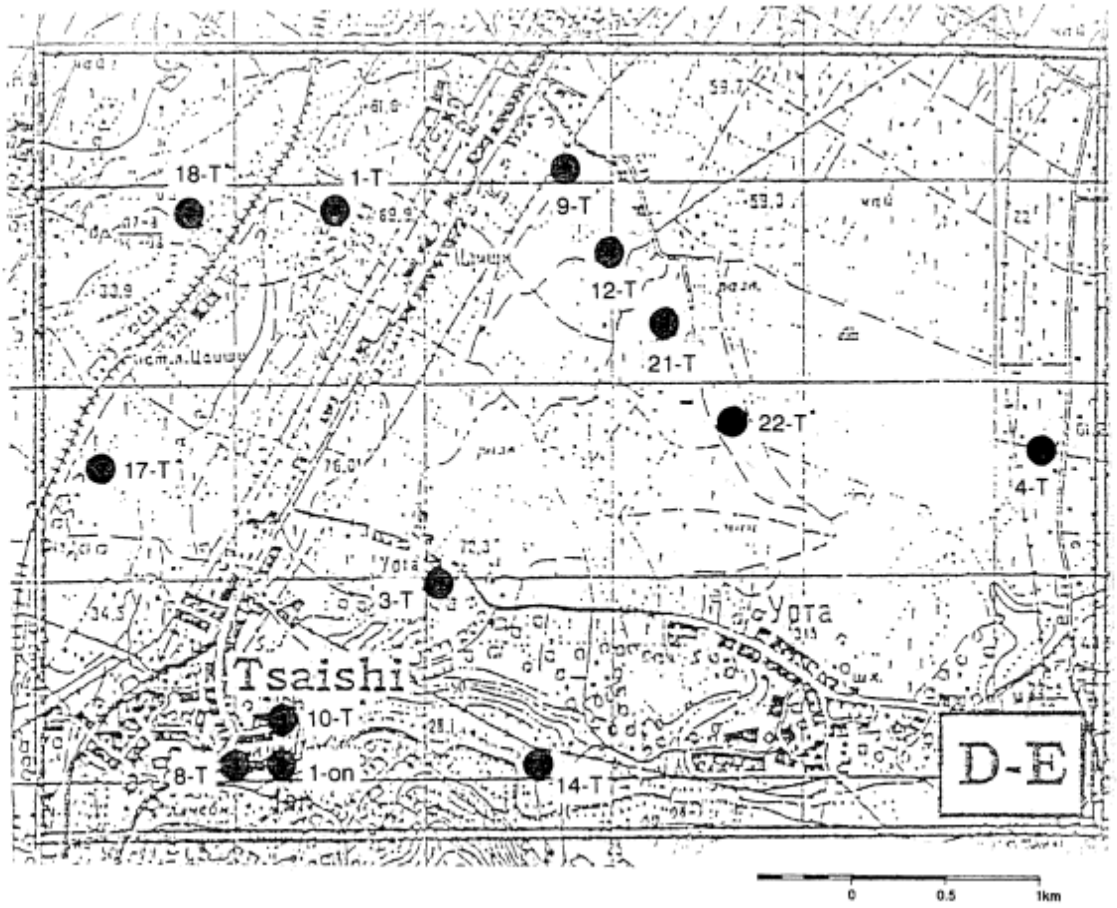


Fig. 6. Zugdidi-Tsaishi geothermal pilot project area and location of existing geothermal wells (source : Gzirishvili *et al.*, 2000 [5])

The project concept is based on the conversion of three existing geothermal wells into a closed geothermal water circulation loop comprising two production and one injection well as well as the installation of heat exchanger(s), flow lines and surface mounted pump equipment required for the re-injection into the aquifer of 250m^3/hr of geothermal water. The installed geothermal heat capacity for the two production wells amounts to 17 MW_t, the reported flowing wellhead temperature is 97.5°C. Applying the LTT power generation process at 20% efficiency would imply an available power capacity of 3.4 MW_e. Based on this a possible project concept could comprise the completion of the geothermal water circulation loop and the installation and hook-up to the existing power grid of 2 x 1.5 MW LTT power generation units connected in parallel. The utilisation of the LTT units at full capacity (3 MW x 8,500 hrs/year) carries an annual geothermal power supply of 25,500 MWh, sufficient to power between 3,000-5,000 homes pending the local household power demand.

Table 5 : Pertinent parameters, the Zugdidi-Tsaishi geothermal power pilot project

Geothermal water circulation rate	250 m^3/hr
Produced water temperature	97.5°C
Injected water temperature	39.7°C
Geothermal heat capacity	17 MW_t
Geothermal power capacity	3 MW_e (2 x 1.5 MW)
Annual power generation	25.5 GWh
Project life	25-30 years

The total installed geothermal capacity for the Zugdidi-Tsaishi area was reported at 74.4 MW_t (Ref. Table 4). Converting this heat energy into power applying the LTT power generation process carries an annual power supply of 126.5 GWh. Assuming an annual local household power demand at 5,000 kWh would hence imply a geothermal power reserve sufficient to power more than 25,000 homes in the Zugdidi-Tsaishi area, i.e. corresponding to approximately 50% of the residential power demand in the towns of Zugdidi and Tsaishi. The total population of the two towns is estimated at 200,000.

5. FINANCIAL AND ECONOMICAL ANALYSES

A simplistic preliminary financial/economic analysis was carried out with regard to the tentative Zugdidi-Tsaishi geothermal power pilot project. The total capital expenditures was assessed at USD 2.74 million, i.e. reflecting the cost for establishment of a) the geothermal loop comprising required flow lines, injection pump(s) and heat exchangers (USD 0.85 mill) and b) the manufacture, delivery and hook-up of 2 x 1.5 MW LTT power generation units (USD 1.89 mill).
The analysis reflects the annual supply of 25.5 GWh_e through utilisation of the 2 x 1.5 MW capacity low temperature turbine (LTT) power generation units connected in parallel, hooked up to the geothermal doublet comprising two producing geothermal water wells and one injection well and further connected to the existing power distribution grid. The analysis is based on a geothermal water circulation rate and flowing wellhead temperature at 250m^3/hr and 97.5°C, respectively. NPV was discounted at 2.5% *p.a.* The analysis reveals a financial rate of return (FRR) at 17% and an economic rate of return (ERR) at 19%. Environmental benefits were based on a CO_2 emission factor at 0.55 ton/MWh priced at USD 4.50/ton (EUR 3.80/ton). The calculations do not comprise discounting for eventual bank loan or construction interest. The power production revenue was based on US cents 2.8/kWh assuming geothermal power production only. Pay-out of the project is expected in year four subsequent to final project implementation. The investment does not incorporate the cost for a technical assistance component (TAC).The financial/economic analysis is summarised and shown in Table 6.

Table 6. Preliminary financial/economical analysis for the Zugdidi-Tsaishi geothermal power pilot project

PILOT CASE	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Opcost, USD 1000's																											
Fuel			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity			55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Salaries			18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Maintenance			22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Total Opcost, USD 1000's			95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95
Gas Emissions, tons/year																											
CO2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benefits																											
USD 1000's gas basis																											
CO2 @ USD 4.50/ton			62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62
SO2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO x			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Benefits, USD 1000's	0	0	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62	62
Investment, USD 1000's	850	1,890																									
Financial revenue, USD 1000's			714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714	714
Economic revenue, USD 1000's			776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776	776
Yearly cash flow, financial USD 1000's	-850	-1,890	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619	619
Yearly cash flow, economic USD 1000's	-850	-1,890	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681
Accum. cash flow, financial USD 1000's	-850	-2,740	-2,121	-1,502	-883	-264	355	974	1,593	2,212	2,831	3,450	4,069	4,688	5,307	5,926	6,545	7,164	7,783	8,402	9,021	9,640	10,259	10,878	11,497	12,116	12,735
Accum. cash flow, economic USD 1000's	-850	-2,740	-2,059	-1,378	-697	-16	665	1,346	2,027	2,708	3,389	4,070	4,751	5,432	6,113	6,794	7,475	8,156	8,837	9,518	10,199	10,880	11,561	12,242	12,923	13,604	14,285
NPV, financial, USD 1000's	-850	-2,628	-2,053	-1,493	-946	-412	109	617	1,113	1,596	2,068	2,528	2,977	3,415	3,843	4,260	4,667	5,063	5,451	5,828	6,197	6,557	6,907	7,250	7,583	7,909	8,227
NPV, economic, USD 1000's	-850	-2,628	-1,996	-1,379	-777	-190	383	942	1,487	2,019	2,538	3,045	3,539	4,021	4,491	4,950	5,397	5,834	6,260	6,675	7,081	7,476	7,862	8,239	8,606	8,965	9,314

Financial rate of return	17%
Economic rate of return	19%

6. CONCLUSIONS

The opportunity to provide geothermal power based on the conversion of low enthalpy geothermal heat into electricity carries a considerable increased use of geothermal energy resources, both in Georgia and adjacent Central Asian regions as well as in Central Europe. In this context it is important to conduct a state-of-the-art field test of the LTT power generation process in order to conclusively assess its efficiency and furthermore determine eventual means for process improvements and repeatability. A cost effective test of the LTT technology can only be conducted in areas where geothermal wells were previously constructed and are in currently operational mode. A further requirement comprises the existence of a sufficient number of wells located at distances that would allow aquifer pressure maintenance and hence the required conservation of the geothermal energy resource. The Zugdidi-Tsaishi pilot area fulfils all basic requirements in this respect and retains an already installed geothermal power capacity to the tune of 15 MW_e, enough to supply more than 50% of the residential power demand in the Zugdidi-Tsaishi area.
Based on the above it is concluded that the proposed geothermal pilot project discussed in this paper should be given the necessary priority in order to allow its implementation.

7. ACKNOWLEDGEMENTS

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