PRELIMINARY REVIEW OF GEOTHERMAL RESOURCES IN KAZAKHSTAN

Final Report Rev. 2

Prepared for the World Bank and the Government of Kazakhstan

May 2019

PROJECT NO.:	18163001 / 18-0115	REPORT NO.:	TBC	DISTRIBUTION:	
		REVISION.:	2	☐	OPEN
		DATE:	2019-05-10	☐	CLOSED
		PAGES:	86 (90)	☒	SUBJECT TO CLIENTS APPROVAL
		COPIES:	1		

REPORT TITLE:

Preliminary Review of Geothermal Resources in Kazakhstan, Final Report

AUTHOR(S): Thorleikur Jóhannesson, Guðni Axelsson, Steinunn Hauksdóttir, Carine Chatenay, Davíð Örn Benediktsson, Tobias B. Weisenberger	PROJECT MANAGER: Thorleikur Jóhannesson
CLIENT: World Bank SUPERVISION: Mitsunori Motohashi	CO-OPERATORS: Government of Kazakhstan ICEIDA

TYPE OF REPORT/STATUS:

Final Report – Rev. 2

ABSTRACT:

The Study was conducted in the fall 2018. It aimed at assessing potential utilisation of geothermal resources in Kazakhstan. Existing data concerning the geothermal potential of the country indicate that potentially exploitable geothermal resources are available, especially in the South and South-East part of the country. The study presents a review of available information on geothermal resources in Kazakhstan. Further to this, the report proposes an overview of the utilisation possibilities that the country geothermal resources offer.

Based on these reviews, the authors focused on two hypothetical case studies: geothermal district heating in the city of Zharkent, and 10 MW binary power plant in the Zharkent sub-basin, to give an indication of the technical and economic viability of such applications. Finally, the report provides a set of recommendations to the Government of Kazakhstan on next steps for possible deployment of geothermal utilisation in the country.

KEYWORDS (ENGLISH): GEOTHERMAL RESOURCE, SEDIMENTARY BASIN, GEOTHERMAL WELLS, DISTRICT HEATING, BINARY, LOAD DURATION, COST, FEASIBILITY	KEYWORDS (ICELANDIC):

PROJECT MANAGER´S SIGNATURE: Þorleikur Jóhannesson	REVIEWED BY: Carine Chatenay/Vilborg Yrsa Þórðardóttir

Contents

List of Figures

List of Tables

List of abbreviations and units

ASHP	Air Source Heat Pump
COP	Co-efficient of performance of a heat pump (heat output/electrical input)
CP	Circulation Pump
DH	District heating
EWSHP	Electrical Water Source Heat Pump
GSHP	Ground Source Heat Pump
GTH	Geothermal Heat
HC	Heat Central
HSE	Health, Safety and Environment
HX	Heat Exchanger
ICEIDA	Iceland Directorate for International Development Cooperation
IRR	Internal Rate of Return
kW_e	kilowatts, electrical energy consumption
MFA	Ministry for Foreign Affairs of Iceland
MoE	Ministry of Energy of Kazakhstan
MW_e	Megawatts, electrical power
MWh_e	Megawatt hour, electrical energy
MWh_t	Megawatt hour, thermal energy
MW_t	Megawatts, thermal power
NG(B)	Natural Gas (Boiler)
NPV	Net Present Value
O&M	Operation and Maintenance (manual & schedule)
PLC	Programable Logic Controller
SCADA	Supervisory Control and Data Acquisition
WB	World Bank
WP	Well Pump

Decimal point and digit grouping

In this report a dot (.) denotes the decimal point. Both commas (,) and in some cases spaces denote digit grouping of thousands.

Example with comma separator:	1,234,567.89
Example with space separator:	1 234 567.89

In some cases, graphs and figures the consultants have borrowed from external source may have different digit grouping.

Assumed values

Burning value of Natural gas:	36,000 kJ/Nm^3 = 10 kWh/Nm^3
Efficiency of natural gas boiler:	90%. Thus, heating energy is 9 kWh/Nm^3

Exchange rate

1 KZT	= 0.0027 USD	1 USD	= 370 KZT
1KZT	= 0.0023 €	1€	= 430 KZT
1 USD	= 0.86 €	1€	= 1.16 USD

Power and energy

Power: 1MW = 0.86 GCal/h

Energy: 1MWh = 0.86 GCal = 3.6 GJ

Energy: 1 kWh = 3,600 kJ

Energy: 1 EJ = 1 000 PJ = 1 000 000 TJ = 1 000 000 000 GJ

Executive Summary

This report constitutes the final report for the “Preliminary Review of Geothermal Resources in Kazakhstan”. The Study was carried out for the World Bank (WB) through the Directorate for International Development Cooperation (ICEIDA) within the Ministry for Foreign Affairs in Iceland (IMFA). The scope of the Study was to review the available information on geothermal resources in Kazakhstan, with a special focus on the Ily Basin and its sub-basins the Almaty and Zharkent Basins in South Kazakhstan. The Study aimed to estimate: resource temperature, reservoir characteristics (size, shape, productivity, water level), and technical and economic feasibility of the resources for heating and other direct use applications or electricity generation.

Various benefits would be associated with the introduction of geothermal district heating systems in Kazakhstan. The main advantage would be the reduction of air pollution and greenhouse gas emission. Using geothermal with full reinjection will allow for considerable reduction of greenhouse gas emission. Furthermore, geothermal energy is an indigenous source of clean energy and can contribute as such to “clean energy” independence of Kazakhstan. Geothermal energy is also an excellent candidate to provide baseload, available at stable price no matter the weather or fossil fuel prices. It is therefore important to consider this source of energy in the energy mix of Kazakhstan.

Geothermal energy can additionally contribute to strengthening the supply of energy close to populated areas and avoid high transmission losses over long distances.

A carefully planned geothermal project aiming at integrating the resource exploitation activities in the community can potentially create more jobs than just the jobs of the power and/or district heating operators. An eco-park close to a geothermal project can create a variety of local jobs, such as food production and food processing, tourism, well-being industry, etc. The diversity of activities that may result from the utilisation of geothermal resources is an important factor to be taken into account by policy makers and project developers.

Considerable research has been conducted to assess the likely energy production potential of Kazakhstan’s sedimentary geothermal resources, although recent research is limited. Available information that demonstrates the potential is to some extent fragmented, incomplete and not always consistent. However, comprehensive data related to the geothermal resources exists in the archives of Kazakhstan and should be compiled.

Kazakhstan is believed to hold considerable low-temperature geothermal resources, mainly of the sedimentary type. Low-temperature geothermal resources are especially suitable for district heating and other direct utilization purposes and there is significant need for adequate heating services for the Kazakhstan population.

The most concentrated potential is estimated to be in the Ustyurt-Buzashin and Manguyshiak basins in SW-Kazakhstan and in the W-Ily (Almaty) and E-Ily (Zharkent) basins in SE-Kazakhstan. The first two are also amongst the basins with the greatest extractable energy per basin, by virtue of their relatively great surface area. Basins with high extractable energy density (per km^2), are generally the most promising in terms of geothermal potential, as they should require less wide-spread production well drilling.

In South and South-East Kazakhstan, the geothermal resources in the Zharkent sub-basin appear to be most promising, based on resource temperature, low concentration of dissolved solids and powerful natural recharge through precipitation. Further research may locate other promising geothermal resources in the South and South-East region.

The estimated extractable energy for the Zharkent basin is in the range of 20 to more than 160 TJ/km^2/yr, depending on resource temperature (depends on depth) and assuming a utilization period of 50 years. Hypothetically, each km^2 could provide space heating for 200 to 1,600 inhabitants. Based on these assumptions, the whole basin could thus provide heat for roughly 1.5 million inhabitants.

Because of the closed nature of most sedimentary geothermal reservoirs, reinjection is essential for their sustainable use. This may not be immediately necessary in all locations in the Zharkent sub-basin, because of the natural recharge, but will become so with time and increased geothermal development. It will certainly be required from the beginning of large-scale utilization of most other sedimentary geothermal resources in Kazakhstan.

However, various barriers can affect the successful implementation of geothermal projects. Considerable risk is associated with the development of geothermal resources, including drilling, and this resource risk is greater than the risk associated with other renewable energy resources. This risk is variable and is often higher in fracture-controlled systems than in sedimentary systems such as identified in Kazakhstan. This risk can be minimized by comprehensive research, both prior to drilling and during the drilling phase of the development of a geothermal project. There are also risks associated with the well-drilling itself and the assessments of the capacity of geothermal resources.

The best way to avoid overexploitation associated with the resource risk is stepwise development. i.e. developing a resource in relatively small steps over a longer period. The first step should be well below the estimated capacity as well as providing essential and more accurate additional information on the resource capacity as the first step progresses.

No specific legal framework appears to be in place in Kazakhstan concerning the utilisation of geothermal resources. This could be a serious barrier for investors wishing to develop projects in this field in the country, due to the resulting uncertainty on issues such as ownership, licensing, fees, monitoring, etc.

The end-users are a critical component of direct utilisation of geothermal resources, especially in the perspective of designing an economic and sustainable system that will be available to the local community in the long term. Energy efficiency of the buildings and of the heating systems will be an issue. Specific attention must be given to improvement of building thermal insulation in parallel with the implementation of a modern geothermal district heating system, selection of the heating devices used, design of the metering and tariff systems as well as the energy prices. In practice, this means that development of a district heating system in an already existing neighbourhood might imply modification of the heating equipment of the users.

Although the prices remain indicative and rather high at this stage, the case studies evaluated suggest that heat from geothermal may become competitive with heat from other sources of energy in the future. However, at present, the current low price of conventional energy in Kazakhstan could be a barrier to the development of geothermal district heating projects.

Harnessing the geothermal resources in Kazakhstan for electricity production is technically feasible. However, the price of electricity from a geothermal binary power plant appears to be in the upper range of the electricity prices seen in the various regions of Kazakhstan. Compared to recent wind projects in Kazakhstan, geothermal electricity looks unattractive, but this can be compensated for with the higher capacity factor for geothermal electricity, or 90% compared to 35% for wind projects.

It is recommended that a comprehensive country-wide compilation and evaluation of data regarding resource assessment be undertaken. Data is believed to exist in the archives of Kazakhstan, from wells drilled in Kazakhstan, mainly for petroleum exploration, having hydrothermal indications. Following this, further exploration should be planned, to fill in gaps in the existing data for selected resource areas. Conceptual models should then be developed, followed by drilling of exploration wells. These wells should be subjected to logging, testing, monitoring and resource assessment and modelling. A resource capacity assessment is a critical part of any utilization plans, where data from surface exploration, exploration drilling and testing is used, based on an accurate conceptual model.

An evaluation of present legal-, institutional-, regulatory- and permit-framework with suggestions for improvements is recommended. This should also involve an evaluation of possible support and tariff-framework as well as data management. The development of geothermal utilisation may need review of components of the legal and regulatory framework such as the National Energy Policy and various regulatory provisions on i.e. electricity, district heating, environment, water and agriculture, rural development, finance, land and property, mining, procurement and foreign investment.

The Government of Kazakhstan is advised to consider having an entity with the authority necessary to manage permitting and licensing as well as monitoring. Specific attention should be paid to the management of concessions and the decisions related to electric production. For long-term sustainable utilization of geothermal resources, comprehensive resource management must be applied.

General risk assessments should be conducted on the different aspects of geothermal development, e.g. on risks associated with exploration, drilling, public or private sector development, risks associated with tenders for international markets, etc.

It is critical for the Government of Kazakhstan to design a pricing mechanism that attracts investors and enables at the same time affordable energy prices for the users. Various mechanisms are currently used for electricity from geothermal, such as feed-in-tariffs, energy auction tariffs, negotiated prices, etc. There are pros and cons for each method and the design of the pricing policy will depend on the Government of Kazakhstan’s objectives in terms of renewable energy targets, price to users, attractivity of the sector and so forth.

Apart from the issues mentioned above concerning the creation of an environment favourable to investment in the geothermal sector and aimed at reassuring investors that their project will be viable in the medium and long term; various policy aspects require careful consideration.

As may be expected in a country with few projects in operation, there are currently very few clearly identified institutes and companies with experience in the field of geothermal in Kazakhstan. The set of basic competence required for developing geothermal projects includes major scientific and technical competence in disciplines such as geology, geochemistry, geophysics, reservoir engineering, environmental science, geothermal drilling and geothermal engineering. The lack of currently ongoing projects indicates that there may be few people trained and experienced in the field, presently employed in Kazakhstan. It is therefore recommended that the strategy for implementation of geothermal utilisation in Kazakhstan is done in such a way that the Government of Kazakhstan receives support and training from experienced partners in this field worldwide.

Introduction

This report constitutes the final report for the "Preliminary Review of Geothermal Resources in Kazakhstan" (the "Study"). The project was awarded to a project team from Iceland (the "Consultants") led by senior scientists and engineers, from the engineering firm Verkís and the research institute Iceland GeoSurvey (ÍSOR). In addition to their input, these senior consultants had access to experts within the companies bringing insight on specific disciplines related to the Study.

The Study was carried out for the World Bank (WB) through the Directorate for International Development Cooperation (ICEIDA) within the Ministry for Foreign Affairs in Iceland (IMFA), under the framework of on-demand technical support from IMFA to the World Bank and its clients. The WB's client in this case is the Government of Kazakhstan (GoK).

Background

Kazakhstan ranks among the top 10 most energy-intensive economies in the world, mainly due to:

- The high contribution of energy-intensive industries to GDP, including the energy and extractives sector;
- The low energy efficiency in key energy-consuming sectors; and
- Adverse climate conditions.

The space heating sector is a major consumer of energy in Kazakhstan and lack of investment has made the sector one of the most energy-intensive in the country.

Energy poverty remains an issue in Kazakhstan, with 67% of households in rural areas still using coal as a primary heating source. Despite relatively low energy prices and energy resource abundance, many households cannot afford adequate energy services due to a combination of income inequality, high heating demand and energy inefficiency. Further to this, combustion coal and solid fuels for heating purposes cause indoor pollution and pose serious health risks.

Kazakhstan has adopted ambitious targets and policy measures on renewable energy development focused on increased renewable energy utilization. This includes the target that the share of renewables in electricity production will not be less than:

- 3% by 2020
- 30% by 2030, and
- 50% by 2050.

Targets and policies regarding household heating are no-less important (World Bank, 2018). Kazakhstan has, furthermore, adopted several policy measures to support investment in renewable energy projects.

Kazakhstan is believed to hold considerable low-temperature geothermal resources, mainly of the sedimentary type. This information is acquired from deep wells, which have mainly been drilled as petroleum and/or gas wells and have yielded hot water. Surface manifestations (hot springs) also provide evidence of such resources. Furthermore, there are parallels between the geological conditions (deep sedimentary basins) in parts of Kazakhstan and the geological conditions of sedimentary basins in other parts of the world with extensive low-temperature geothermal utilization, e.g. in Eastern Europe and in China. Information on the geothermal resources of Kazakhstan in international science and technology literature is very limited, but more extensive literature exists in Kazakh and mainly in Russian.

Low-temperature geothermal resources are especially suitable for district heating and other direct utilization purposes such as industrial application, balneology, etc. Given that, there is significant need for adequate heating services for the Kazakhstan population, provided in a sustainable manner, there is an opportunity to assess the potential and characteristics of geothermal energy resources in Kazakhstan, and identify whether and how they can be harnessed to meet some of the household energy needs. Hot springs and hot water from wells are already used to some extent in certain areas in Kazakhstan, for direct purposes, yet only on a very limited scale.

Geothermal systems in Kazakhstan have been identified in the western, south, and central parts of the country and are generally hosted in sedimentary basins ranging in age from Mesozoic to Cenozoic. Some of the available information were collected from wells drilled specifically for the purpose of geothermal exploration, whereas oil and gas exploration wells have also been a good source of geothermal information as mentioned above.

Figure 1 – Map of Kazakhstan

Figure 1 highlights the Almaty and Zharkent sub-basins of the Ily Basin in the SE-corner of the country, the geothermal areas in focus for the Study.

Temperatures range from ambient to over 150°C at depths of up to 4 500 m in some systems. Wells are pressurized in some locations whereas others require pumping for utilization. The salinity (dissolved chemical content) of geothermal fluids in Kazakhstan is highly variable; ranging from hypersaline brines with up to 200,000 mg/kg of dissolved solids to fairly dilute fluids with around 1,000 mg/kg of dissolved solids. The most benign geothermal fluids in terms of chemical content appear to be found in reservoirs of the Ily basin and its sub-basins, the Almaty and Zharkent basin, which will be the main subjects of this Study.

Objective and Scope

The scope of the Study was to review the available information on geothermal resources in Kazakhstan, with a special focus on the Ily Basin and its sub-basins the Almaty and Zharkent Basins in South Kazakhstan. The Study aimed, to the extent possible with the availability of relevant data, to estimate: resource temperature, reservoir characteristics (size, shape, productivity, water level), and technical and economic feasibility of the resources for heating and other direct use applications or electricity generation.

The key objective of the Study is thus threefold:

- Review available information on geothermal resources in Kazakhstan;
- Assess technically and economically viable applications; and
- Make recommendations to the Government on next steps for possible deployment of geothermal resources in the future as may be applicable.

The scope of the Study, therefore, focuses on the Almaty and Zharkent sub-basins of the Ily Basin, discussed above. During a site mission to Kazaksthan during 15 – 19 October 2018, it was determined by GoK representatives and the Consultants to focus specifically on the Zharkent sub-basin, as an initial example or case study.

Specific focus was also given to low-temperature direct utilization, such as household heating, while small-scale electricity generation was investigated for the high temperature resources.

This report presents the main findings of the Study. It starts out by presenting general information on geothermal resources worldwide and then continues by summarizing available information regarding the geothermal resources in Kazakhstan.

The following chapter deals more specifically with geothermal resources in South- and SE-Kazakhstan with special emphasis on the Zharkent sub-basin. Consequently, the report moves on to presenting general aspects of geothermal utilization, with emphasis on direct use and the associated surface technology.

After this general introduction, a basic technological and financial analysis of hypothetical utilization in the Zharkent sub-basin is presented, followed by a discussion of other aspect of geothermal implementation, including environmental, social and economic impacts.

The report is concluded by a short summary of the results of the Study as well as comprehensive recommendations on the way forward towards successful large-scale geothermal utilization in Kazakhstan.

1 Geothermal Resources Worldwide and Assessing their Potential

1.1 Nature and Classification

Geothermal energy stems from the Earth's outward heat-flux, which originates from the internal heat of the Earth leftover from its creation as well as generated by the decay of radioactive isotopes in the Earth's mantle and crust. Geothermal systems are regions in the Earth's crust where this flux, and the associated energy storage, are abnormally great. In the majority of cases, the energy transport medium is water and such systems are, therefore, called hydrothermal systems. Such geothermal resources are distributed throughout the planet.

Even though most geothermal systems and the greatest concentration of geothermal energy are associated with tectonic plate boundaries, geothermal energy may be found in most countries. Geothermal activity is highly concentrated in volcanic regions but may also be found as warm ground-water in sedimentary formations world-wide. In many cases geothermal energy is found in populated, or easily accessible, areas. But geothermal activity is also found at great depth on the ocean floor, in mountainous regions and under glaciers and ice caps. Numerous geothermal systems probably still remain to be discovered, since many systems have no surface activity. Some of these are, however, slowly being discovered. The following basic definitions are commonly used (Saemundsson, 2009):

- A Geothermal Field is a geographical definition, usually indicating an area of geothermal activity at the earth's surface. In cases without surface activity this term may be used to indicate the area at the surface corresponding to the geothermal reservoir below.
- A Geothermal System refers to all parts of the hydrological system involved, including the recharge zone, all subsurface parts and the outflow of the system.
- A Geothermal Reservoir indicates the hot and permeable part of a geothermal system that may be directly exploited. For spontaneous discharge to be possible, geothermal reservoirs must also be pressurised.

Geothermal systems and reservoirs are classified based on different aspects, such as reservoir temperature or enthalpy, physical state, their nature and geological setting.

Table 1 – Classifications of geothermal systems based on temperature, enthalpy and physical state (Saemundsson, 2009)

Low-temperature (LT) systems with reservoir temperature at 1 km depth below 150°C. Often characterised by hot or boiling springs.	***Low-enthalpy*** geothermal systems with reservoir fluid enthalpy less than 800 kJ/kg, corresponding to temperatures less than about 190ºC.	***Liquid-dominated*** geothermal reservoirs with the water temperature at, or below, the boiling point at the prevailing pressure and the water phase controls the pressure in the reservoir. Some steam may be present.
Medium-temperature (MT) systems.		
High-temperature (HT) systems with reservoir temperature at 1 km depth above 200°C. Characterised by fumaroles, steam vents, mud pools and highly altered ground.	***High-enthalpy*** geothermal systems with reservoir fluid enthalpy greater than 800 kJ/kg.	***Two-phase*** geothermal reservoirs where steam and water co-exist and the temperature and pressure follow the boiling point curve.
		Vapour-dominated geothermal where temperature is at, or above, the boiling point at the prevailing pressure and the steam phase controls the pressure in the reservoir. Some liquid water may be present.

It should be noted that a common classification is not set forth in the geothermal literature available, even though one based on enthalpy is often used. Different parts of geothermal systems may, furthermore, be in different physical states and geothermal reservoirs may also evolve from one state to another. As an example, a liquid-dominated reservoir may evolve into a two-phase reservoir when pressure declines in the system, because of production. Steam caps may also evolve in geothermal systems, because of lowered pressure. Low-temperature systems are always liquid-dominated, but high-temperature systems can either be liquid-dominated, two-phase or vapour-dominated.

Geothermal systems are also classified based on their nature and geological setting (modified from (Axelsson G. , 2016)):

A. In **fracture-controlled convective systems** the heat source is the hot crust at depth in tectonically active areas, with above average heat-flow. Here the geothermal water has circulated to considerable depth (> 1 km), through mostly vertical fractures, to extract the heat from the rocks.

B. **Volcanic systems** are in one way or another associated with volcanic activity. The heat sources for such systems are hot intrusions or magma. They are most often situated inside, or close to, volcanic complexes such as calderas and/or spreading centres. Permeable fractures and fault zones mostly control the flow of water in volcanic systems.

C. **Sedimentary systems** are found in many of the major sedimentary basins of the world. These systems owe their existence to the occurrence of permeable sedimentary layers at great depths (> 1 km) and above average geothermal gradients (> 30ºC/km). These systems are conductive in nature rather than convective, even though fractures and faults play a role in some cases. Some convective systems (A) may, however, be embedded in sedimentary rocks.

D. **Geo-pressured systems** are sedimentary systems analogous to geo-pressured oil and gas reservoirs where fluid caught in stratigraphic traps may have pressures close to lithostatic values. Such systems are generally quite deep; hence, they are categorised as geothermal.

E. **Hot dry rock (HDR) or enhanced (engineered) geothermal systems (EGS)** involve volumes of rock that have been heated to useful temperatures by volcanism, or abnormally high heat flow, but have low permeability or are virtually impermeable. Therefore, they cannot be exploited in a conventional manner. However, experiments have been conducted in a number of locations to use hydro-fracturing to try to create artificial reservoirs in such systems, or to enhance already existent fracture networks. Once such systems become economical, they will likely be mostly used through production/reinjection doublets.

F. **Shallow resources** refer to the thermal energy stored near the surface of the Earth's crust, partially originating from solar radiation. Recent developments in the application of ground source heat pumps have opened up a new dimension in utilizing these resources.

See Figure 2 for sketches of the three main types; A, B and C.

Geothermal systems of the convective type (A) exist outside the volcanic zone in Iceland, in the SW United States and in SE China, to name a few countries. Numerous volcanic geothermal systems (B) are found for example in The Pacific Ring of Fire, in countries like New Zealand, Indonesia, The Philippines, Japan, Mexico and in Central America, as well as in the East-African Rift Valley and Iceland. Sedimentary geothermal systems (C) are for example found in France, Germany, Central Eastern Europe and throughout China. Typical examples of geo-pressured systems (D) exist in the Northern Gulf of Mexico Basin in the U.S.A. and in SE-Hungary. The early Fenton Hill project in New Mexico in the U.S.A. and the Soultz project in NE-France, which is now in the pilot demonstration phase after 2 decades of intense research and testing, are well known HDR and EGS projects (E). Shallow resources (F) can be found all over the globe.

(Saemundsson, 2009) discuss the classification and geological setting of geothermal systems in more detail than done here. They present a further subdivision, principally based on tectonic setting, volcanic association and geological formations. Volcanic geothermal systems (B) are e.g. subdivided into systems associated with rift-zone volcanism (diverging plate boundaries), hot-spot volcanism and subduction-zone volcanism (converging plate boundaries). The reader is referred to that reference for more detail.

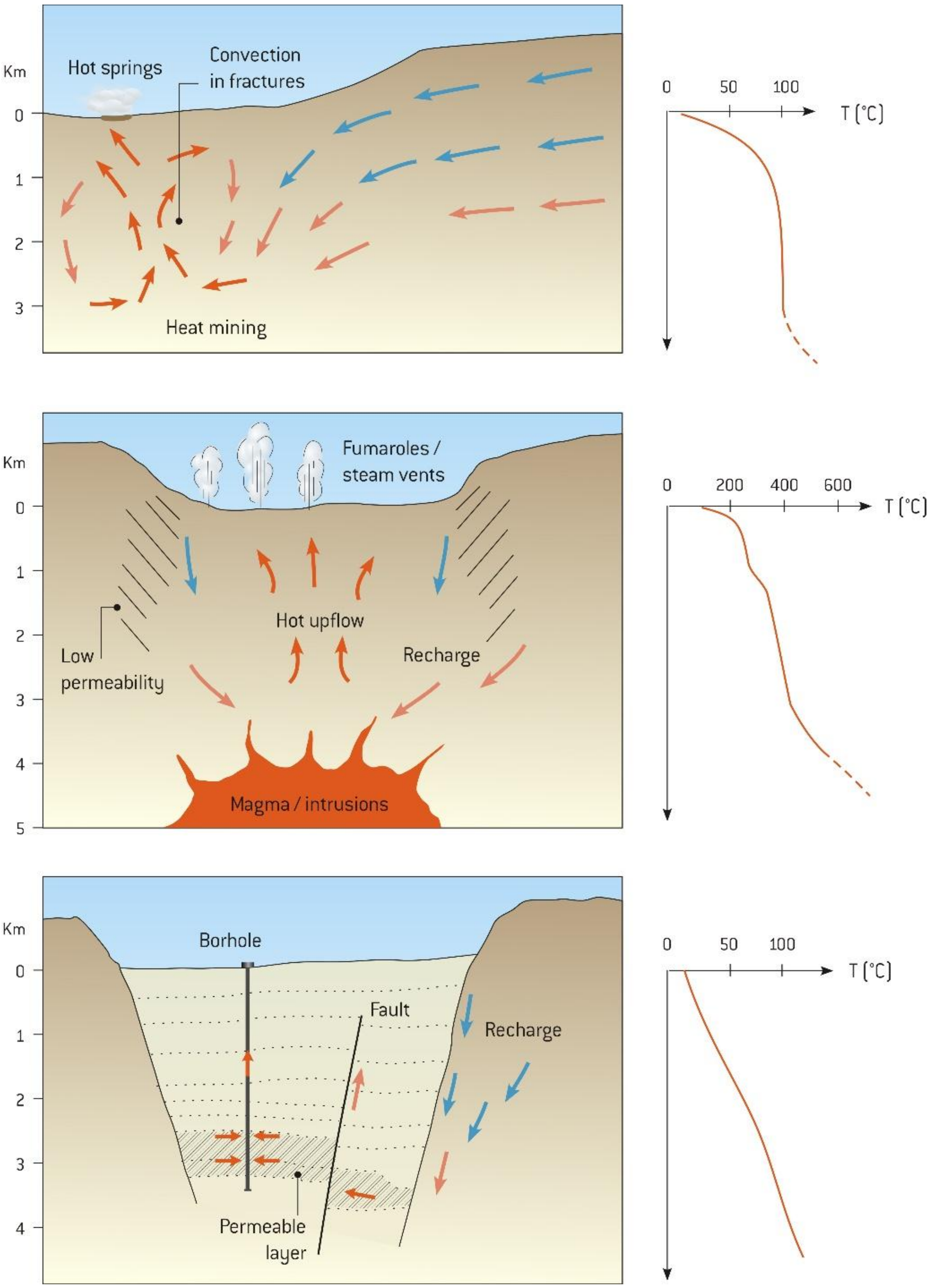

Figure 2 – Schematic figures of the three main types of geothermal systems (A, B and C) along with typical temperature profiles. Note that the vertical scale for type C is exaggerated.

The potential of the Earth's geothermal resources is enormous when compared to its use today and to the future energy needs of mankind. (Stefánsson, 2005) estimated the technically feasible electrical generation potential of identified geothermal resources to be 240 GWe (1 GW = 109 W), which are likely to be only a small fraction of hidden, or as yet unidentified, resources. He also indicated the most likely direct use potential of lower temperature resources (< 150°C) to be 140

EJ/yr (1 EJ = 10^{18} J). The Earth's ultimate geothermal potential is, however, impossible to estimate accurately at the present stage of knowledge and technology. Even though geothermal energy utilization has been growing rapidly in recent years, it is still miniscule compared with the Earth's potential. (Bertani, 2010) estimated the worldwide installed geothermal electricity generation capacity to have been about 10.7 GW_e in 2010 and (Lund, 2010) estimated the direct geothermal utilization in 2009 to have amounted to 438 PJ/yr (1 PJ = 10^{15} J). (Fridleifsson, 2008) have estimated that by 2050 the electrical generation capacity may reach 70 GWe and the direct use 5.1 EJ/yr. There is, therefore, ample space for accelerated use of geothermal resources worldwide in the near future.

The key to the successful exploration, development (incl. drilling) and utilization of any type of geothermal system is a clear definition and understanding of the nature and characteristics of the system in question. This is best achieved through the development of a conceptual model of the system, which is a descriptive or qualitative model incorporating, and unifying, the essential physical features of the system (Axelsson G. , 2013). Conceptual models are mainly based on analysis of geological and geophysical information, temperature and pressure data, information on reservoir properties as well as information on the chemical content of reservoir fluids. Monitoring data reflecting reservoir changes during long-term exploitation, furthermore, aid in revising conceptual models once they become available.

Conceptual models should explain the heat source for the reservoir in question and the location of recharge zones, the location of the main flow channels, the general flow patterns within the reservoir as well as reservoir temperature and pressure conditions. A comprehensive conceptual model should, furthermore, provide an estimate of the size of the reservoir involved. Cooperation of the different disciplines involved in geothermal research and development is of particular importance.

Conceptual models are an important basis of field development plans, i.e. in selecting locations and targets of wells to be drilled and ultimately the foundation for all geothermal resource assessments, particularly volumetric assessments and geothermal reservoir modelling, used to assess the energy production capacity of a geothermal system. Initially a conceptual model depends mostly on surface exploration data, but once the first wells have been drilled into a system subsurface data come into play, increasing the knowledge on a geothermal system. Most important are feed-zone, temperature-logging and well-test data. Conceptual models should be revised, and improved, continuously throughout the exploration, development and utilization history of a geothermal system, as more data and information become available.

1.2 Sedimentary Geothermal Systems

Geothermal resources and associated reservoirs in Kazakhstan are mainly of the sedimentary type (C). Deep sedimentary basins, which host such systems, are widespread in the continental regions of the World. In some cases, these have been utilized for decades so considerable experience exists in their exploration, in the relevant drilling technology and in their long-term sustainable utilization. The best known sedimentary geothermal resources in the world are the following:

- The Paris Basin in France, which has been utilized since about 1970 (Lopez, 2010).
- The North-German Basin along with sedimentary resources in Belgium, the Netherlands and Denmark.
- The Molasse Basin in South-Germany.
- The very extensive Pannonian Basin, which covers most of Hungary and extends into neighbouring countries, including Slovakia, Poland, Romania and Croatia.
- Widespread in the extensive sedimentary basins of China, in particular in NE-China.

This list is not exhaustive but covers the regions where extensive geothermal utilization is already ongoing. Sedimentary geothermal resources are certain to exist in other continental regions, like Central-Asia, North-America and South-America, to name examples.

In the sedimentary basins, temperature increases approximately linearly with depth, according to the local temperature gradient, as the heat flow is mainly by conduction. Exploitable sedimentary resources, therefore, owe their existence to sufficient permeability of the reservoir rocks at depth where temperature is sufficiently high.

Permeable sedimentary layers are generally either composed of sandstone or carbonate rocks, either limestone or dolomite. The nature of the permeability of these two rock types is quite different. The permeability of sandstone is caused by intergranular flow-paths in-between sand-particles while the permeability of carbonate rocks is caused by fractures (often quite variable in scale), often karstified[1] to a variable degree. The thickness of the sequence of sedimentary layers in sedimentary basins is quite variable but can be from a few km or less up to more than 10 km. Often sandstone layers top deeper carbonate layers. Sandstone layers are generally separated by numerous poorly permeable clay layers.

The temperature of sedimentary geothermal reservoir is mainly determined by their depth, by virtue of their conductive nature. The average temperature gradient in sedimentary regions is of the order of 20 – 40°C/km approximately, but in certain regions crustal heat-flow anomalies (caused by tectonic activity, crustal thinning, etc.) may raise the gradient and hence the reservoir temperature. In shallow (~ 500 – 1 000 m) sedimentary layers, water temperature may be as low as 20 – 30°C, suitable for ground-source heat-pump utilization (GSHP), while in deeper ones (~2 – 4 km) water temperature may even be above 100°C, suitable for direct space heating.

Sedimentary geothermal systems usually extend over very large areas (thousands or tens of thousands of km^2), much larger than the areal extent of other geothermal systems. Because of this and their often great depth, they have limited natural water recharge. Thus, they can be classified as closed geothermal systems where water level declines continuously in phase with net mass extraction as the total extraction from the system in question is much greater than the limited recharge (Axelsson G. , 2016). This is seen clearly in the example in Figure 3. Despite this lack of water recharge, the sedimentary layers contain enormous amounts of thermal energy that can be extracted by applying reinjection of used water. Exceptions to this closed nature are some carbonate reservoirs embedded in layers that have links to recharge areas (outcrops) in hills or mountains nearby.

---

[1] Permeability due to flow channels, of quite variable dimensions, formed by the dissolution of soluble rocks such as limestone, dolomite.

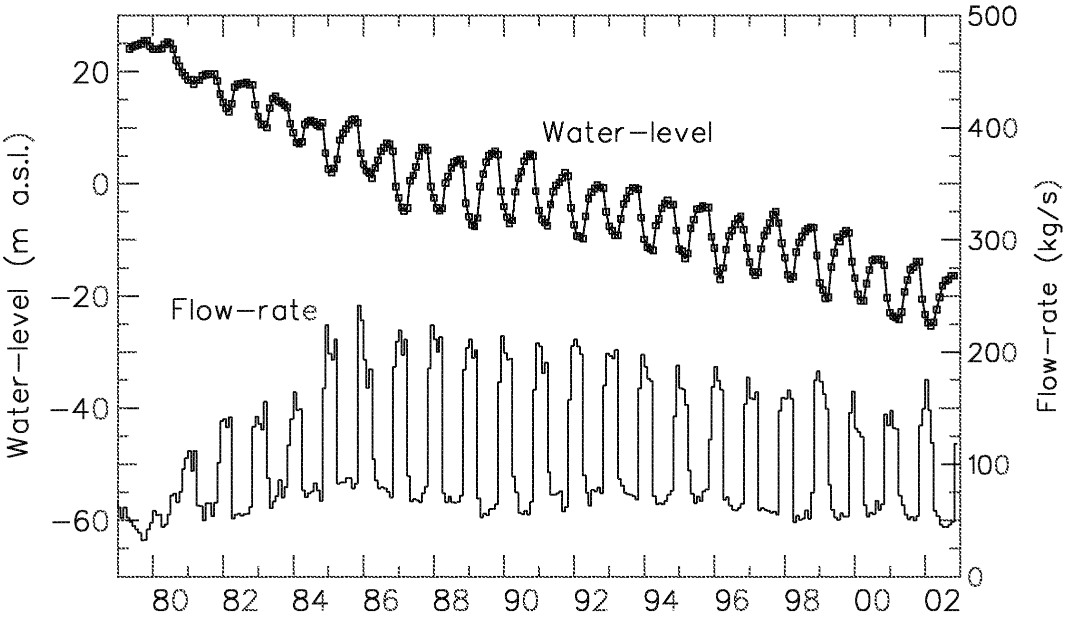

Figure 3 – Typical production and water level history of a sedimentary geothermal system during utilization with no reinjection (Axelsson G. S., 2005).

Because of the great areal extent of most sedimentary geothermal resources, several utilization concessions may have been granted to different developers, covering the same geothermal system. This will ultimately cause problems as production from one concession will cause a water-level draw-down in other concessions near-by and vice-versa. For long-term sustainable utilization of geothermal resources in such situations, comprehensive resource management must be applied. This includes, to name the most significant aspects:

- Improved monitoring of mass extraction and reservoir response (water-level and temperature changes);
- Limiting extraction through government initiatives/regulations;
- Providing exclusive rights to experienced/responsible companies; and
- Applying reinjection (which limits interference between concessions, if close to 100%).

1.3 Assessment of the Capacity of Geothermal Systems

The energy production capacity of hydrothermal systems is predominantly controlled by reservoir pressure decline caused by hot water/steam production, which is in turn determined by the size of a geothermal reservoir, its permeability, reservoir storage capacity, fluid recharge and geological structure. More generally the capacity of geothermal systems is also controlled by their energy content, dictated by their size and temperature conditions (enthalpy if two-phase). Modelling plays a key role in understanding the nature of geothermal systems and is the most powerful tool for predicting their response to future production, which is used to estimate their production capacity (Axelsson G. , 2016). Models are also an indispensable part of geothermal resource management during utilization.

In addition to the volumetric assessment method (static modelling) different methods of dynamic modelling are the main techniques used for geothermal reservoir modelling and resource assessment, including simple analytical modelling, lumped parameter modelling or detailed numerical modelling. Thorough understanding of the nature and properties of geothermal resources, via comprehensive interdisciplinary research, as well as reliable and accurate assessment of their production capacity, through modelling, are an absolute prerequisite for sustainable utilization of geothermal resources.

The volumetric method is the main static modelling method, as already stated. It is presented and discussed in detail by (Sarmiento, 2013). It is often used for first stage assessment, when data are limited, and was more commonly used in the past, but is still the main assessment method in some countries. It is increasingly being used, however, through application of the Monte Carlo method, which enables the incorporation of overall uncertainty in the results. The main drawback of the volumetric method is the fact that the dynamic response of a reservoir to production is not considered, such as the pressure response and the effect of fluid recharge. Reservoirs with the same heat content may have different permeabilities and recharge and, hence, very different production potentials.

The volumetric method is based on estimating the total heat stored in a volume of rock (referred to some base temperature), both thermal energy in rock matrix and in water/steam in pores. In the volumetric method the likely surface area and thickness of a resource are initially estimated from geophysical and geological data, and later from well-data as well. Consequently, likely temperature conditions are assumed on the basis of chemical studies and well temperature data, if available. Based on these, estimates of reservoir porosity and thermal properties of water and rock involved, the total energy content is estimated. The reservoir temperature can either be assumed to be approximately constant, to be variable between different reservoir parts or to be a certain fraction of the boiling point curve at prevailing pressure conditions, in the calculations. The reference temperature used is the base temperature of the energy production process involved (space heating, electricity generation, etc.).

Only a relatively small fraction of the total energy in a system can be expected to be extracted, or recovered, during a several decades long utilization period. This fraction is estimated by applying two factors. First so-called surface accessibility (A), which describes what proportion of the reservoir volume can be accessed through drilling from the surface. Then the recovery factor (R), which indicates how much of the accessible energy may be technically recovered. The recovery factor is the parameter in the volumetric method, which is most difficult to estimate. The results of the volumetric assessment are also highly dependent on the factor. It depends on the nature of the system; permeability, porosity, significance of fractures, recharge, as well as on the mode of production, i.e. whether reinjection is applied. It is also to some extent dependent on utilization time. (Williams, 2007) provides a good review of the estimation of the recovery factor, which is often assumed to be in the range of 0.05–0.25. In recent years researchers have become more conservative in selecting the recovery factor than in the past, based on experience from long-term utilization of numerous geothermal systems worldwide.

For direct use, the thermal power is estimated by dividing the extractable thermal energy, as estimated, by the utilization time period considered. To estimate electrical generation capacity (total energy or power potential) on basis of the recoverable energy an appropriate conversion-efficiency is used. It should incorporate the conversion of thermal energy into mechanical energy and consequently that of mechanical energy into electrical energy. The efficiency depends on resource temperature, the generation process used (conventional steam turbine, binary fluid generation, etc.) and the reference temperature.

The volumetric method can be applied to individual geothermal reservoirs, whole geothermal systems or on a regional scale, i.e. for a whole country. The volumetric method, or variants thereof, have been used to some extent to estimate the potential of geothermal resources in Kazakhstan in a general sense, in different reports and papers. It has also been used by the Consultants in this work, especially for the Zharkent sub-basin. For individual systems the Monte Carlo method is commonly applied. It involves assigning probability distributions to the different parameters of the equations above and estimating the system potential with probability.

It must be emphasized that the volumetric method is not suitable for the estimation of the long-term (sustainable) production capacity of geothermal systems. This is because of its limitations mentioned above, mainly the fact that it neglects the dynamic response of geothermal systems during utilization. Thus, the results of a volumetric assessment should only be considered indicative. It is also important to put emphasis on the lower limit of the Monte Carlo outcome, often referred to as the P95 or P90 value, rather than the average outcome or upper limit.

As the volumetric method isn't sufficient to estimate the ultimate capacity of a geothermal resource the results should be combined with the cumulative capacity of wells already drilled to plan the first development step. Detailed numerical modelling will provide a much more accurate capacity estimate.

2 Geothermal Resources in Kazakhstan

2.1 Background and data

A key part of the scope of this Study is to review available information on geothermal resources in Kazakhstan and relevant resource characteristics and potential. Kazakhstan is believed to hold considerable low-temperature geothermal resources, yet these have only been explored and utilized to a very limited extent up to now.

The following information and data were made available for this work, or found independently by the Consultants:

1) Two major reports regarding geothermal potential and utilization in Kazakhstan, published in 2006 and 2016, respectively, and made available by the Ministry of Energy of Kazakhstan (MoE). English translations of these reports were provided through the assistance of the World Bank.
2) Several shorter documents, some of unknown origin, were provided (mainly through the MoE) after being translated from Russian to English.
3) Detailed information on many of the wells included in the 2006 and 2016 reports listed in 1). This information was provided in excel-sheets set up by the Consultants, filled in by Kazakhstan counterparts.
4) Papers and reports in the international literature, found through an internet search. The most notable international publication on geothermal potential in Kazakhstan is the paper by (Boguslavsky, 1999) where geothermal resources in Kazakhstan are described and quantified (see section 3.2 for more detail).

Appendix A presents information on the reports and documents listed under 1) and 2). In addition, some relevant information was obtained verbally through discussions during the site mission and final workshop. Finally, some additional information was found in publicly available general reports on energy potential and production in Kazakhstan, but these naturally focusing mainly on the hydrocarbon and coal industries.

Only a small part of the available geothermal information was collected from wells drilled specifically for the purpose of geothermal exploration, whereas oil and gas exploration wells have and can be a good source of geothermal information, as already mentioned.

2.2 Geothermal research in Kazakhstan

In Kazakhstan, geothermal waters have been encountered in the course of regional geological studies, during deep well drilling for hydrocarbons and other work/studies. It is the Consultants understanding that some geothermal research was conducted in Kazakhstan during the Soviet period, while geothermal research has been limited after independence. Some research has been conducted during the latter period, however, as will be reviewed briefly below. Some geothermal research has also been conducted as a part of more general hydrogeological studies.

According to information provided to the Consultants, comprehensive studies of geothermal resources in Kazakhstan were conducted in the 1980’s, in the most promising regions of South Kazakhstan. This included prospecting and appraisal work during 1982 – 1991 regarding space heating and hot water supply in the cities of Turkestan and Arys, as well as in the Almaty Oblast (Ily and Usek). The results indicated considerable geothermal reserves.

In 2006, 40 existing deep wells in the south and southeast parts of the country were inspected and a feasibility study presented. The study identified the most promising areas for further prospecting and exploration (Kasymbekov, 2006).

In 2008, prospecting and exploration was conducted in the Zharkent sub-basin in SE-Kazakhstan, and exploitable geothermal reserves assessed. This included the study of a deep well (2800 m), producing 90°C water, which consequently has supplied a large greenhouse complex with thermal energy.

In 2015-2016, prospecting and deep exploration drilling for geothermal energy at the Zharkunak site in the Zharkent basin was carried out for the purpose of assessing whether sufficient geothermal reserves for direct use existed in the area (The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, 2016). This project was successful and hot water from 2 – 3 wells is now used for space heating, hot water supply, greenhouse heating, fish-farming and other needs.

2.3 Overview of potential geothermal resources

Kazakhstan is believed to possess considerable low-temperature geothermal resources, as already mentioned. These are mainly of the sedimentary type (see Chapter 2). This belief is based on knowledge provided by deep wells, which have mainly been drilled as petroleum and/or gas wells in sedimentary environments. Some of these have yielded hot water because of permeable sedimentary layers at great depth, where temperature is sufficiently high by virtue of the geothermal gradient in the region. Some surface manifestations (hot springs) also exist in the country. This belief is also supported by clear parallels between geological conditions (deep sedimentary basins) in parts of Kazakhstan and the geological conditions of sedimentary basins in other parts of the world with extensive low-temperature geothermal utilization, e.g. in Eastern Europe and in China.

Fifteen sedimentary basins in Kazakhstan that have been identified as bearing hydrocarbon resources, or prospects thereof, are presented in Figure 4. These are also expected to hold geothermal resources, due to their nature, to a variable extent. The sedimentary basins that are believed to contain the greatest potential for geothermal resource utilization are: Mangyshiak and Ustyurt-Buzashin basins in the southwest, Syrdaria Basin in the south and the Ily Basin in the southeast. Figure 5, which presents a geothermal atlas for Kazakhstan, provides more information on inferred geothermal resources of the country. Generally, the resource formations are either composed of sandstone or carbonate rocks, which are quite different in nature, as is described in section 2.2.

In this report the focus is on the geothermal potential of the Ily Basin, which is subdivided into the Almaty sub-basin (West-Ily) and Zharkent sub-basin (East Ily) [A]. The focus is particularly on the Zharkent sub-basin, in accordance with the agreement between GoK and the Consultants/WB reached during the October 2018 mission. A brief review of the Airys sub-basin of the Syrdaria basin is also presented. More detailed information on these areas is presented in Chapter 4 below, while general information for Kazakhstan as a whole is presented in the present chapter.

According to the Ministry of Industry and New Technologies of the Republic of Kazakhstan, there are six major geothermal areas that have been explored near the cities of Shymkent and Kyzylorda, in the northern part of Kyzyl Kum desert, near Almaty, as well as on the Ustyrt plateau on the coast of the Caspian Sea. Thus, regions in South Kazakhstan are strongly believed to have favourable conditions for the development of geothermal energy (Uyzbayeva, 2015).

In the review report from 2016, already mentioned, previous studies on thermal springs and geothermal potential in Kazakhstan are listed (KazEnergy Association, 2015). Data on geothermal resources is generally obtained from wells drilled in the process of oil and gas prospecting, as already mentioned. From research done in the late 1960’s and early 1970´s it became clear that the areas holding the most potential for geothermal included the Arys and Ily basins, and since then most of the effort has been towards estimating the potential of these resources.

Other types of geothermal systems are found in Kazakhstan, apart from the sedimentary ones. These include fracture controlled geothermal systems where heat transfer is through convection from great depth (some km), in near-vertical fractures in tectonically active areas (see Chapter 2). These have not been studied during the present work as the sedimentary resources are believed to be much greater in comparison, due to the vast areal extent of the sedimentary basins. Fracture controlled systems are e.g. believed to exist in the tectonically active areas of South and SE-Kazakhstan. Well known examples (including hot springs) are e.g. found in mountainous regions on the boundaries of the Almaty sub-basin, especially to the east and southeast (~30 hot springs). These are utilized to some extent in spas and resorts. Another type is the high-temperature (>200°C) volcanic geothermal system where the heat source is magma intrusions at great depth. Such systems have not been discovered yet in Kazakhstan.

Figure 4 – The main deep sedimentary basins of Kazakhstan classified on basis of their hydrocarbon exploration/exploitation status based on (KazEnergy Association, 2015)

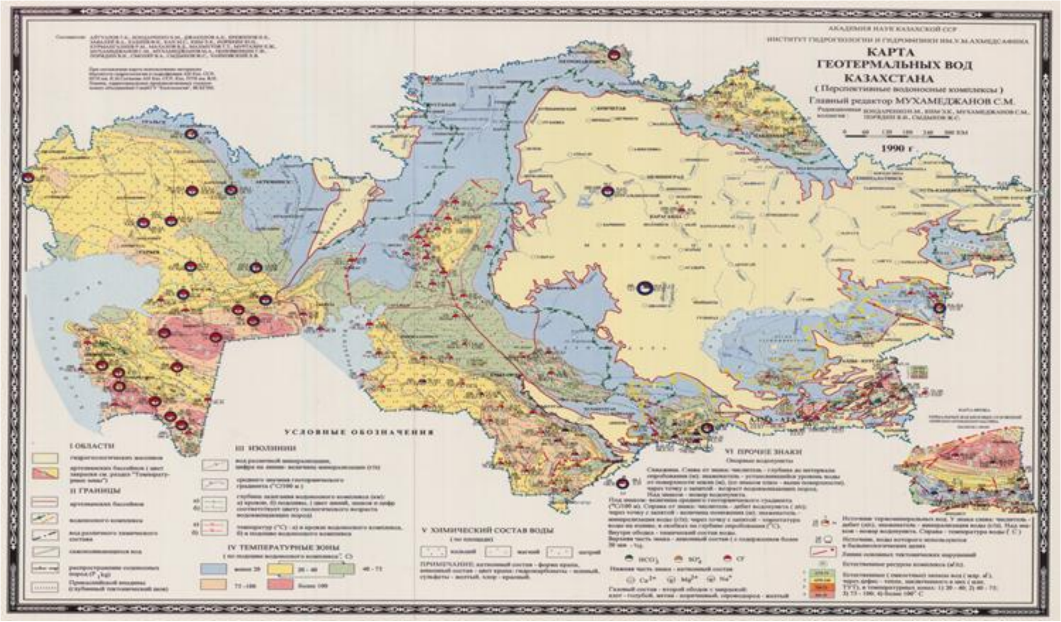

Figure 5 – Geothermal atlas of Kazakhstan [A].

2.4 Previous estimates of geothermal potential

Some assessments of the potential of different parts of the sedimentary geothermal resources of Kazakhstan exist in the local literature (see some of the documents listed in Appendix A). These mainly use the volumetric assessment method (see Chapter 2.4), or variants thereof. These show variable results, which are difficult to discern but most likely result from a variability in basic parameters such as surface area and thickness (hence volume) as well as temperature conditions and recovery factor. Evaluating these assessments is beyond the scope of the present study. All these assessments demonstrate great production potential for the main sedimentary basins of the country, even though the results are variable. In addition, some assessments have been made on the basis of well discharge data, adding to the volumetric assessment results, including well assessments presented by (The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, 2016).

The most comprehensive, country-wide assessment available is the one presented by (Boguslavsky, 1999). Their work presents an estimate of thermal energy in place in the sedimentary layers of 12 of the 15 sedimentary basins of Kazakhstan, up to as much as 5,000 m depth (depending on basin). They estimate the energy content for different temperature ranges. Boguslavsky et al., furthermore, present their results as energy per km^2.

Table 2 presents the results of (Boguslavsky, 1999) with the estimates for resource temperature above 40°C summed up, in the table’s second column (energy density). The Consultants have taken the results of (Boguslavsky, 1999) further to estimate extractable energy per km^2. In doing this we have assumed a recovery factor of only 1%, as only a small part of the total thickness will constitute permeable reservoir layers and only a small fraction of the energy in these particular layers will be extractable. The table also shows the Consultant’s estimate for the total extractable energy for the 12 basins (area x extractable energy per km^2) and the corresponding value per year.

Table 2 – Estimates of energy content in sedimentary basins of Kazakhstan for the resource temperature range above 40°C according to (Boguslavsky, 1999), along with further estimates done as part of the present study.[2]

Basin	Energy density PJ/km^2	Extractable per km^2 and year TJ/km^2/yr	Area km^2	Total extr. energy EJ	Extractable per year PJ/yr
Prikaspiy	184	18	380 000	690	6 900
Ustyurt-Buzashin	475	48	85 000	410	4 100
Manguyshiak	509	51	59 000	300	3 000
Aral	264	26	61 000	160	1 600
Syr-Daria	86	8.6	135 000	120	1 200
S-Torgay	68	6.8	86 000	59	590
N-Torgay	-	-	188 000	-	-
N-Kazakhstan	-	-	60 000	-	-
Teniz	-	-	61 000	-	-
Shu-Sarysuy	213	21	185 000	390	3 900
W-Ily	382	38	(19 000)	(71)	(710)
E-Ily	577	58	(19 000)	(110)	(1 100)
Balkhash	26	2.6	91 000	24	240
Alakol	56	5.6	31 000	18	180
Zaisan	54	5.4	28 000	15	150
Priirtysh	155	16	101 000	160	1 600

The results in the table demonstrate the following:

- The greatest extractable energy per km^2 is estimated for the Ustyurt-Buzashin and Manguyshiak basins in SW-Kazakhstan and in the W-Ily (Almaty) and E-Ily (Zharkent) basins in SE-Kazakhstan. This is mainly due to the likely existence of higher temperature resources in these basins relative to the other basins.
- The Ustyurt-Buzashin and Manguyshiak basins are also amongst the basins with the greatest extractable energy per basin, by virtue of their relatively great surface area. In addition the table shows that the Prikaspiy basins in NE-Kazakstan and the Shu-Sarysuy in S-Kazakhstan are also amongst the basins with the greatest extractable energy per basin, simply because of the great surface area of these basins.

Here it should be noted that basins with high extractable energy density (per km^2) are generally the most interesting concerning geothermal potential, as they should require less wide-spread production well drilling.

Even though the focus of this study was on the geothermal resources of SE-Kazakstan, information was provided verbally (during final work-shop) on two regions with promising potential, where some utilization has been ongoing in the past and interest exists in reviving and expanding the utilization. These are firstly in the Ustyurt-Buzashin basin in SW-Kazakhstan where petroleum exploration wells have demonstrated resource temperature as high as 150 – 160°C at 4 – 5 km depth. Secondly, resources exist in the Prikaspiy basin in NE-Kazakhstan where some wells were drilled to

---

[2] *Boguslavsky's results are presented as energy density (column 2). Also shown are the estimated extractable energy per km^2 estimated in this work assuming 1% recovery and a 100 year utilization period (column 3). Column 4 shows the estimated surface area of a few of the most significant sedimentary basins and column 5 the estimated total extractable energy for the same basins. Finally, column 5 shows the estimated extractable energy per year for the same basins. Note that EJ = 10^{18} J, PJ = 10^{15} J and TJ = 10^{12} J. Note that numbers in parenthesis are uncertain estimates.*

approximately 1.5 km depth in the 1970's. Many of these wells have been utilized, yielding water at a temperature of 40°C approximately.

2.5 Conclusions on status of exploration

Kazakhstan holds considerable geothermal resources, only assessed to a limited extent, mainly in some of its fifteen deep sedimentary basins. This is confirmed by wells drilled, mainly as petroleum exploration wells, which have intersected permeable structures yielding hot water. This is also supported by similarities with geothermal conditions in other countries where sedimentary geothermal resources are utilized on a large scale, such as in France, Germany, Hungary and China, to name a few well-known examples.

Considerable research has been conducted to assess the likely energy production potential of these sedimentary resources, even though such research has not been extensive during the last 2 – 3 decades. Information made available for this study demonstrating the potential, has to some extent been fragmented, incomplete and not always consistent[3]. Comprehensive data related to the geothermal resources exists in the archives of Kazakhstan and should be compiled, data both from wells having hydrothermal indications, as well as surface exploration data.

Further analysis of a countrywide assessment by (Boguslavsky, 1999), which is considered reliable, has been further expanded in this study to estimate extractable energy density (TJ/km^2/yr) and yearly extractable energy per basin for four of the most significant basins. The most concentrated potential is estimated to be in the Ustyurt-Buzashin and Manguyshiak basins in SW-Kazakhstan and in the W-Ily (Almaty) and E-Ily (Zharkent) basins in SE-Kazakhstan. The first two are also amongst the basins with the greatest extractable energy per basin, by virtue of their relatively great surface area.

The following chapter provides more information on geothermal resources in south and SE-Kazakhstan. These are the Arys, Almaty and Zharkent sub- basins; the first two are discussed relatively briefly, having been selected because of favourable market conditions, while the greatest emphasis is placed on the Zharkent sub-basin. Recommendations concerning the development of other promising basins, including Ustyurt-Buzashin and Mangyshlak, are provided in Sections 6 and 7.

---

[3] This may likely be attributed to some extent to translation problems.

3 Sedimentary Geothermal Resources in South and SE-Kazakhstan

3.1 Overview

Geothermal resources with promising potential have been identified in the southern parts of Kazakhstan. They are hosted in sedimentary basins and include Arys sub-basin in Syr-Daria basin in S-Kazakhstan and Ily basin which hosts Almaty and Zharkent sub-basins in SE-Kasakhstan.

The sedimentary formations of the Ily-basin are generally of Mesozic to Cenozioc age and composed of sequences of sandstone with minor interlayers of carbonate rocks (Kan, 2017). The formations from Cretaceous and early Plaeogene are considered the best reservoir aquifers in the Ily basin (Almaty and Zharkent) where 40 – 165°C hot water may be expected to be produced from 1,200 – 4,600 m depth [A].

Wells are pressurized in some locations whereas others need to be pumped to be utilized. The salinity (dissolved chemical content) of geothermal fluids in Kazakhstan is highly variable; ranging from hypersaline brines with up to 200 000 mg/kg of dissolved solids to fairly dilute fluids with around 1,000 mg/kg of dissolved solids. The most benign geothermal fluids in Kazakhstan, in terms of chemical content, appear to be found in reservoirs of the Ily basin and its sub-basins, Almaty and Zharkent.

The geological setting and possible geothermal potential of each sub-basin will be discussed in the following chapters where an overview of the Arys and Almaty sub-basins is presented but most emphasis will be on the Zharkent sub-basin.

3.2 Arys sub-basin / Syr-Darya basin

The Arys river basin is a part of the Syrdaria (Syr-Darya) sedimentary basin (Figure 6). The Syr-Darya artesian basin is located in the northeast part of the Iranian Plate and is limited to the ridge of the Great Karatau, middle arcs of the Western Tien Shan and rises in the Central Kyzyl Kum [B].

One of the aspects that has given this area more relevance is the proximity of the geothermal resources to a large city, Shymkent, and the availability of potential users of the energy extracted.

Figure 6 – A map of the Syr-Darya basin and the Arys river in southern Kazakhstan[4].

In references available for this Study [A] the geothermal reservoirs of Syr-Darya basin are generally associated with aquifers in Cretacious formations, at 2,000 m depth. Estimated potential of geothermal water from the whole of Syr-Darya basin is 171 000 m^3/day of artesian flow and almost 5 million m^3/day with well pumping[5].

The Arys artesian basin is confined to the southeast part of the Syr-Darya depression. The reservoir within the Arys basin is characterized as being up to 90°C, and hot water from flowing wells has been measured at 75°C. Current commercial production of geothermal water from the Arys basin amounts to 17 300 m^3/day [A]. Some of the wells are high flowing artesian wells, up to 35 l/s but no information has been found on the depth of these wells.

Figure 7 presents a part of a geothermal map of Kazakhstan and shows the location of the Arys artesian sub-basin, presented by boundaries of temperature at the bottom of the artesian layer as well as isotherms and depth of the aquifer system (Kasymbekov, 2006). The map also shows the location of wells and various data from measurements such as geothermal gradient. An overview of available data from wells in Arys sub-basin, is presented in Table 3 and in Figure 8. Temperature measured at well head, varies from 26 to 75°C, and the fluid contains low concentration of total dissolved solids, generally from 400 to 1200 mg/l. There is general consensus that geothermal resources in the Arys sub-basin are suitable for direct use, such as house heating, other direct use and industrial use, as well as through the application of heat pumps [B].

---

[4] from Wikipedia

[5] These numbers are quoted here directly, without having been verified. They may not be fully comparable between different regions.

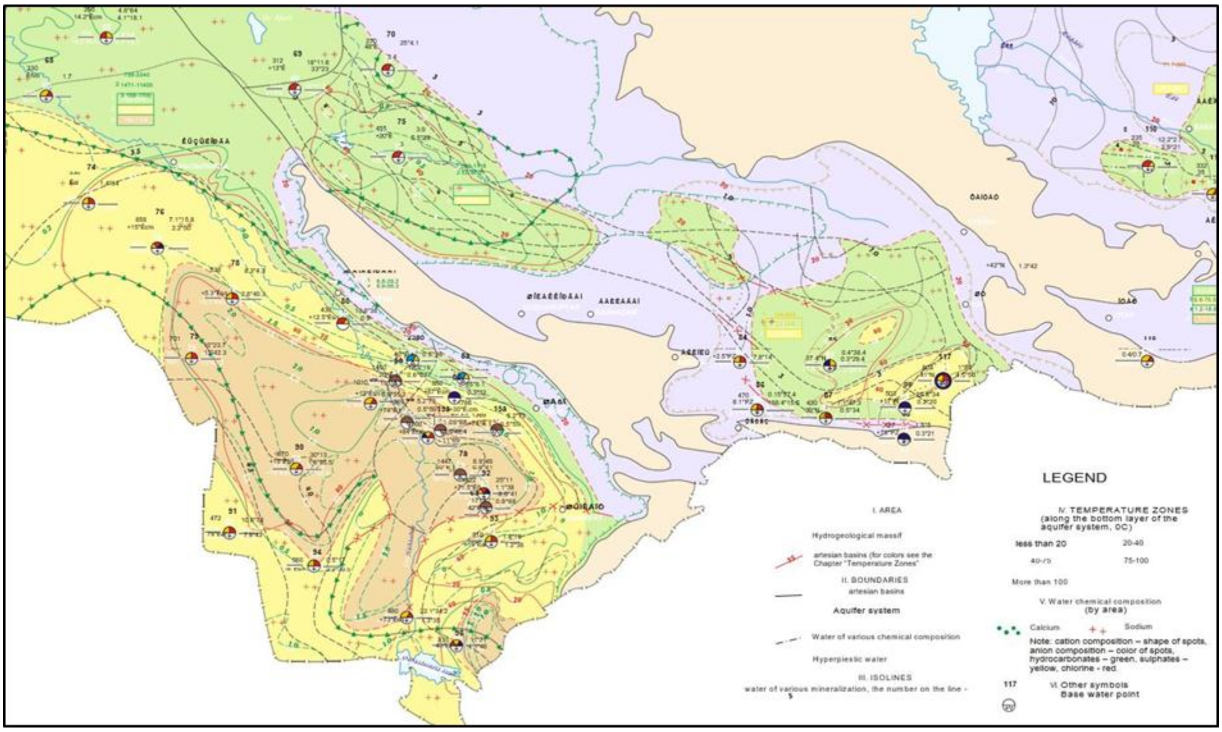

Figure 7 – Geothermal artesian basin boundaries within Arys sub-basin in SE-Kazakhstan (Source: (Kasymbekov, 2006))

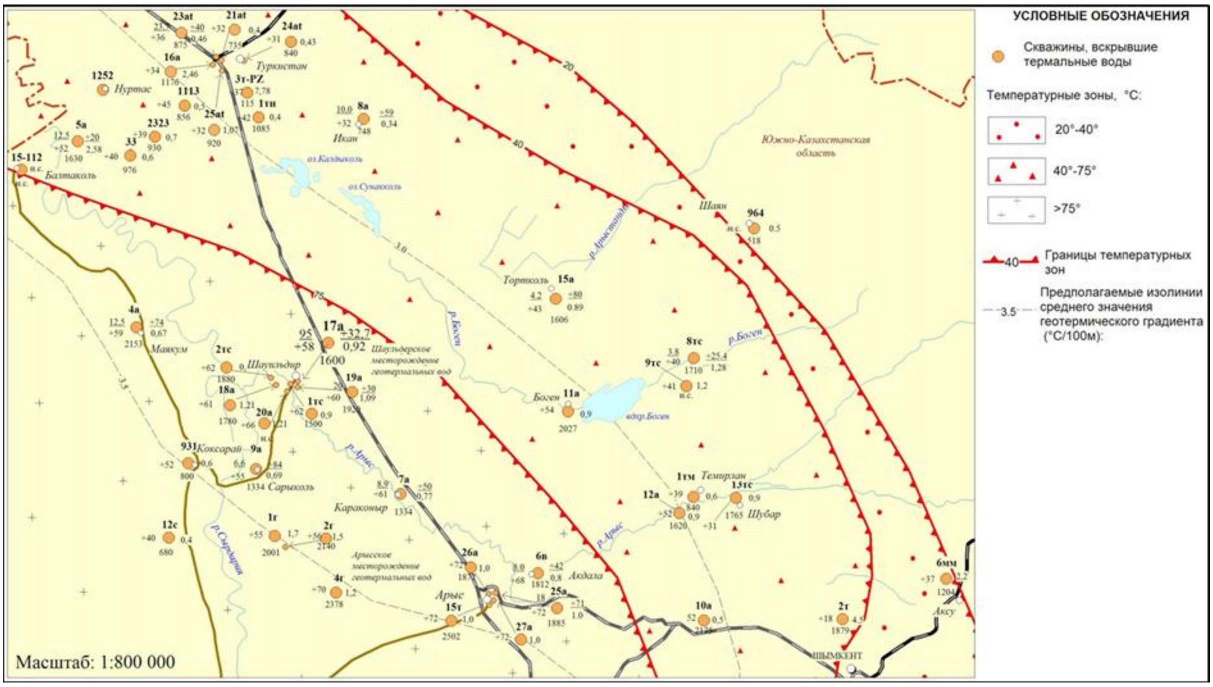

Figure 8 – Location of wells with geothermal indications/potential in the area of Arys sub-basin, S-Kazakhstan [E].

Table 3 – Information on production/potential of geothermal water from selected wells in the Arys sub-basin.

Well name or number	Temperature at well head (°C)	Artesian flow (l/s)	Total Dissolved Solids (mg/l)
13к (контр) 12а			983
15а	36.6		888
15т			1345
16а	37.0	17.2	456
17а	59.0	22,2/1918 m3 a day	919
18а	68.0	1494.0	1213
19а	62.8	33,3/2877 m3 a day	1090
1ТС	63.0	12.7	1211
20а	62.9	1564 m3 a day	1212
21ат	30.9	35.0	429
23а	35.0	35.0	474
23ат	30.1		460
24ат	26.3		433
25а	44.9	18.0	436
25ат			1068
26а	65.6	25.0	1117
27а	72-75	25.0	1000
2ТС	68.0	17.3	1117
4а	54.0		669
5а	49.2		582
6в	72.2	8.0	801
7а	55,7/52,1	8.9	770
8а	29.8		342
8тс	38.3		1283
9а	56.0		686

Note that temperatures as high as 85°C have been recorded in other wells not listed in the table above.

3.3 Almaty sedimentary sub-basin

The Almaty sub-basin occupies the western part of the Ily basin. The Ily basin is located between the mountain ridges of Tien Shan and Dzungarian Ala Tau and includes two promising artesian sub-basins Almaty and Zharkent, with geothermal aquifers within formations of Cenozoic age.

Figure 9 shows a part of a geothermal map from (Kasymbekov, 2006) showing temperature zones and location of wells for Ily basin. The map outlines NE direction of the temperature increase within the basin, from Almaty in SW to Zharkent in NE.

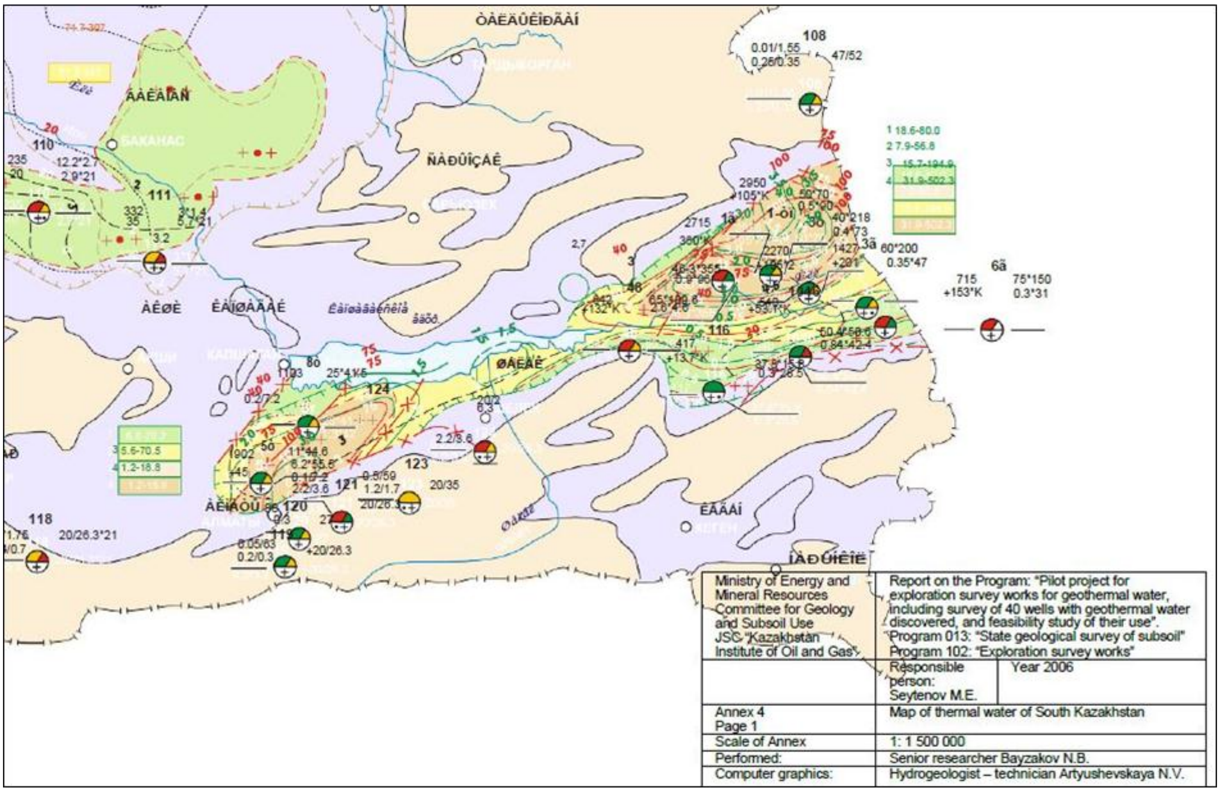

Figure 9 – Geothermal artesian basin boundaries within Almaty and Zharkent basins in SE-Kazakhstan (source: (Kasymbekov, 2006))

Several deep wells have been drilled within the Almaty sedimentary basin and some of them are listed in Table 4 with attributes such as depth and temperature of water at well head. The location of some of the wells listed in the table is presented in Figure 10 along with the area where temperatures higher than 75°C have been measured.

Geothermal water from aquifers at the depth of 7-800 m are measured up to 40°C but water from aquifers at 2 600 to 3 000 m depth reaches 84°C, at well head [A].

Flow rates from artesian wells in the Almaty basin ranges from 10–500 to 800–2200 m3/day, from 0.1 to 25 L/s from each well. The water generally contains a low concentration of TDS, from 500 to 15 000 mg/l. In a few locations a more concentrated brine is produced, where the concentration of TDS is up to 120 000 g/l. The estimated reservoir capacity within the Almaty basin is 62 000 m^3/day with well pumping[6]. The water is from sulphate-chloride to chloride-sodium in composition [A].

---

[6] See footnote 5

Table 4 – Information production/potential of geothermal water from selected wells in the Almaty sub-basin.

Well name or number	Well depth (m)	Temperature at well head (°C)	Artesian flow (l/s)	Total Dissolved Solids (mg/l)
1/78				2356
1/83	2430 m	45.0	5.5	600-700
14/78				53900
14/86		42.0	2.0	2400
17/87	2500 m	45-50	20.0	115000-120000
2/80	2400 m	52.0	10.3	5664
2/83	1850 m	34.5	6.2	661
23/89	2400 m	50.0	3.0	562
3/82	2400 m	55.0	7.7	6819
3-T		60.0	12.0	14274
5-T	2200 m	45.5	6.2	6179
8/85	2320 m	55.0	2.8	580
8-T		42.0	25.0	1076

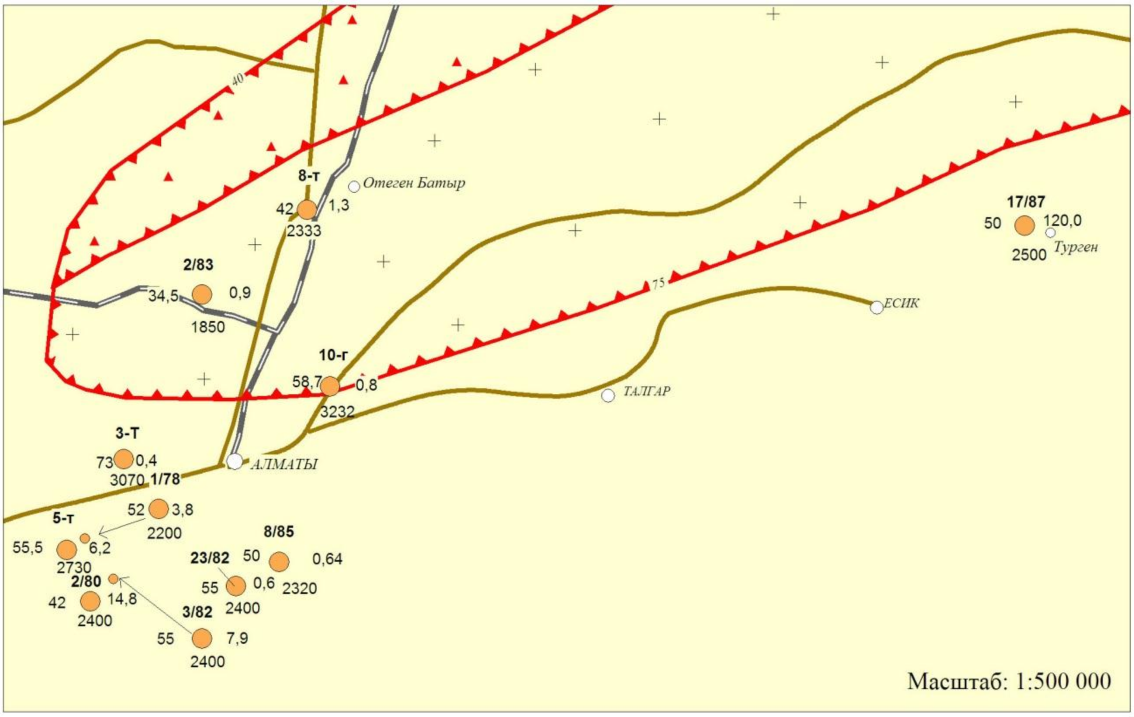

Figure 10 – Location of wells with geothermal indications/potential in the area of Almaty basin, SE Kazakhstan [E].[7]

3.4 Zharkent sedimentary basin

Information on the geological characteristics of the Zharkent basin is found is some detail in a report from 2016 (The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, 2016). The

---

[7] Legend: see Figure 8

geological formations of different ages are described based on the wells that have been drilled for oil prospecting and more recently for geothermal exploration.

The early formations of the Zharkent sub-basin are from the mid-Lower Permian time, which was marked by an active tectonic period. Throughout Mesozoic and early Cenozoic the processes involved generally active sedimentary upload, forming the Zharkent (Ily) basin. Formations ranging from Triassic to Neogene in age are composed of a range of various lithological sediments, generally being described as sandstone. Sandstone with siltstone and conglomerate layers are dominant formations in the basin and formations of limestone of Cretaceous age are found in deep wells in the southern part of Zharkent basin (The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, 2016).

Hydrogeological conditions in the central and north part of the Zharkent sub-basin are characterized by more complex geological conditions than in the southern (left bank of Ily). This includes a Paleozoic basement, network of tectonic fractures, deep occurrence of Mesozoic sediments and Mesozoic to Cenozoic cover (Kan, 2017).

3.4.1 Geothermal conditions

In the Zharkent basin geothermal waters were encountered in deposits of Neogene, Palaeogene, Cretaceous, Triassic and Jurassic complexes, see Figure 9. Geothermal waters in the Cretaceous complex are the most promising and widespread in the basin and estimated temperature at the bottom of thermal aquifer systems, depending on the depth varies between 40–75 and 155–165°C (Kasymbekov, 2006). Potential natural reserves of geothermal waters in the Zharkent basin are estimated at 216 billion m^3 but the commercial reserves of thermal waters at two sites (Ily and Usemskiy) in the central part of the basin were estimated at 4500 m^3/day[8].

In 2006, in the southern and south-eastern parts of the country (Arys, Almaty and Zharkent sub-basins), 40 wells were inspected, and feasibility studies were drawn up. These feasibility studies identified the areas of prospecting and exploratory works, the Zharkent basin being one of the more promising sites (Kasymbekov, 2006). Further exploration was conducted in the Zharkent sub-basin, at the Zharkunak site, in 2008 where exploitable geothermal reserves were assessed [E]. Subsequently, three deep geothermal exploration wells were drilled during 2015-2016, bringing the number of geothermal wells drilled in the Zharkent sub-basin up to a total of 11 wells, drilled for the purpose of assessing whether sufficient geothermal reserves for direct use existed in the area (The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, 2016).

As a whole, in the Zharkent sub-basin, geothermal water is found, or expected to be found, at depths ranging from 250-400 m at the foothills to 4,000 – 4,500 m in the central part, generally in connection with the upper boundaries of Cretacious formations (Figure 11). Well flow rates are from 120 to 12 000 m^3/day (1.4 – 140 L/s), the water mineralization varies from 1,000 – 15,000 mg/l, the water temperature at the well head is from 35 to 90 °C.

Figure 12, Figure 13 and Figure 14 show cross sections through Zharkent sedimentary basin, showing the geological formations, thermal gradient, wells penetrating as well as temperature isotherms based on temperature logging in the wells (The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, 2016).

In the central part of the Zharkent artesian basin, thermal aquifer systems were encountered at a depth of 1400-2900 m [A]. The water found is of high-pressure, with piezometric levels measured at 70-240 m above the surface and artesian well flow 1,900 – 5,200 m^3/day. Water mineralization is less

---

[88] See footnote 5

than 1,000 mg/l, with hydrocarbonate-sulphate and chloride-hydrocarbonate sodium composition [A]. Here the temperature at well head has been measured 100 – 120°C from the most submerged parts of the Zharkent depression. The estimated potential of the geothermal reservoir in the central part of Zharkent basin is about 51 000 m^3/day[9]. In comparison utilization of the thermal water in two areas taken as examples have combined approved operational commercial reserves of 4500 m^3/day.

In the southern part of Zharkent artesian basin the Triassic and Jurassic geothermal aquifer systems are yielding between 110 and 4700 m^3/day (1.3 – 55 L/s) from each well. The water is low in TDS content, about 1,000-3,000 mg/l. The "Karadala hot springs" are located in this part of the basin, where up to 60°C hot water is being produced from 650 m depth. The balneological site utilizes artesian wells that yield up to 12 000 m^3/day (139 L/s) and the water mineralization varies from 3 000 mg/l to 15 000 mg/l [A].

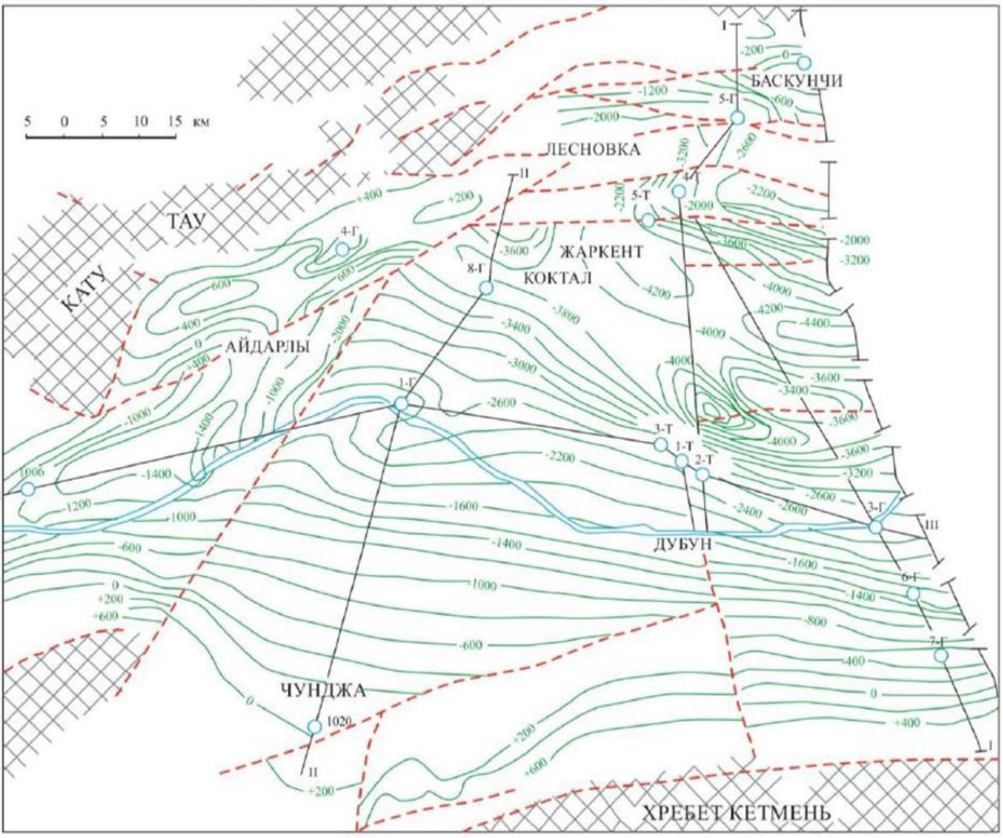

Figure 11 – Structural map of the Zharkent basin[10]

---

[9] See footnote 5

[10] The green lines represent the depth of the roof of Cretaceous formations. Source: (The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, 2016)

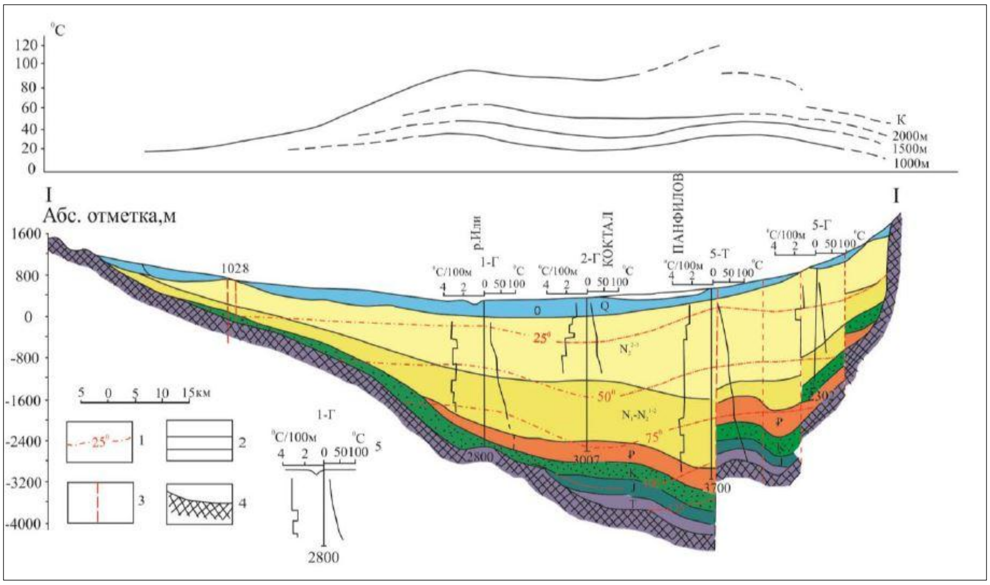

Figure 12 – Zharkent sedimentary basin. Cross section along line I from Figure 11. [11]

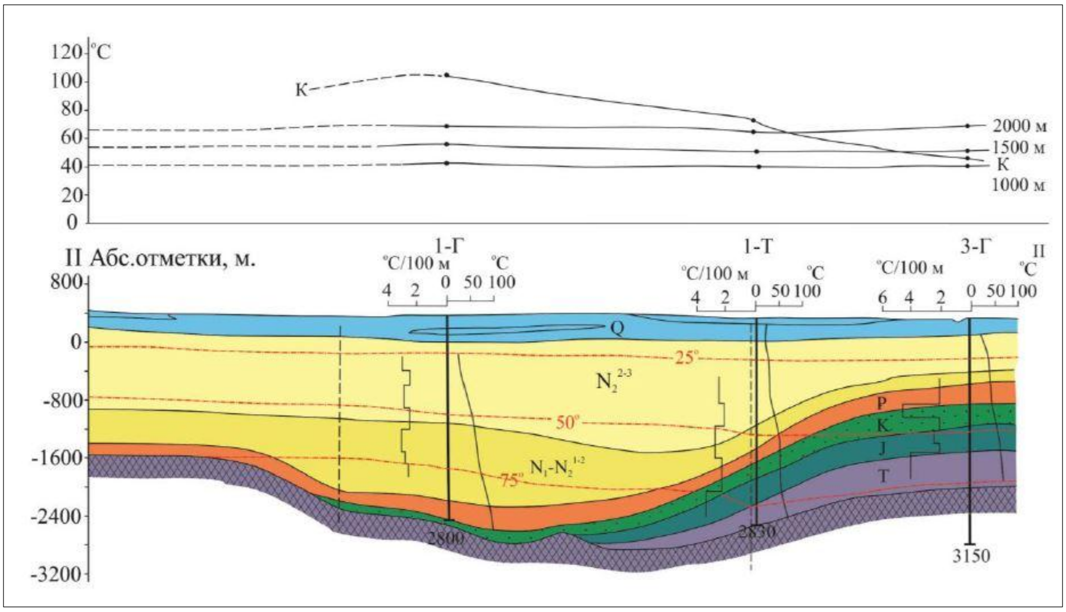

Figure 13 – Zharkent sedimentary basin. Cross section along line II from Figure 11. [12]

---

[11] Legend: 1 - temperature contour; 2-Cretaceous aquifer; 3-line tectonic disruption; 4 Paleozoic basement; 5-well, top number, bottom-depth, m; the left is a diagram of the values of geothermal gradients; right thermogram [19].

[12] Legend: See Figure 12

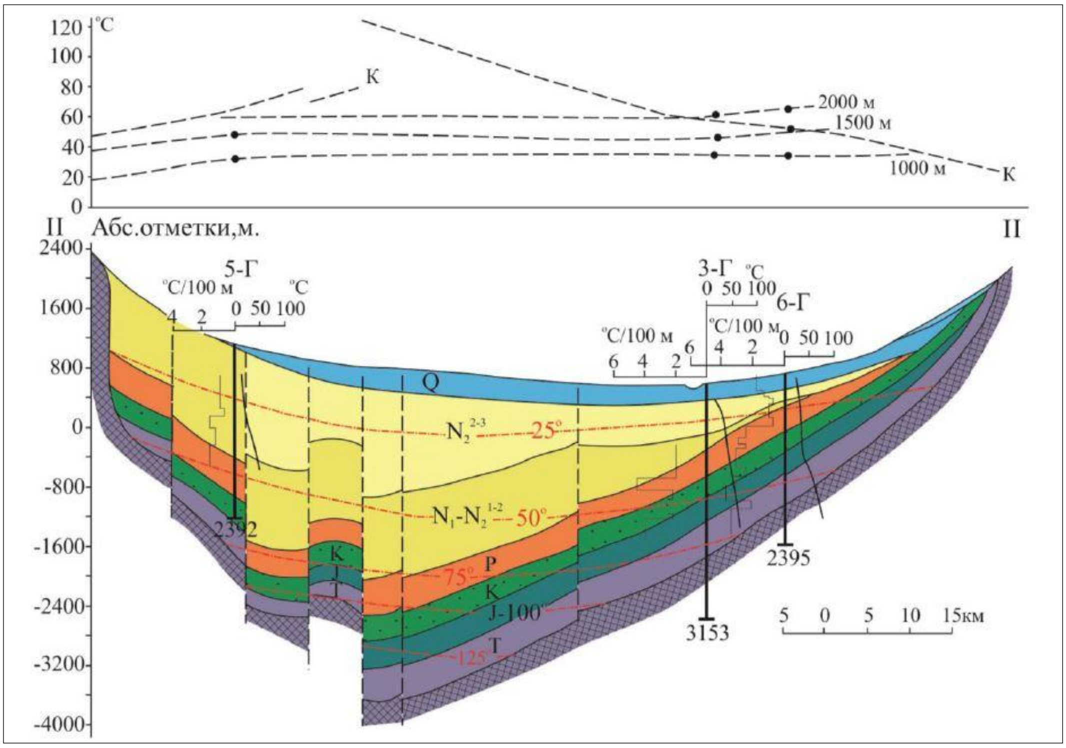

Figure 14 – Zharkent sedimentary basin. Cross section along line II from Figure 11[13]

Geothermal conditions in the Zharkent sub-basin are in several ways quite favourable, as compared to other sedimentary resources, both in Kazakhstan as such and worldwide. The reservoir formations discovered reaching great depth outcrop at the surface in mountainous regions on the margins of the sub-basin (see cross sections above). Thus, the formations are provided with substantial recharge through precipitation. This recharge is also demonstrated by high well-head pressure and artesian flow. The information provided during the site-visit to the Zharkent sub-basin during this Study also indicated that this well-head pressure and artesian flow had not declined with time as far as the limited available information indicates, which is normally expected however.

3.4.2 Information on deep wells drilled

Out of 11 deep geothermal wells drilled in the Zharkent basin, four wells (1-G, 1-TP, 2-TP and 3-T) found geothermal water at 2 800 m to 3 200 m depth; their flow rates are from 11 to 50 l/s with pressure head from +195 to +360 m and the water temperature of up to 103°C [B]. Figure 15 shows the location of geothermal wells within the Zharkent basin, some of which are listed in

---

[13] Legend: See Figure 12

Table 5. The wells where temperature is higher than 60°C are located in the central basin where depth to the aquifer formations is greatest and therefore temperatures highest. Other wells show lower temperatures, but the depth of the wells has not been made available.

Hot water from at least 3 wells in the Zharkent basin is now used for space heating, hot water supply, greenhouse heating, fish-farming and other needs in the Zharkent basin.

Table 5 – Information on production/potential of geothermal water from selected wells in the Zharkent basin.

Well name or number	Well depth (m)	Temperature at well head (°C)	Artesian flow (l/s)	Total Dissolved Solids (mg/l)
1046		42.4	5.4	800
11a		47.2		3030
1478		28,2/38,9	43,5	482
1598		35.2		1216
1Г				
1-РТ	2885 m	98.0	24.2	975-1323
1-Т	2830 m	74.0	17.4	2600
1-ТП	3000 m	83.2	4500 m3 a day	589
2-Т		31.0	1.0	500
2-ТП	2953 m	87.2	1900 m3 a day	587
3-Т	3200 m	65.3	30.0	412
48		46.0	65.0	
5539	2850 m	103.0	50.5	1000
963		39.7		450
963a		31,5/35,0	49.5	

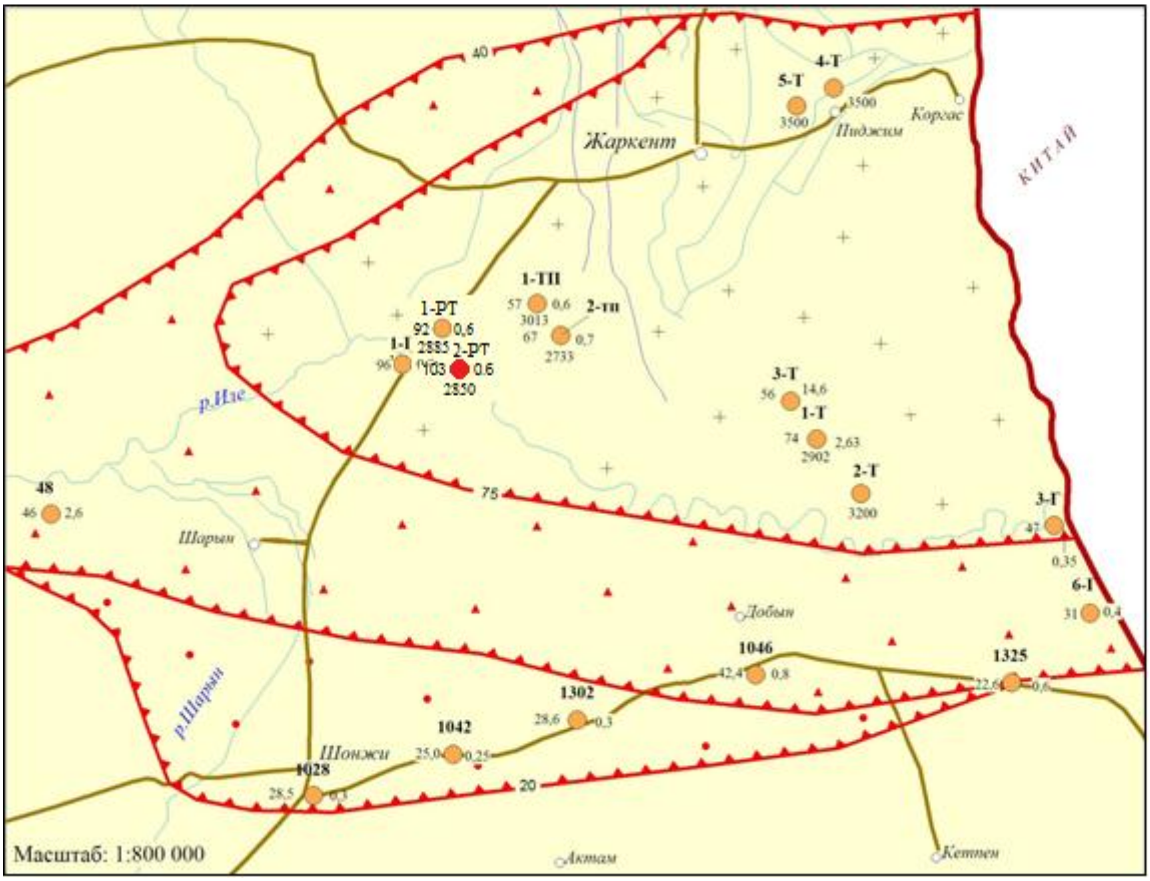

Figure 15 – Location of potential geothermal wells in the area of Zharkent basin, SE Kazakhstan [E].[14]

---

[14] Legend: see Figure 8.

3.4.3 Temperature conditions

The Zharkent basin geothermal reservoir has potentially some of the highest recorded temperature of geothermal water in Kazakhstan, with well-head temperature ranging from 30-103°C. The temperature at reservoir depth is estimated as high as 165°C at depth [B]. Generally, the geothermal gradient in Kazakhstan is expected to be in the normal continental range of 25 – 30 °C/km, while in the Zharkent sub-basin existing well data points to somewhat higher gradient values, as will be discussed below, and hence higher reservoir temperatures at comparable depth in other parts of Kazakhstan. This is likely to be caused by tectonic activity, crustal thinning and other geological processes.

Figure 16 and Figure 17 show examples of temperature logs from wells in the Zharkent sub-basin and diagrams of geothermal gradient plotted with depth. They show that the temperature gradient is as high as 40°C/km, or even higher, in some depth intervals. In addition, a maximum temperature of about 100°C is observed at about 2 700 m depth in well 1-Г and at about 3 900 m depth in well 5-T.

These results correlate with the mapped depth of deeper Cretaceous formations shown in Figure 11. The thermal gradient estimated for well 5-T, which is located in the northern part of the sub-basin, furthermore shows a sharp increase at the depth of about 3,300 m where Paleogene formations are overlying Cretaceous formation.

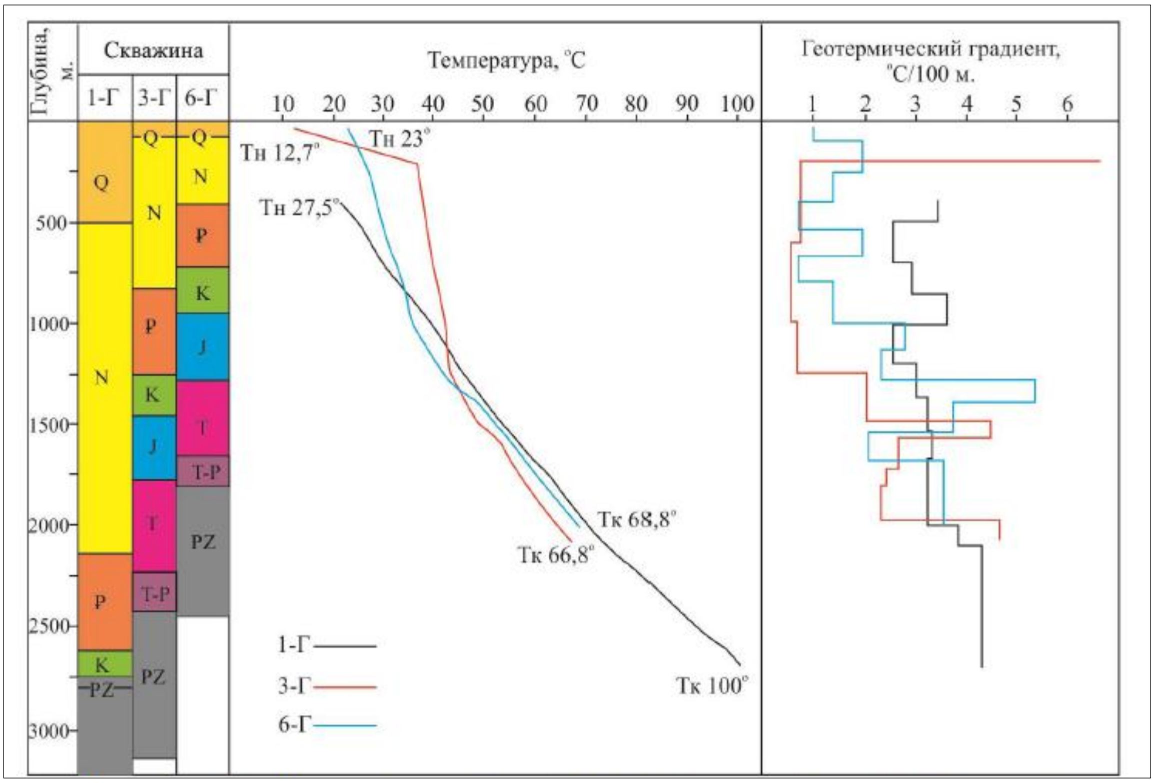

Figure 16 – Temperature logging results and estimated geothermal gradient (°C/100m) for wells 1-Г (1-G), 3-Г (3-G) and 6-Г (6-G) in the Zharkent sub-basin (source: (The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, 2016))

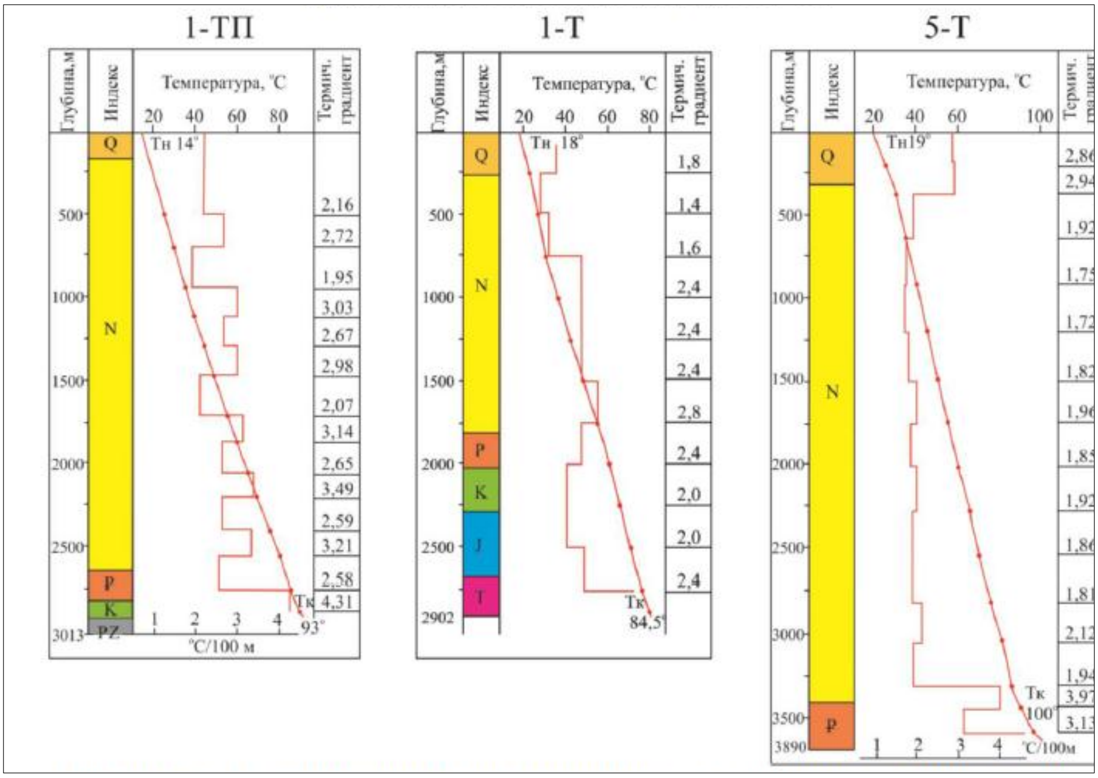

Figure 17 – Temperature logging results and estimated geothermal gradient (°C/100m) for wells 1-ТП (1-TP), 1-T and 5-T in the Zharkent sub-basin (source: (The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, 2016))

Figure 18 presents the results of a simple analysis of temperature conditions in the Almaty and Zharkent sub-basins performed by the Consultants. The figure shows well-head temperature of several productive geothermal wells in these sub-basins plotted as a function of well-depth. Even though well-head temperature is usually somewhat lower than reservoir temperature, the figure demonstrates clearly the higher resource temperatures found in Zharkent. These are partly caused by deeper wells and partly by higher temperature gradient.

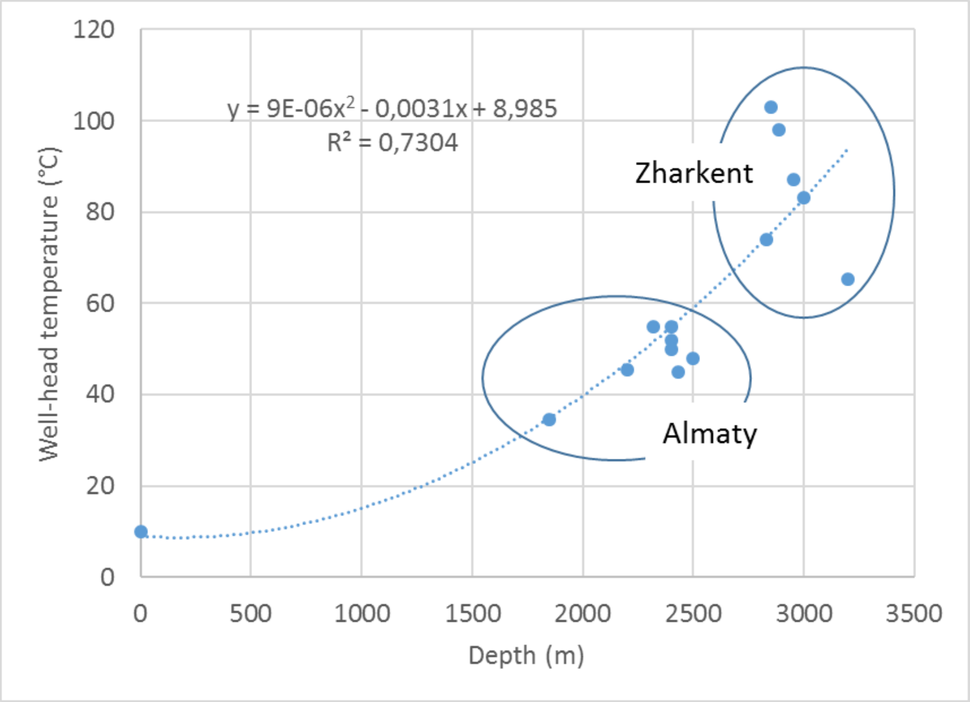

Figure 18 – A view of temperature conditions of wells in the Zharkent sub-basin presented by plotting well-head temperature as a function of well depth.[15]

3.4.4 Simple resource capacity assessment

---

[15] Note that well-head temperature is considerably lower than resource temperature and that the inflow into the wells may not always be at their bottom.

Table 2 presents estimates of the extractable energy, both per km^2 and per basin, as well as per year assuming a 100-year utilization period, for all the main basins of Kazakhstan, including the Zharkent sub-basin. As these constitute single values for the whole sub-basin, a more detailed assessment was performed by the Consultants by using the volumetric assessment method (see sub-chapter 2.3). The results are presented in Figure 19 where the extractable energy per km^2 is presented as a function of reservoir temperature, which in turn depends on depth and local temperature gradient. The following key parameters were used:

- Reservoir thickness = 500 m
- Energy recovery factor = 10%
- Utilization period = 50 years
- Reference temperature = 30°C

The results in the figure first indicate very clearly that great amounts of thermal energy should be extractable from the geothermal reservoirs in the Zharkent sub-basin, to be used for various direct applications (see later). The results in the figure can, furthermore, be used to estimate roughly how much energy should be extractable from a drilling area of a certain size (km^2). Based on an expected average flow-capacity of production wells drilled in the area, the number of production wells can consequently be estimated.

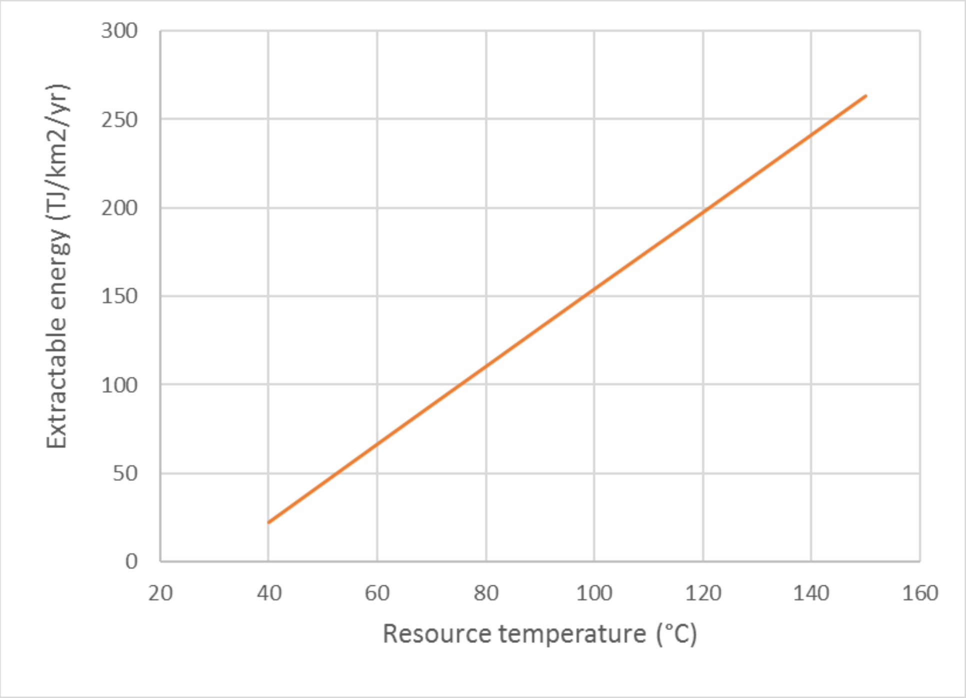

Figure 19 – Extractable thermal energy per km^2 presented as a function of reservoir temperature (which in turn depends on depth and local temperature gradient) estimated by the volumetric assessment method for the Zharkent sub-basin.

Considering the case studies presented in Chapter 6 the graph above can be used to estimate approximately the surface of the drilling area needed to sustain a certain utilization scheme.

As an example, the 2,360 TJ/year needed to heat the town of Zharkent would require a drilling area of about 15 km^2 (2,360 / 155), which is somewhat less than the area of the town. This estimate assumes a resource temperature of about 100°C.

Similar resource area can be calculated for 10 MW electrical plant, utilizing 125°C geothermal water. About 3,000 TJ/yr will be needed or an area about 14 km^2 (3,000 / 210), ref. to section 5.3.1.

3.5 Sustainable utilization and reinjection

Because of the closed nature of most sedimentary geothermal reservoirs, reinjection is essential for their sustainable use. Otherwise water-level in the reservoirs will decline continuously with time (see Chapter 2) and the hot water extraction can’t be maintained in the long-term. By now this has become accepted in most countries where sedimentary geothermal resources are utilized. In some countries local governments are increasingly imposing a policy of full reinjection in all sedimentary geothermal operations.

Reinjection is, of course, the perfect antidote to declining water-levels. It is, however, associated with some risks and challenges. The main risk is the possible cooling of near-by production wells, which mainly depends on the distance between injection and production wells, but also on whether the reinjected water finds preferential flow-paths instead of dispersing uniformly through the reservoir rocks. In sedimentary reservoirs, particularly sandstone ones, the reinjected water is expected to flow uniformly and thus the distance between wells can be shorter than in other types of geothermal systems. Once wells have been drilled, the most efficient way of assessing the danger of cooling of production wells due to reinjection is to perform so-called tracer tests and associated cooling modelling. Another risk is scaling in pipelines and injection wells (Axelsson G. , 2012). This depends entirely on the chemical and gas content of the geothermal fluid involved but is usually resolved through the use of inhibitors injected into production wells at depth, if needed. It should be pointed out, however, that reinjection may not be immediately necessary in all locations in the Zharkent sub-basin, because of the natural recharge, but will become so with time and increased geothermal development.

The main challenge associated with reinjection into sedimentary geothermal reservoirs is the clogging of the sandstone layers next to reinjection wells. If counteracting measures are not taken the reinjection wells clog up in a relatively short time (days – weeks), rendering the reinjection non-sustainable. A solution to this problem was developed in Germany/Denmark in the 1990’s. Sandstone reinjection has also been a major problem in China, to name an example. A Chinese version of the European solution is now successfully being adapted there. The solution involves the following main aspects:

A. The reinjection wells are drilled with significantly greater diameter than production wells, usually 50 – 100% greater.

B. At reservoir depth, a gravel pack is put in place between the well-liner and the sandstone formation.

C. Efficient two-stage filtering (often 50 µm and 5 µm) is employed at surface.

D. The whole piping system from production well to reinjection well is set up as a closed-loop system, which is kept oxygen-free by efficient sealing. In some cases, this is further supported by injecting N_2 gas into the pipe system at the production well.

Managing reinjection by incorporating all these aspects is not the rule; aspect A. is e.g. not always included, even though it’s certain to be highly beneficial, even resulting in a lower number of reinjection wells in operation.

3.6 Conclusion on potential of South and SE-Kazakhstan

Initially this Study was to bring special focus on the Ily Basin and its Almaty and Zharkent sub-basins. During the October 2018 site visit to Kazaksthan, greatest emphasis was placed on the Zharkent sub-basin, as an initial example or case study. It also became clear that there was also specific interest in the Arys sub-basin of the Syr-Daria Basin as well as the Almaty sub-basin, because of potential geothermal resources within, or near, heavily populated urban centres.

The Arys and Almaty sub-basins clearly hold extensive geothermal resources, albeit at relatively low temperature suitable for direct use, specifically space heating. Incomplete information indicates that well-head temperatures up to 75°C have been measured in producing wells in the Arys sub-basin and up to 85°C in the Almaty sub-basin. Corresponding reservoir temperatures are, of course, correspondingly higher. In the Arys sub-basin the geothermal water appears to contain relatively little dissolved solids (~1 g/L), while in the Almaty sub-basin the solid content appears to be much higher (up to ~15 g/L, or even higher). This warrant comprehensive further studies of both basins.

At the moment, the geothermal resources in the Zharkent sub-basin appear most interesting because of higher resource temperature than in e.g. the Arys and Almaty sub-basins, low concentration of dissolved solids and powerful natural recharge. It is therefore suitable for demonstration projects. The Zharkent geothermal resources were also the focus of a recent, comprehensive geothermal assessment study, during which 11 geothermal exploration wells had been drilled up to 2015 – 2016. Thus, more geothermal information/data is available for the Zharkent sub-basin, than for other locations in Kazakhstan. It should be pointed out, however, that even though the Zharkent basin appears most promising now, further research may locate other promising geothermal resources.

In addition to the relatively high resource temperature and low dissolved solids, geothermal conditions in the Zharkent sub-basin are in further ways favourable compared to other sedimentary resources in Kazakhstan and worldwide. The reservoir formations discovered reaching great depth outcrop at the surface in mountainous regions on the margins of the sub-basin and are provided with natural recharge through precipitation. This recharge is also demonstrated by high well-head pressure and artesian flow. Available information also indicates that this well-head pressure and artesian flow have not declined with time, which is generally the case in geothermal systems, sedimentary ones in particular.

The estimated extractable energy for the Zharkent basin is in the range of 20 to more than 160 TJ/km^2/yr, depending on resource temperature, and assuming a utilization period of 50 years. The significance of this regarding utilization are discussed in detail in later chapters, but hypothetically each km^2 could provide space heating for 200 to 1,600[16] inhabitants. The whole basin could similarly provide heat for roughly 1.5 million inhabitants (based on Table 2). These numbers should not be taken literally, however, they're only presented to demonstrate the potential.

Because of the closed nature of most sedimentary geothermal reservoirs, reinjection is essential for their sustainable use. Otherwise water-level in the reservoirs will decline continuously with time and the hot water extraction can't be maintained in the long-term. This may not be immediately necessary in all locations in the Zharkent sub-basin, because of the natural recharge, but will become so with time and increased geothermal development. It will certainly be required from the beginning of large-scale utilization in most other sedimentary geothermal resources in Kazakhstan.

Reinjection is associated with some risks and challenges, with the main risk being possible cooling of near-by production wells. The most efficient way of assessing the danger of cooling of production wells due to reinjection is to perform so-called tracer tests and associated cooling modelling. The main challenge associated with reinjection into sedimentary geothermal reservoirs is the clogging of sandstone layers next to reinjection wells. A solution to this problem was developed in Germany/Denmark in the 1990's. An updated version of the European solution is now successfully being adapted on a large scale in China, to name an example.

---

[16] Assuming that approximately 1 TJ/yr is sufficient heat for 10 individuals under conditions in Kazakhstan.

4 Geothermal utilization

The purpose of this section is to describe in general terms how geothermal resources can be utilised and the key factors impacting the feasibility of its utilization.

4.1 Geothermal utilisation possibilities

Geothermal energy is the thermal energy generated and stored in the Earth. Utilization of geothermal resources has been conducted for over 2,000 years.

Finding an adequate application for geothermal resources is not always a straightforward task since utilization possibilities will highly depend on various factors such as:

- The characteristics of the resource such as temperature, flow, chemistry and other parameters related to its sustainable utilization; and
- Economic considerations related amongst other things to the potential market for the product resulting from the resource exploitation or how easily available the resource is.

The utilization of geothermal energy depends highly on the resource temperature as is shown in below.

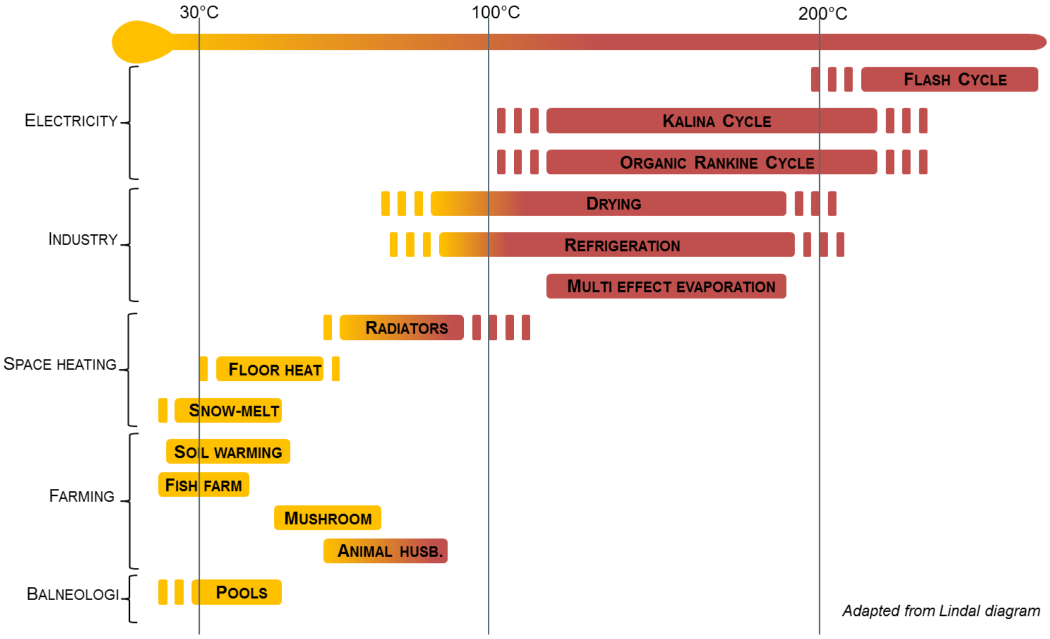

Figure 20 – Geothermal utilization (adapted from the Lindal diagram)

Geothermal resources can be roughly divided into two categories:

- Low temperature <150°C at the depth of 1 000 m; and
- High-temperature >200°C at 1 000 m.

Low temperature geothermal resources have been used for ages, originally for bathing and washing but more recently for space heating and farming applications.

The utilization of geothermal energy for commercial generation of electricity has only been practiced since the late 1950's. The technology for harnessing geothermal energy is now considered mature and nowadays geothermal energy offers competitive sources of renewable energy. As a result, the world's installed geothermal power capacity has increased over the past decade and is estimated to be over 14 GW_e in 2018[17]. Most of the geothermal power plants currently operated are in high temperature areas, where the temperature of the geothermal resource is higher than 220°C. However, the Organic Rankine Cycle, otherwise called ORC or binary, technology has in recent years been on the rise and is increasingly used to harness energy from geothermal resources at temperature below 200°C.

The following sections provide details on the potential utilization of low and medium temperature geothermal resources as expected to be exploitable in Kazakhstan and highlights a few practical points that must be considered when planning for a geothermal project.

4.2 Geothermal production

Irrespective of potential use, harnessing of a low and medium geothermal resource always entails drilling activities and installation of gathering and re-injection system. Drilling the first wells to reach the resource and confirm its utilization potential is always a critical step in geothermal project due to the many unknowns. Typical risks related to the uncertainty on the resource are i.a.: the capacity of the resource; whether it can easily be harnessed or not; and the cost of drilling. It is however possible to address such risk with careful and systematic exploration activities aiming at gaining confidence in the resource, its location and capacity.

A constant component of geothermal projects is the drilling of production and reinjection wells, together with the installation of equipment enabling to bring the geothermal fluid to the surface. This point of extraction is also commonly connected by piping to a potential user interface point and back to the reservoir, when heat has been extracted. Together this forms the geothermal loop. Typical components that form a geothermal loop are shown in Figure 21 below.

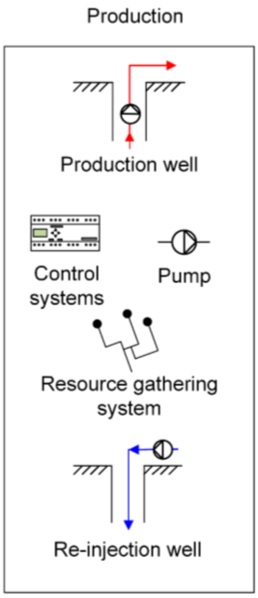

Figure 21 – Typical components for production of geothermal fluid from a reservoir

A few critical technical and economic factors regarding utilization are further described in the sections below.

---

[17] http://www.thinkgeoenergy.com/global-geothermal-capacity-reaches-14369-mw-top-10-geothermal-countries-oct-2018/

4.2.1 Drilling and pumping from wells.

Drilling cost will vary from one project to the other depending on the location, the underground features and how deep the resource is situated. Furthermore, not all drilled wells are successful, and their output may vary greatly in terms of flow and temperature depending on the resource. The risks involved in reaching the target flow and temperature are significant and geothermal projects are generally characterized by high upfront cost risks.

In some locations, self-flowing hot springs may be used for direct geothermal applications but only in small scale, with a temperature limit of about 100°C. In general, it is necessary to drill to gain access to more flow and in some cases higher temperatures. Although drilling can increase artesian flow (self-flow), the most common way to enhance the capacity of a well is to install well pumps.

Wells can be from a few hundred meters down to 4-6 km deep depending on the location of the targeted resource. Wells are nowadays mostly drilled at either standard diameter well with a production casing of $9^{5/8}$ inches or a large diameter well with a production casing of $13^{3/8}$ inches. Apart from what the resource itself offers, the size of the wells, the depth of the water table and the type of pumps used will all have an impact on the well output as is illustrated in Table 6 below.

Table 6 – Geothermal wells

	Production Casing	Line Shaft Pump – 3 000 rpm		Submersible pumps – 3 600 rpm	
	in	Size, in	Output, kg/s	Size, in	Output, L/s
Standard diameter well	$9^{5/8}$	8	40	6	80
Large diameter well	$13^{3/8}$	10	80	8	120
Large diameter well with a large pump chamber	16 - $13^{3/8}$	12	120	10	200

Selection of well pumps proceeds from the analysis of various factors related to the operation of the system and its performance such as price, space in the well, temperature rating, efficiency, installation depth, material selection. Two types of well pumps are used in geothermal applications: Line shaft Pumps (LSP) and Electrical Submersible Pumps (ESP).

The motor in Line Shaft Pumps is located at the surface, on top of the well head, while the pump is installed in the well. The pump casing is connected to the well head with a riser pipe to bring the water to the surface. A rotating shaft from the motor is in the center of the riser pipe and spins the impellers in the pump casing. In most geothermal applications, the shaft bearings are lubricated with an external fluid and the shaft is enclosed by a lubricating tube.

The motor in Electrical Submersible Pumps is submerged in the geothermal fluid below the pump. In this case, the motor is connected to the pump with a relatively short driving shaft. A riser pipe connects the pump to the surface to bring the water up.

Well pumps used to be fixed speed pumps 1 500 or 3 000 rpm although they are nowadays often driven with a variable frequency drive that allows operation from 1 500 – 3 600 rpm. Pump selection for a specific well usually defines a narrower operation window, i.e. 2 800 – 3 600 rpm for better performance under given operational conditions.

Wells are designed with closed cemented steel casings that seal the upper ground layers to avoid inflow of ground water or cold geothermal fluid and prevent them from collapsing. Liners are installed in the production zone, located deeper in the well, for the production fluid to flow from the target aquifer into the well.

Although the inflow and outflow of geothermal fluid occurs close to the lower part of the wells, well pumps are installed in the upper part of the well. They are situated just under the static liquid level but deep enough to be submerged under the dynamic fluid level, caused by the well draw down when pumping. It should be noted that the dynamic fluid level can be considerably lower than the static liquid level.

4.2.2 Re-injection

Large scale harnessing of geothermal fluid from sedimentary basins requires, almost without exception, re-injection to create sustainable operation conditions, see section 0. The re-injection rate is in general dependent on the characteristics of the resource and on the intended production. Sound resource management practice is to have a 1:1 well ratio at initial stages of utilization, i.e. the production rate of a production well is similar as the re-injection rate of the re-injection well. The ratio can also be 2:1, 3:1 or higher if the natural recharge of the system is good compared to the production rate, implying lower re-injection rate. A set of one production well and one reinjection is usually called a geothermal doublet.

4.2.3 Discussion on various cost parameters

Typical investment costs involved in harnessing of geothermal fluid include:

- Preparation:
    - Exploration cost
    - Environmental impact assessment for geothermal well field development
- Geothermal well field development:
    - Access roads and well pads
    - Drilling of wells and well testing
    - Well pumps
    - Resource Gathering System (RSG) for the geothermal fluid to a user and back to the re-injection well
    - Re-injection pumps, if needed

Presently, Electrical Submersible Pumps (ESP) are becoming more popular and economical than Line Shaft Pumps (LSP). This is mainly because their installation depth can be greater, and their diameter is smaller for the same flow rate. In practice, the use of ESP translates into a more dynamic drawdown and increased output. A typical ballpark price for an EPS pump is 1 000 USD pr. kW of shaft power to the pump, for an installation depth of 300 -500 m.

Geothermal well field development generally accounts for 40-60% of the investment cost of a geothermal project involving power generation. For district heating project the well field development is generally 20-40%. For direct utilization to be installed near the geothermal field, like greenhouse heating, industrial application etc. the cost ratio can even be higher 60-90% of the total cost of the heat supply system.

Cost of drilling geothermal wells into sedimentary basins varies significantly depending on location, rig availability time, raw material prices etc. Table 7 highlights the ranges of cost that may be expected based on simple parameters. The cost as introduced under the column “Kazakhstan” is used in this study.

Table 7 – Overview of drilling cost of a single straight well

	Low, China MUSD	**Kazakhstan MUSD**	**General MUSD**	**High MUSD**
Standard well, 1500 m deep	0.4	1.0	2.0	2.5
Large well, 1500 m deep	0.6	1.2	2.5	3.0
Standard well, 3000 m deep	0.8	2.0	3.0	4.0
Large well, 3000 m deep	1.0	2.5	4.0	4.5
Standard well, 4500 m deep	1.2	3.5	4.0	5.0
Large well, 4500 m deep	1.5	4.4	5.0	6.0

Information on cost of geothermal drilling in Kazakhstan is limited. The cost set forth in the table for Kazakhstan is an estimate by the Consultants, based on benchmark from a large scale geothermal sedimentary drilling in China scaled with actual cost of the few geothermal wells that have been drilled in South East Kazakhstan.

Table 8 below proposes an overview of the cost of a geothermal doublet*, including cost of well pumps (ESP) and resource gathering systems (RGS) for various well depth and sizes. The cost of the well pump is estimated, based on installed pumping power needed to raise the water table by 200 m or 20 bar.

Table 8 – Capital cost of well field development from a sedimentary basin. Standard doublet price

	Output kg/s	2 wells* MUSD	RGS MUSD	ESP MUSD	Other MUSD	**Total cost MUSD**	Ratio total cost to output MUSD/(kg/s)
Standard well, 1 500 m deep	**50**	2.0	0.25	0.1	0.1	**2.45**	0.05
Large well, 1 500 m deep	**120**	2.5	0.3	0.25	0.2	**3.50**	0.03
Standard well, 3 000 m deep	**50**	4.0	0.25	0.1	0.1	**4.45**	0.09
Large well, 3 000 m deep	**120**	5.0	0.3	0.25	0.2	**5.75**	0.05
Standard well, 4 500 m deep	**50**	7.0	0.25	0.1	0.1	**7.45**	0.15
Large well, 4 500 m deep	**120**	8.75	0.3	0.25	0.2	**9.50**	0.08

* 1 production well and 1 reinjection well

The ratio of total cost to output shows that drilling large wells is more economical. This is of course provided the resource is adequate for production through a large well. Furthermore, the characteristics of the resource must always be taken into consideration when designing a well so selection of well size cannot be decided based solely on this ratio.

Geothermal well flow rate may decrease with time, although to a different extent. The decrease is dependent on the geothermal fluid composition and on various local conditions and production patterns. Drilling of new wells to replace wells whose production has declined over time is therefore a factor that must be taken into consideration when planning a geothermal project. If the conditions are good and little or no scaling occurs in the well, then flow rate can be expected to decrease slowly or not at all as may be expected in the low and medium temperature wells.

Typical yearly operation and maintenance cost for the geothermal production system is in the range of 1.5% of the installation cost. This includes remuneration of operation and maintenance work on well pumps and possibly inhibitors injected into the fluid to prevent scaling. This percentage is low for this part of the system compared to other mechanical installation systems where maintenance cost is in the range of 5% of the mechanical investment, mainly because of the high investment cost for wells and the resource gathering system where low maintenance activities expected

4.3 Power generation with binary power cycles

Kazakhstan does not have geothermal resources with very high temperature suitable for production of electricity with steam turbines. This is not unusual, many places around the world aside from Kazakhstan have low and medium temperature geothermal fields with temperature between 100°C and 180°C. Such fields may be suitable for production of electricity with binary power cycles.

The first binary unit for generation of electricity by geothermal resources were installed in late 1960’s. Production cost of binary plants, harnessing low and medium geothermal resources is higher than for steam plants and such power plants have been uncompetitive compared to coal and oil-fired plants. However, the binary production technology has recently become more competitive, not only due to higher energy prices and subsidiaries to electricity from renewables, but also due to increased efficiency.

The binary technology allows for production of electricity from low temperature resources that could otherwise not be used for such purpose. In a conventional steam power plant, the turbine is driven directly by the steam for power production whereas in a binary plant, the geothermal fluid is used indirectly. It vaporizes a working fluid in a closed-loop that is then used to drive the turbine for power generation. Various working fluids are available and are presented further in the section on cycles.

Typical heat sources suitable for electricity production with binary plants are:

- Geothermal two-phase resource 180°C;
- Geothermal resource between 100 - 180°C; and
- Waste heat from industrial processes.

Utilization of the binary technology for production of energy from geothermal is therefore an option worth assessing for project developers with low temperature geothermal resource field in their portfolio. The next sections introduce how geothermal fluid is harnessed and technical aspects of the binary technology.

4.3.1 The Organic Rankine Cycle

The Organic Rankine Cycle (ORC) technology is commonly used in geothermal to produce electricity from low and medium temperature geothermal reservoirs. Most of the geothermal binary cycle power plants currently in operation in the world are of the ORC type.

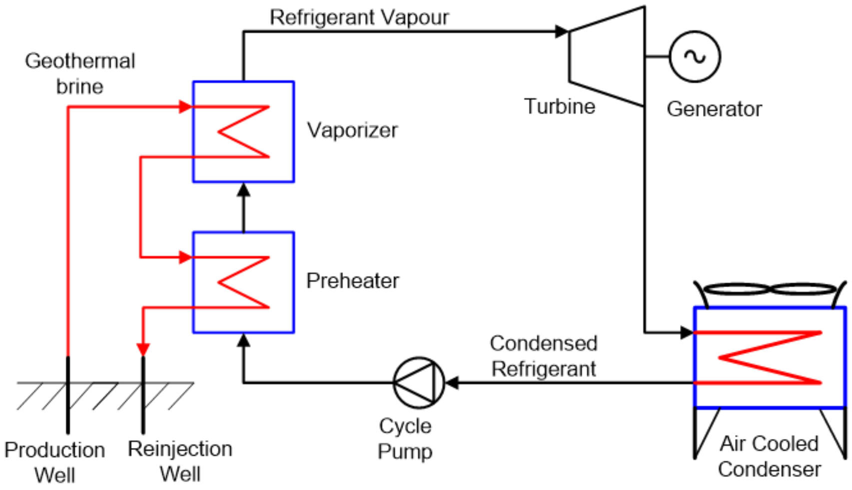

Figure 22 – Typical Organic Rankine Cycle flow diagram

For a working fluid to be used in ORC cycles, its boiling point must be lower than the temperature of the geothermal fluid. The most common working fluids used for binary application are hydrocarbons such as isopentane and isobutene. Other fluids include ammonia, R134a and R245fa, with the last two being hydrochlorofluorocarbons commonly used in the refrigerant industry. Isopentane and isobutane are the most widely spread organic working fluids used for binary application despite their high flammability. There is limited experience in using the R134a and R245fa.

The Figure 22 features the most basic binary cycle. The diagram describes a single stage ORC cycle with an air-cooled condenser.

In an ORC plant the geothermal fluid is passed through a heat exchanger and used to heat the working fluid which is vaporized to be used in the turbine. The vapor created in the evaporator is admitted to and expanded in a turbine, like the geothermal steam in a steam plant turbine, producing shaft power to a generator. After this step, the working fluid is condensed in a condenser and pumped back to the evaporator for the cycle to be repeated. The depleted geothermal fluid can then be pumped back into the geothermal reservoir for replenishment.

ORC plants use either water cooled or dry air condensers. The use of water-cooled condensers requires source of cooling water or make-up water for the cooling tower. The power output for ORC plants with air cooled condensers is more sensitive to changes in the outside temperature than for ORC plants with water cooled condensers.

Access to cooling is important for a binary power plant. The temperature of the cold source influences significantly the power output of the plant: the higher the temperature difference between the two media, the more the energy extracted from the system. Lower condenser temperature increases the pressure drop over the turbine which in return delivers more work.

All condensers in binary plants are closed, with no contact between the working fluid and the cooling agent. There are three main types of cooling: direct cooling, evaporative cooling towers and air-cooled condensers. The last method is by far the most used in geothermal binary applications.

A simplified scheme featuring the main components of a binary power plant is presented in Figure 23 below.

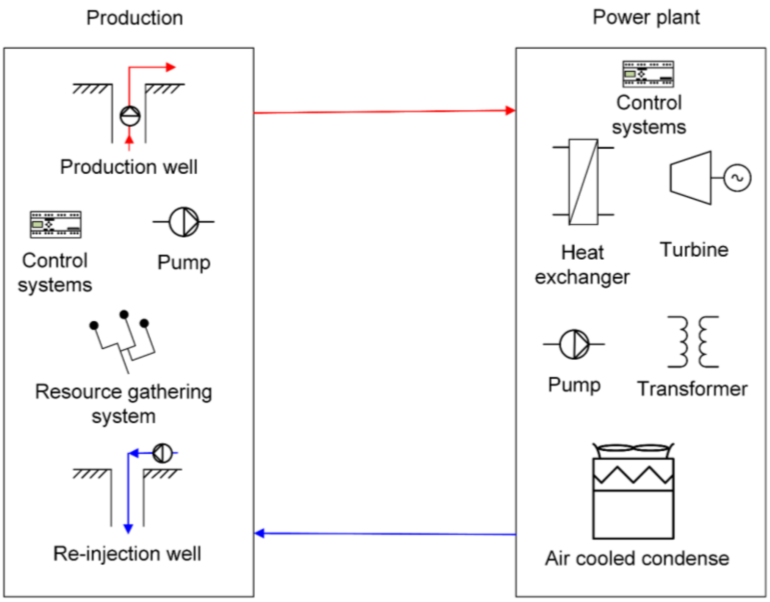

Figure 23 – Key components of a geothermal production system and a binary power plant

There is a direct link between the components schematically presented in the figure and the investment costs. However, the feasibility of a geothermal project does not only depend on the investment cost since the power output and ultimately the energy production and energy price are also critical issues. The next section explains how the power output may vary between projects.

4.3.2 Process cycle

Since the present study has been conducted with no specific project location or geothermal resource information, the authors have prepared a comparison of plants operating at different temperatures, based on a fixed power plant output. The main varying parameters are the temperature, brine flow and cooling flow.

Table 9 – Geothermal water temperature, heat input and net power output

Resource temperature °C	Brine flow kg/s	Re-injection temperature °C	Heat input kW	Net power output kW	Net conversion ratio %
150	20.3	59.9	7 618	1 000	13.0
125	32.9	57.0	9 396	1 000	10.6
100	59.5	51.5	12 120	1 000	8.2

The required geothermal fluid flow for 1 MW net power output gives an indication of the number of wells that are needed for the same power output at various resource temperature. One can assume that the power plant cost will be similar in each set-up and that the investment cost will greatly increase with decreased resource temperature since more wells will be required together with a larger brine gathering and reinjection system. The calculated net annual output of a 1 MW power plant is 8 322 MWh.

The details of the power cycles that were simulated to obtain the values indicated in the table above are shown in the Figures below. All cases are based on a binary cycle using n-butane with air-cooled (7°C ambient air) condensers to simplify the comparison.

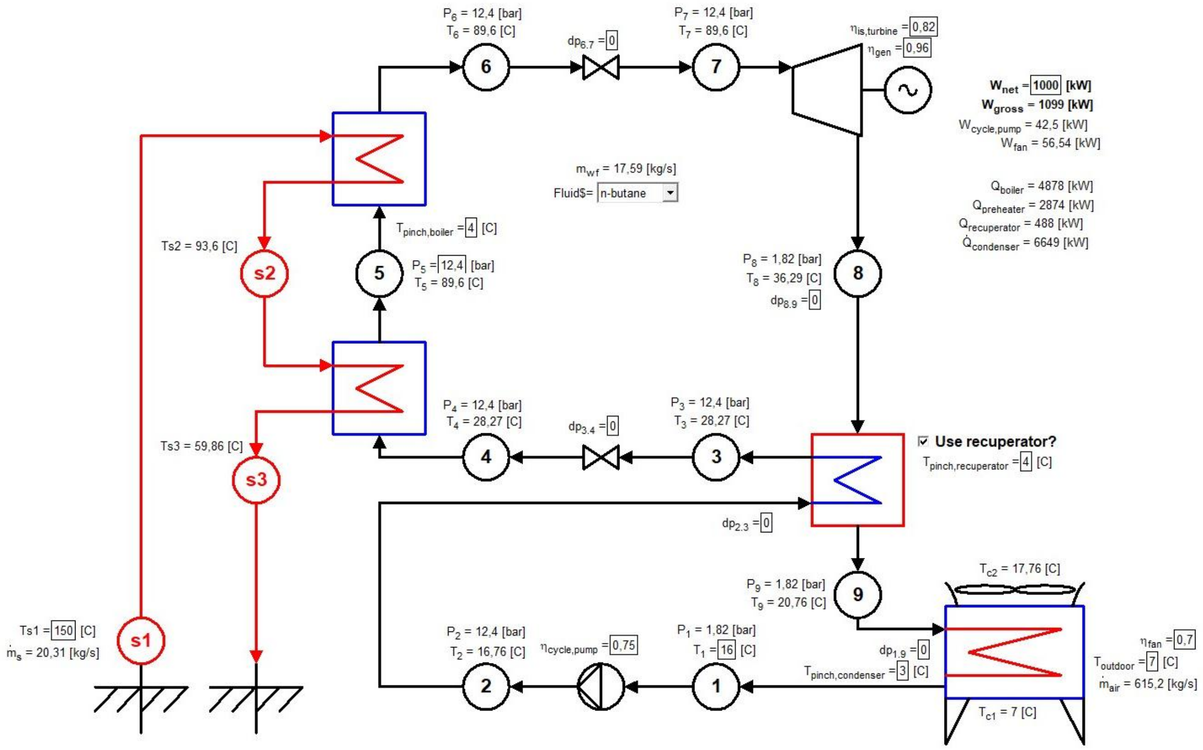

Figure 24 – Single stage liquid - binary cycle with 150°C geothermal fluid temperature

Figure 24 features the most favourable case, with a geothermal fluid temperature of 150 °C. The mass flow required to produce 1 MW in these conditions is about 20 kg/s. The flow rate of the working fluid is about 18 kg/s and the condensing temperature is around 20°C.

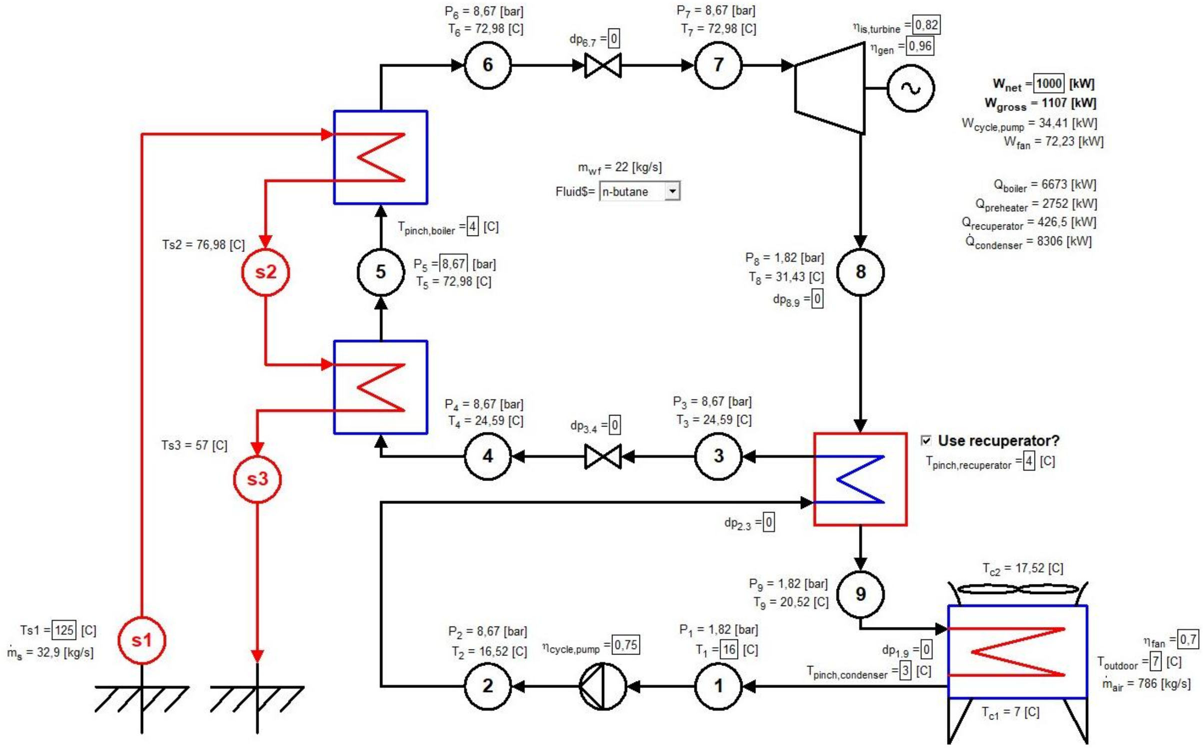

Figure 25 – Single stage liquid - binary cycle with 125°C geothermal fluid temperature

Figure 25 features a binary plant similar to the previous one only with a geothermal fluid temperature of 125 °C. The mass flow required to produce 1 MW in this case is about 33 kg/s, or approximately 65% more than in the case with geothermal fluid at 150°C. The flow rate of the working fluid 22 kg/s and the condensing temperature is the same as in the previous example, 20°C.

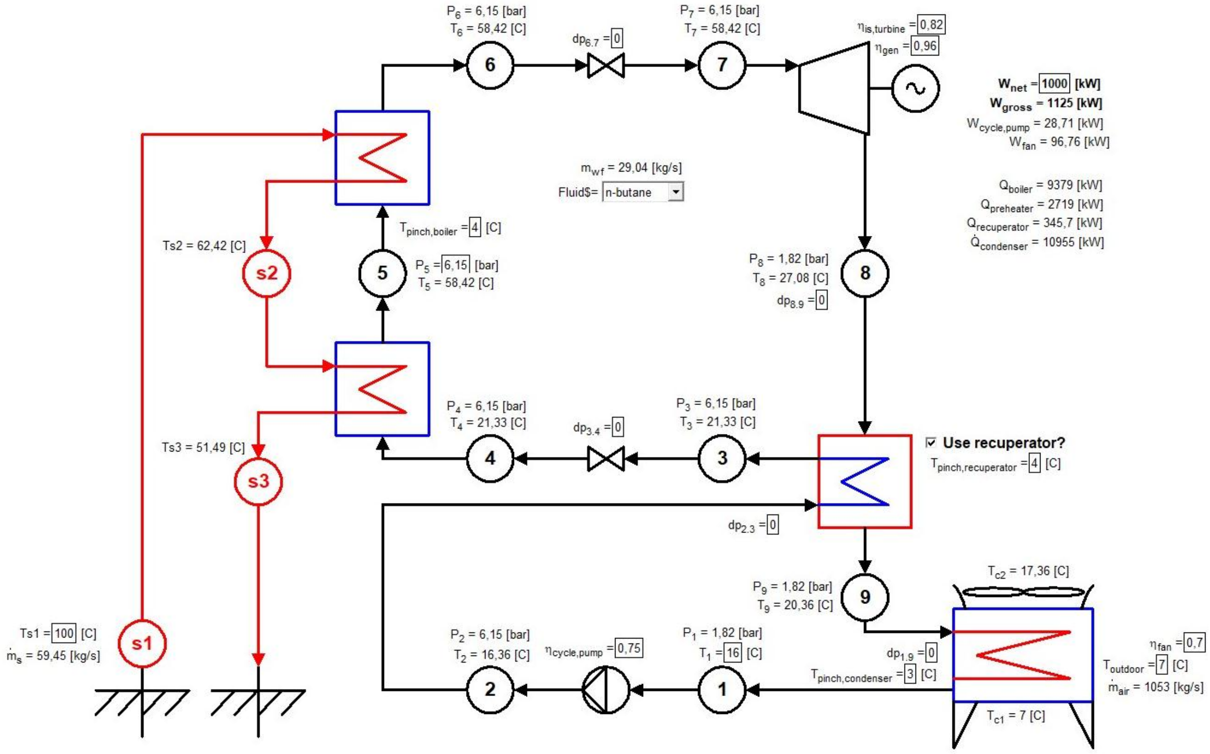

Figure 26 – Single stage liquid - binary cycle with 100°C geothermal fluid temperature

Figure 26 features the least favourable case with a geothermal fluid temperature of 100 °C. The mass flow required to produce 1 MW in this case is about 60 kg/s, or about 3 times the flow required to produce 1 MW from geothermal fluid at 150°C. The flow of the working fluid is now 30 kg/s or 1,7 times more than for the 150°C case. Also note that the vapor pressure is reduced 50% compared to the 150°C case. The condensing temperature is the same temperature as it is governed by the ambient conditions.

Increased flow and lower ORC vapor pressure means larger pipes and larger heat exchangers and will have a cost impact but not as big as may be expected since the control system remains similar and the electrical output also.

4.3.3 Discussion on cost and production parameters

An important factor for the feasibility of a geothermal power project is its cost compared to how much energy can be produced. This section proposes a brief introduction to investment cost, operation and maintenance cost and provides comments on basic energy production factors.

Investment cost

Typical investment cost for a binary power plant include:

- Power plant:
    - Civil structures
    - Sometimes
    - Mechanical installation, pipes, heat exchangers, turbine and condensers
    - Electricity and control

The order of magnitude of investment cost of an ORC binary power plant is 2.5 – 3.5 MUSD per MW of net power. In general, the cost is higher for lower temperatures and lower for higher temperatures

Operation and maintenance cost

Typical operation and maintenance costs include:

- Personnel
- Spare parts and plant consumables
- Scheduled maintenance
- Overhead and insurances
- Well replacement

Operation and maintenance costs may vary from one plant to the other depending on the size and type of plant, its location and the plant operation philosophy selected at the design stage by the plant owner. Typical yearly operation and maintenance cost is in the range 4–5% of the total installation cost of the plant.

Energy production and prices

Various elements impact the efficiency of a binary power plant:

- Temperature of the geothermal fluid
- Flow rate from each well, i.e. number of wells
- Depth of water level
- Cooling technology and ambient temperature
- Size of the plant

This means that the amount of energy that a plant can produce is the factor that varies most from one project to another, given projects of similar size. Keeping the pressure drop over the turbine as high as possible without excessive use of geothermal fluid is one of the most important parameters impacting power plant efficiency.

Typical efficiency of plant equipment:

- Isentropic efficiency of the turbine is usually around 80%. Isentropic efficiency describes the ratio between the actual work of the turbine and the maximum theoretical work as if the entropy during the process would remain constant during the process.
- Generator efficiency might be around 95%. It includes the losses in the generator and gears.
- Efficiency of pumps and motors could be around 75%.

Geothermal power plants generally use their own electricity production to cover the parasitic load. The cycle-parasitic load is not listed as operational cost; it reduces the amount of energy sold to the grid. Parasitic load of a geothermal binary cycle can be in the range of 8-12% of the gross power.

Electricity needed to pump the geothermal fluid from the production wells and back into the reservoir is sometimes handled separately as it may be purchased from an external source. The power needed for well pumping can be in the range of 5 – 25% of the gross power.

Geothermal power plants are interesting in the energy mix of an area because the impact of external factors on their production capacity is quite low. Unlike solar and wind farms, solely dependent on whether conditions, a geothermal power project will be able to provide the base load and supply almost constant amount of energy over the year no matter the weather.

In addition to the above, the cost production of electricity from geothermal can also be expected to be constant over the years compared to conventional projects. It will not be dependent on volatile energy prices as is the case in projects relying on fossil fuels.

4.4 Direct use of geothermal resources

Direct use of geothermal resources is usually a very efficient process and it makes sense to investigate such utilisation when local markets are available, for instance when there is a community with space heating needs nearby or when local industries can use the heat directly. Replacing conventional heat sources like fossil fuel or coal with geothermal is considered to have a positive impact on climate change, improve air quality and enhance energy independence of the local community as is further discussed in section 6.1.

The potential market for direct use of geothermal is vast. As an example, about 25% of US energy use occurred at temperatures < 120°C in 2012 and most of it came from burning natural gas and oil. This ratio is higher in Europe and one can expect this to apply as well in Kazakhstan. Most direct use applications can be applied for geothermal fluids in the low to moderate temperature range 50 - 150°C. Direct use of geothermal for industrial purposes should therefore be a priority for developers during the planning stage of a project. It is also a good way to distribute risk by having revenues not only dependent on the length of the heating season and coming from various economic sectors. In the absence of already existing potential users, this would translate into the planning of an industrial or eco-park at early stage of the project, in collaboration with the local community to create room for potential users served by a transmission pipe, like a district heating system.

From a historical point of view, the most widespread forms of direct use are space heating, balneology, horticulture, aquaculture and some industrial uses. These applications are usually simple and concern mainly thermal utilisation, although some applications also deal with chemicals, gases or minerals contained in the geothermal fluid.

It is to be noted that geothermal heat pumps are currently the most widespread type of direct utilization of low temperature energy. They are usually used in the case of so-called “shallow” resources with very low temperature and required power input up to 20-40% of the energy output depending on the conditions. These applications will not be discussed further in this Study since it focuses on resources with higher enthalpy potential.

The most common direct use applications are presented in the sections below.

4.4.1 District heating

District heating systems supply thermal energy to a community for space heating and in some cases for domestic hot water as well. Geothermal district heating system harness most of their energy from geothermal resources. For various economic reasons, peak power can in some cases be supplied by other sources of energy.

Geothermal district heating systems usually combine wells, gathering, transportation and distribution systems, heat centrals and peak load equipment to supply heating or cooling to a group of buildings.

A simplified scheme featuring the main components of a geothermal district heating is presented in Figure 27 below.

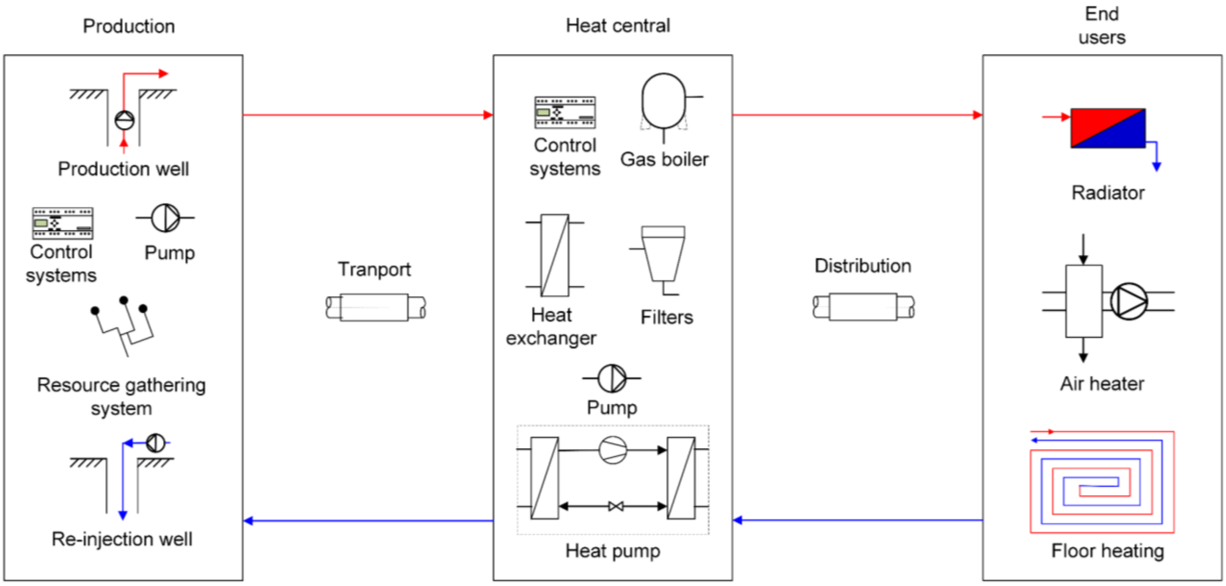

Figure 27 – Main components of geothermal District Heating project

Various concepts may be applied to use geothermal resources for space heating, depending on the characteristics of the geothermal fluid, the elements of the system already in place or other technical or economic aspects. Transport of the energy between the geothermal production and the heat central is usually done with large mains. The distribution on the other hand is more extensive and with smaller diameters to reach each single end-user.

Transportation of geothermal energy

To transport geothermal fluid from a geothermal field to a heat central, within or near a populated area, a double pre-insulated piping system is the general choice. A single pipe system is an open system using the geothermal fluid directly in the space heating elements. It is more economical than a double pipe system, but it is not convenient when reinjection is necessary.

A double pipe main system is a closed system, used in this part of the system to transport geothermal fluid from a geothermal field to and from a heat central where district heating water is heated via heat exchangers.

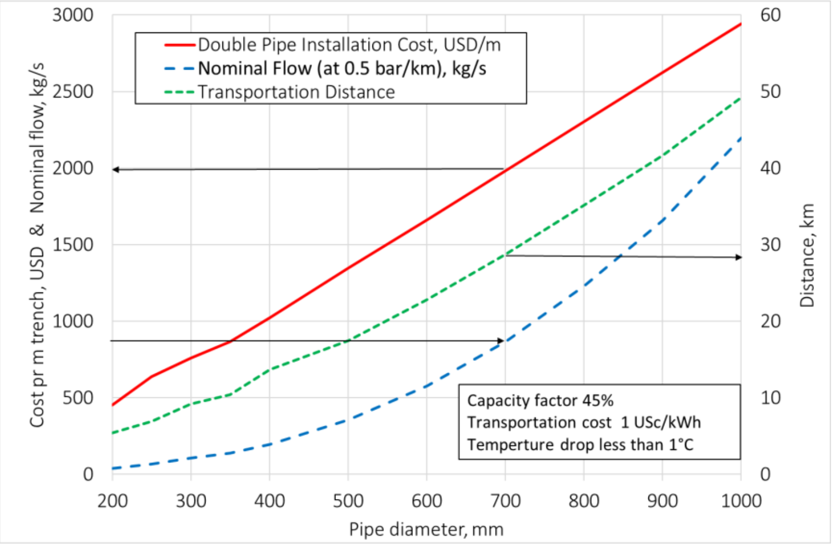

Figure 28 – Installation cost, flow and reasonable transportation distance for a double pipe main

Figure 28 shows basic selection curves for geothermal pipe mains. It provides an indication of the maximum economical transportation distance based on estimated heat loss from the piping and the share of transportation cost in the user's energy bill of 1 US¢ /kWh. The flow is assumed to be constant 45% of the year, which is relevant if treated as base load in Kazakhstan.

As an example, a suitable pipeline size to transport 800 kg/s flow would be 2 x DN 700. Associated cost is 2 000 USD per meter of trench and the maximum economical transportation distance is 28 km.

Heat Central

Various heat central systems can be used to provide the end users with hot water. Heat centrals with a peak load boiler might be an economic solution and such a configuration should be assessed among other options based on the capacity of the geothermal resource and on the peak space heating demand.

The heat central functions as a connection point between the geothermal production and the users. It receives energy from the geothermal fluid and transmits it to the users via a heat exchanger and a pumping system. When a district heating system covers the end-users' needs for space heating and domestic hot water, the geothermal energy production system will be in use all year long. Energy from an external supplier, gas boiler or waste energy, can be delivered to the heat central and used during the peak load period as an additional source of energy.

Cost of heat centrals is highly dependent on the set-up and equipment required for each project as well as on various local conditions. However, a bulk price for a geothermal heat central and an optimum combination of heat pumps and peak load boiler is about 120 000 USD per MW of installed capacity.

Distribution system

The distribution system consists of supply and return pipes connecting the heat central to the end users.

Typical cost of a distribution system, including connection to users, in an urban area is about 50 000 USD per hectare. Installation cost is almost constant per hectare and does not vary with building/land density. The cost is more sensitive to the surface finish and can be in the range of 40 000 USD – 80 000 USD per hectare and even higher in fully developed high density areas.

It is of course cheapest to install such a system parallel with housing and street development. It is more expensive to install a distribution system in fully developed streets with grass and paved surface because of the cost associated with the surface repairing and finish. As an example, surface finish in the streets in Zharkent is in many cases not completed and the authors of the report believe the cost of installing a distribution system in such conditions will be in the lower range.

Figure 29 – Street view in downtown Zharkent

A typical street in Zharkent is shown in Figure 29. It seems common to have a gravel area between streets and sidewalks where the pipes could be installed, thus implying minimum cost for surface finishing.

Metering and tariff design

Metering and tariff methods might have a significant impact of the users' energy usage and consumption pattern. Special emphasis should be put on the metering methods and design of the tariff system in a geothermal energy heating perspective, as these are a matter of concern for sustainable use of the geothermal resources and the success of the district heating projects.

A good metering method constitutes an incentive that encourages users to reduce energy squandering and energy use, preferably with low cost metering equipment. Lesser metering methods do not form these incentives at all, or with a significantly poorer focus. In the context of a geothermal district heating system, metering should:

1. Encourage energy saving behaviour;
2. Encourage optimum energy extraction from the district heating water; and
3. Be installed to sell as much as possible, depending on the availability of the heating media.

Issues 1 and 2 are the most sought-after goals in cases where geothermal energy is extracted from a reservoir with limited potential that is used mainly for heating purposes. In district heating networks, users not only have to pay for their energy consumption, user payments must also suffice for capex and opex of the system – i.e. salaries of operator staff, peak load energy, and the installation cost of the network. The cost of the heating utility is carried out to the users in form of billing with a combination of three types of fees:

- One-time connection fee: It is a fee that an owner pays for connecting the house to the district heating grid. This fee is used to pay for parts of the installation cost of the heating utility. The remaining installation cost is paid by users with usage fees.
- Fixed annual fee: A fixed annual fee is nearly always used. This can be the only fee, or part of the fee depending on the charging method used. The fixed annual fee often pays for fixed maintenance costs of the heating network.

- Variable annual fee: A variable fee is used in many types of charging methods. This fee is often related to each user's usage, for instance as a proportion of incoming flow or used energy.

The financial fundamental of a heating utility is to get fees to cover for its expenses. Finding a feasible ratio between the one-time connection fee and the two types of annual fees is the first decision that must be made.

Different metering methods should be used to suit each and one of the conditions mentioned above. The following proposes an overview of various possible metering methods:

- Using flow meters as a metering basis is considered a rather good method. When using flow meters as a metering basis, the consumer is charged according to the amount of water used (cubic meters or tons). This metering method is commonly used in Iceland. This method incentivizes energy savings and is rather applicable to serve as a basis for heat selling when utilizing limited low enthalpy heat sources. In practice, the use of heat will vary with outdoor temperature. The drawback of this method is that a consumer living far from the heat source receives colder water resulting in higher flow and higher variable cost than those living close to the heat source. From the consumer point of view, a user living far from the heat central will get less energy for each dollar spent than a use living close to the heat central.
- An energy meter with calculated (or fixed) return temperature is a theoretically correct meter, where significant cooling may occur in the distribution system. This meter charges users equally for the energy that they are provided with from the supply water. The meter uses flow and supply temperature as necessary incoming parameters. Outside temperature can be used to calculate the expected return temperature for a correctly designed inhouse heating system, based on guidelines from the district heating provider. This metering system is currently not commercially available, but it would be a quite good method, especially in geothermal heating networks and would contribute to an equal treatment of customers in large district heating systems.
- Using energy meters as a basis for charging consumers is considered an unsatisfactory method for geothermal heating. This method is common in conventional systems where the use of energy meters is based on measurements of the flow and the supply and return temperatures. In addition to this, the energy usage is calculated and accumulated in a computer or advanced meter. Energy metering is an improvement when the heating utility is based on coal or natural gas burning only, as these methods are less dependent on a low return temperature. The method gives some idea of various buildings' energy usage and can increase awareness of excessive use in this manner. However, this kind of metering is not deemed suitable for geothermal systems because does not pay any attention to the return temperature or the consumers' usage temperature. A small temperature drop in users' heating equipment goes un-penalized and creates higher cost on the utility side. A high return temperature is negative in geothermal heating and may result in unsustainable use of the resource.
- Using square meters (m^2) as a metering basis is considered an insufficient method. This metering method does not consider any of the variables of importance with respect to energy savings, i.e. the supply and return temperatures, the mass flow or the used heat.

It should be kept in mind that competition with the previous heating utility exists. To minimize their energy bill, users could for instance improve the energy efficiency of their building or choose to purchase energy from another cheaper source, so the metering and tariff system should be carefully designed.

End user

Housing insulation and house heating systems in geothermal district heating systems are among the most critical components for utilizing a geothermal heat source. If geothermal heat is used in unsuitable house heating systems, the utilization of the energy source will be poor, and the resource will not be used in a sustainable manner.

A common temperature drop in conventional district heating systems, fuelled with fossil fuels, is from 90°C to 70°C during periods of maximum heat load for an average apartment building. To be able to use low temperature district heating systems, i.e. 65 - 75°C supply, the overall size of a heating elements must be large.

Implementing a geothermal district heating system in an old neighbourhood with old existing hydronic systems might be difficult and almost always implies upgrading of the space heating system at the end users.

Furthermore, the type of heating system used in houses should be carefully chosen, in accordance to the temperature level of the fluid provided by the district heating system. Radiators or floor heating systems are commonly used for geothermal space heating although air heating systems are also possible. Cascaded system using radiators with supply/return temperatures 75°C/35°C combined with floor heating system could also possibly be installed.

Energy efficiency of houses is a key issue here and it is not recommended to install geothermal heating without improving insulation. Heat loss for well insulated buildings can be as low as 1.6 W/m^2 °C but it is estimated that this figure is close to 2.3 W/m^2 °C in general in Kazakhstan.

If the difference between indoor and outdoor temperature is 30°C the heat loss is about 50 W/m^2 for a high-performance building but will be 70 W/m^2 for a typical, less insulated, building.

4.4.2 Agriculture and horticulture

Geothermal resources are ideal for horticultural applications especially when a large amount of low temperature geothermal fluid is available for heating greenhouse, soil warming and irrigation.

Geothermal horticulture was first experimented in Iceland in naturally warm soil to grow potatoes in 1850 (Hansson, 1982). Various kind of crops – including tomatoes, mushrooms, cucumbers, paprika and potted plants or flowers - can be grown with the aid of geothermal heat. Such use might contribute to significantly reduced operation cost and is seen as an interesting option for commercial operation in cold climates, with high heating requirements. In hot regions, the geothermal energy is used for humidity control or to counteract the night cold in desert areas. It might also be a source of CO_2 for enrichment inside greenhouses.

Heating greenhouses is a rather energy consuming activity and is suitable where access to geothermal energy is good. Heat loss is 7.5 W/m^2 °C in large greenhouses. When outdoor temperature is -15°C and indoor temperature is +20°C, the heat loss is 260 W/m^2.

There are already greenhouse installation using geothermal energy in Zharkent and such activity should be promoted further.

4.4.3 Balneology

Thermal waters have been used for centuries all around the world. Hot spring resorts are very popular facilities and, in some places, where thermal waters are known for their therapeutic properties, health centres have been in place for decades or centuries. Geothermal heat can also be used in swimming pools and spas. In such instances, the temperature of the resource and its mineral content are important parameters.

In a small village called Sarypyldak in the Zharkent basin there is a balneology centre using geothermal heat for swimming pool and bathing facilities along with space heating of hotels, school etc. Such activity based on geothermal should be promoted further in the area.

4.4.4 Fish farming

Aquaculture or aqua farming is the raising of aquatic animals such as fish, crustaceans, molluscs and aquatic plants. The farming activities are practiced under controlled conditions. The most common species raised are catfish, bass, tilapia, sturgeon, shrimp, and tropical fish. One of the purposes of using geothermal resources for fish farming is to enhance the growth rate. Livestock farming is also a rather common application of geothermal utilisation.

The use of geothermal resources in aquaculture depends on the type of aquatic animals raised, the quality of water and its composition. The geothermal fluid can in some case be used directly in the pond or pool, to provide the heat required. Heat exchangers might be required if the chemical composition of the geothermal fluid is unfit for the aquatic animals to be raised. This depends of the quality of the geothermal water

There is at least one fish farm, “Too Ecofish Products”, using geothermal water directly from a borehole in ponds in the Zharkent basin. Figure 30 shows a photo of this site taken during the site visit. The ponds are sheltered from the cold weather with a glass roof aimed at minimising heat loss due to wind chill, a critical factor in large outdoor fish farming.

Figure 30 – Fish farming in the Zharkent Basin

This example shows that growing fish in geothermal water in the Zharkent basin is possible and further development of such activities should be investigated and promoted.

4.4.5 Industrial use

Industrial applications encompass a rather wide range of industrial activities requiring fluid at low to medium temperature for instance to preheat, wash, evaporate, distillate or dry. They may also be used to produce salt and other chemicals. Geothermal resources might also be used for refrigeration via heat pumps. Higher temperatures than those required for the applications described above might be required. For instance, drying and refrigeration usually require temperature above 90°C.

There is a broad range of industrial applications that may use geothermal resources. Conventional industrial processes that utilize heat can in many cases be used with minor adaptation in a technically efficient and economically feasible way.

An interesting example related to industrial use is the Rittershoffen geothermal heat plant operated by ÉS Géothermie in France since 2016. The geothermal doublet provides heat to the «Roquette Frères» industrial site about 15 km away. This heat plant covers 25% of the process heat needed on the site. Nominal power of the plant is 25 MW_{th}. The geothermal fluid is about 170°C and it is reinjected at 70°C. The project is expected to avoid the emission of 39 000 tons of CO_2 per year.

In New Zealand, the Miraka milk processing plant has been in operation since 2011, using waste heat from the Tuaropaki geothermal plant nearby in its process. About 60 gigajoules a day of waste heat produced at the plant is processed and recycled. The plant can process supplies from 50 000 cows, or 210 million litres of milk annually, to produce 32 000 tons of whole milk powder.[18] Another milk processing plant is on its way in Kawerau. It will produce 8 000 metric tons of dried milk products per year and it is expected to create 30 jobs, which will have a consequent impact on the local Maori community.

4.5 Cascaded and integrated use of geothermal resources

As previously mentioned, it could be an advantage to have other direct use applications either as part of the users' mix of a district heating system or as a set of large users, for instance in an eco-park with various industrial application requiring heat in their process.

A simplified scheme featuring the main components of multi-use applications is presented in Figure 31 below.

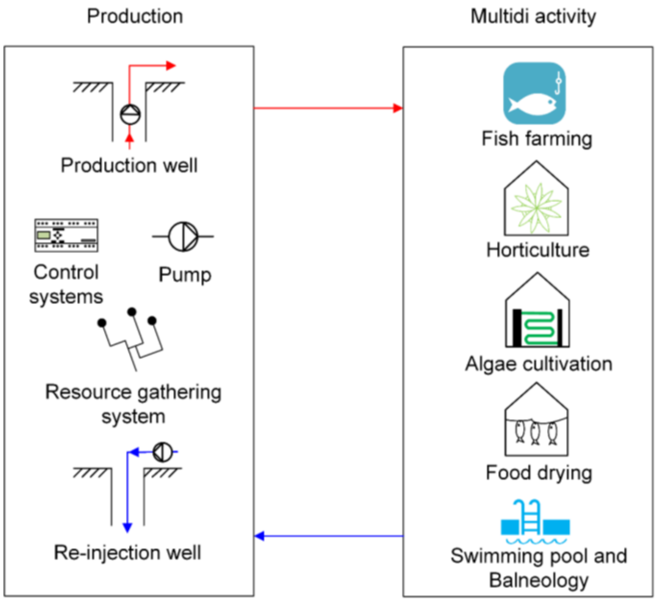

Figure 31 – Main components of multi-use applications

Cascaded use is when a series of users can harness energy from what the earlier process sends out after its utilisation process. Integrated use refers to a utilisation scheme that aims to find the best use of the resource and the investment involved. This is accomplished by for example finding use for the geothermal power installed in a district heating application outside the heating season.

---

[18] https://www.foodprocessing-technology.com/projects/miraka-milk-powder-plant/

It is very important that those provided a utilization licence for a geothermal resource be required to assess cascaded or integrated utilization, to ensure that the energy is being put to maximum use and that the investment will reap as high a return as reasonably possible. This will not only benefit the operator but also the community, as well as being more environmentally sound than solely focusing on one form of utilization.

4.5.1 The “Geothermal Resource Park” concept in Reykjanes, Iceland

The “Geothermal Resource Park” concept in the Reykjanes in Iceland is one of the best examples of cascaded and integrated use of geothermal energy. The main products and areas of operation of the parks include hotels, balneology, fish drying, fish farming, wellness tourism, production of methanol, algae, cosmetics etc. from substances present in the geothermal resource and resources involved in the process of the geothermal power plants such as fresh water and seawater.

The revenue streams created by the geothermal power plants are:

- Electricity
- Geothermal fluid
- Geothermal steam
- Hot water
- Cold water
- CO_2

The Svartsengi geothermal field has been actively developed since the 1970s through Hitaveita Suðurnesja, a public company. The initial goal was to produce hot water for adjacent communities with small electricity generation for the district heating system's own consumption. This company has since been divided in accordance with the Act concerning structural separation in the energy sector in Iceland. Today, HS Orka operates the Svartsengi and Reykjanes plants with a capacity of 75 MW_e and 175 MW_{th} and HS Veitur operates various district heating systems, including those connected to geothermal power plants. HS Orka is now a private company.

From a historical point of view, however, the history of these plants is far from stopping there. Shortly after the start of operations at Svartsengi, the Blue Lagoon formed by the geothermal fluid discharged by the plant soon became a popular bathing place. Following studies on the benefits of the fluid on psoriasis, first aid for the poor is marketed in 1995. Today, the Blue Lagoon has gained international fame and attracts more than one million people each year. About 700 people are employed around this activity and other spin-off activities.

In another area, the Icelandic economy owes a lot to fishing and the processing of fishery products in an optimal way to maximize its use is important for this sector. Fish conservation is a key element of this approach and the country has moved from the traditional use of drying in open air to that of dryers using geothermal steam. Haustak is a remarkable example of this approach with the drying of various fisheries waste with the energy provided by the Reykjanes geothermal power plant. The company is thus promoting products that would otherwise be wasted, once again illustrating the geothermal park concept of a waste-free society.

Geothermal energy also presents various aspects that remain to be explored in terms of research and development. The geothermal park has enabled the development of biotechnology start-ups such as ORF Genetics or innovative companies such as Carbon Recycling International dedicated to the production of methanol. CO2 is also extracted to enrich the atmosphere of structures intended for the production of algae or for greenhouses. Innovative concepts are also being developed to optimize the extraction of energy from power plants and the extraction of CO_2 for various purposes.

Although it makes sense, the concept of a waste-free society that underlies the development of geothermal resource parks is not so obvious in the context of companies dedicated to energy production and in a context where economic activities are more or less restricted to a certain sector. In the case of Svartsengi and Reykjanes, the pugnacity of a visionary, Mr. Albert Albertsson, was needed to recognize and hear the peculiarity of geothermal energy and contribute to show case the feasibility of such a model. More than 4 decades after the start of energy production operations in Svartsengi, the economic impact of geothermal activities on the Reykjanes Peninsula speaks for itself. While the Svartsengi and Reykjanes plants directly employ about 60 people, the activities developed around the geothermal resource directly employ 500 people and it is estimated that around 600 additional indirect jobs are related to geothermal energy in the Reykjanes.

In 2013, out of an income of about 130 MEUR generated by the resource park, about 60% was generated by HS Orka and HS Veitur, with an additional 24% generated by the Blue Lagoon. The additional 15% of income is related to the diversification of the use of geothermal energy. It is important to note that apart from the fact that this diversification brings a new source of income, it allows diversifying the risks, which is considered as an advantage for the geothermal operator.

5 Geothermal utilisation case studies in the Zharkent basin

5.1 Local weather conditions

One of the fundamental aspects that must be investigated when it comes to direct use of geothermal resources, is an analysis of the outdoor temperature because space heating loads depend mainly on the building characteristics and on the local weather data. Weather records have been retrieved on an hourly basis, for typical year and have been used to draw up the load duration curve. Figure 32 shows a temperature profile of a typical year in Zharkent.

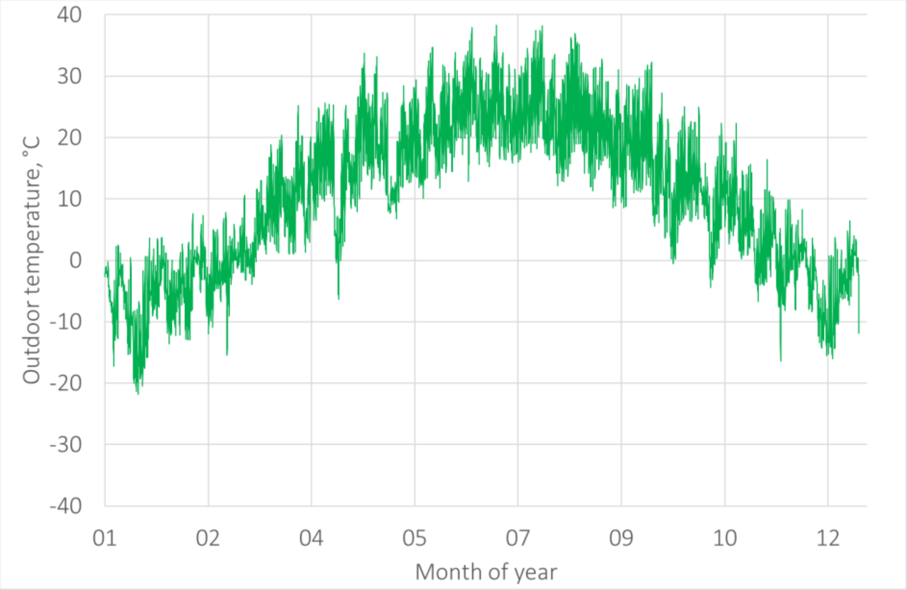

Figure 32 – Temperature profile for Zharkent

The annual average outdoor temperature is about 10°C. A simple frequency analysis is then used to present the temperature duration curve as shown in Figure 33.

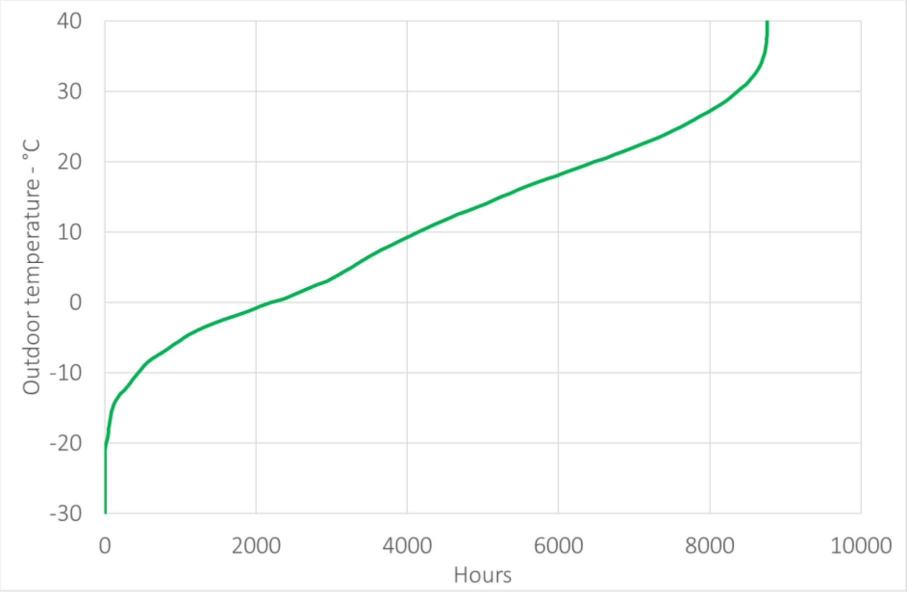

Figure 33 – Outdoor temperature duration curve for Zharkent

What we aim at showing with a temperature duration curve is the number of days or hours per year that have an outdoor temperature lower than any outdoor temperature. The duration curve is also used to indicate the heating period and the load factor, an important element of the geothermal district heating economics.

Severe cold waves are also carefully investigated with the temperature duration curve. They are characterized by their rarity and by their intensity, i.e. much colder temperature than usual. The steep end of the curves on the left side of Figure 33 provides information on the intensity of this phenomenon. If the district heating was to be designed for the coldest weather recorded, it would be run at a partial load most of the time. Since investment costs are proportional to the installed power, installing a district heating system for the coldest weather recorded would not be viable. One of the design premises for district heating is that the indoor temperature might drop to a certain extent below design temperature during the coldest weather conditions. This assumption is quite safe in the case of such systems because, among other things, of the inertia of the whole system, as has been shown in various district heating system’s behaviour studies. When selecting an outdoor design temperature for space heating, it is common to overlook temperature than occur less than 0.1% of the time, or 100 hours per year. This means that the design temperature will be the temperature above which outdoor temperature is 99.9% of the time. Such an analysis for the weather data available for Zharkent indicates an outdoor design temperature of -15°C.

The temperature duration curve indicates that there are 5 200 h per year, or about 220 days, on average with temperatures lower than 15°C. This indicator is relevant as an outdoor temperature lower than 15°C is considered the benchmark for space heating, i.e. if the temperature outdoors falls below 15°C then heating is required.

It is also interesting to note that there are 2 200 h per year on average, or about 90 days, with temperatures lower than 0°C.

5.2 District heating in Zharkent

Zharkent is a small town in the centre of the east Ily basin. The footprint of the town has been measured and estimated to be around 2 000 ha (20 000 000 m^2). The population is close to 35 000 or 17.5 persons per ha of land.

It is difficult to estimate how much floorspace must be heated without access to real building data. Evaluating the heat demand is also challenging with existing buildings of different age and type resulting in energy efficiency spanning the entire scale.

The building density is low since buildings are quite sparse. A rough estimate based on site visit and assessment of the maps provide give a building density of 0.2. On this basis, the heated floorspace in the town is assumed to amount 4 Mm^2.

5.2.1 Power and energy demand

To secure at least an 18°C indoor temperature, the heating system must be able to provide enough power to maintain 15°C. The remaining 3°C are emitted from people, lighting, cooking and other internal heat.

The assessment of power and energy requirements is based among other things on data from the local construction standards. In the absence of such information, the Consultants have assumed the power and energy demand based on weather data from nearby weather stations (Energy, 2018) and typical heat loss coefficient of buildings of 2.3 W/m^2 °C, which is not a very performant insulation and deemed to reflect the age and conditions of the buildings in Zharkent. Based on these premises, the peak heating power demand is estimated to be 70 W/m^2. The heat loss coefficient for buildings in

Reykjavík, Iceland is around 1.8 W/m^2 °C. Many new modern large apartment buildings in China have reported heat requirement as low as 1.6 W/m^2 °C.

Figure 34 shows the predicted duration curve for heating in Zharkent. The area under this curve is proportional to the number of degree-hours required for heating and gives a measure of the amount of energy required for space heating.

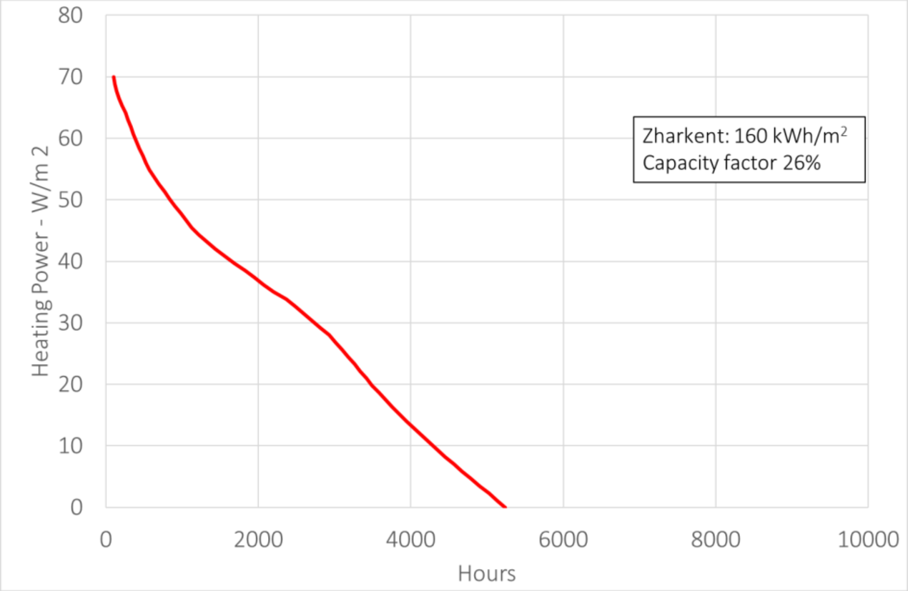

Figure 34 – Load duration curve for Zharkent

This curve enables to assess the total energy requirements for the system which is also an important element for the financial analysis because it indicates the energy that can be sold to the end users. The annual heating energy demand is represented by the area under the load duration curve, or 160 kWh/m^2 (0.138 Gcal/m^2).

It should be noted that according to published data from World Bank (World Bank, 2018) the average energy demand in Almaty is 180-200 kWh/m^2 (0.154-0.172 Gcal/m^2). This value looks rather high, and the likely explanation is energy waste resulting from poorly insulated buildings and more importantly, the very low price of heating energy in Almaty leading people to pay less attention to their energy bill. The Consultants did not investigate in detail the temperature duration curve for Almaty for comparison, but it is assumed to be similar to Zharkent.

The capacity factor is calculated 26% (160 kWh / (0.070 kW x 8 760 h)) for the city of Zharkent. The fact that this value is low has an impact on how the energy combination will be planned for. It will hardly be feasible to provide energy solely from geothermal in these conditions because this would imply drilling many wells, resulting in high investment cost compared to their overall use over the year. For comparison the capacity factor is 50% in Reykjavík, Iceland.

5.2.2 Geothermal district heating concept

A geothermal district heating system is usually composed of a combination of primary geothermal, secondary geothermal with heat pump and gas boilers to extract as much from the geothermal fluid before re-injection. A correct combination of the above is influenced by the load duration curve, the capacity factor and the cost of the various heat sources. Figure 35 proposes a schematic overview of such concept.

The temperature of the geothermal fluid is assumed to be 100°C @ 4,000 m depth near Zharkent. The geothermal flow is 40% of the secondary district heating flow.

At maximum power the geothermal flow is cooled directly from 100°C to 40°C by heating 50% of the secondary distribution water from 35°C to 83°C. It is then further cooled to 10°C in a loop connected in serial where a heat pump is used to transfer the 40/10°C drop to a 35/67°C temperature increase in the secondary loop. The secondary fluid of 83°C is mixed with this 67°C flow from the heat pump resulting in 75°C secondary fluid upstream of a gas boiler. Finally, the gas boiler is used to raise the supply temperature up to 85°C.

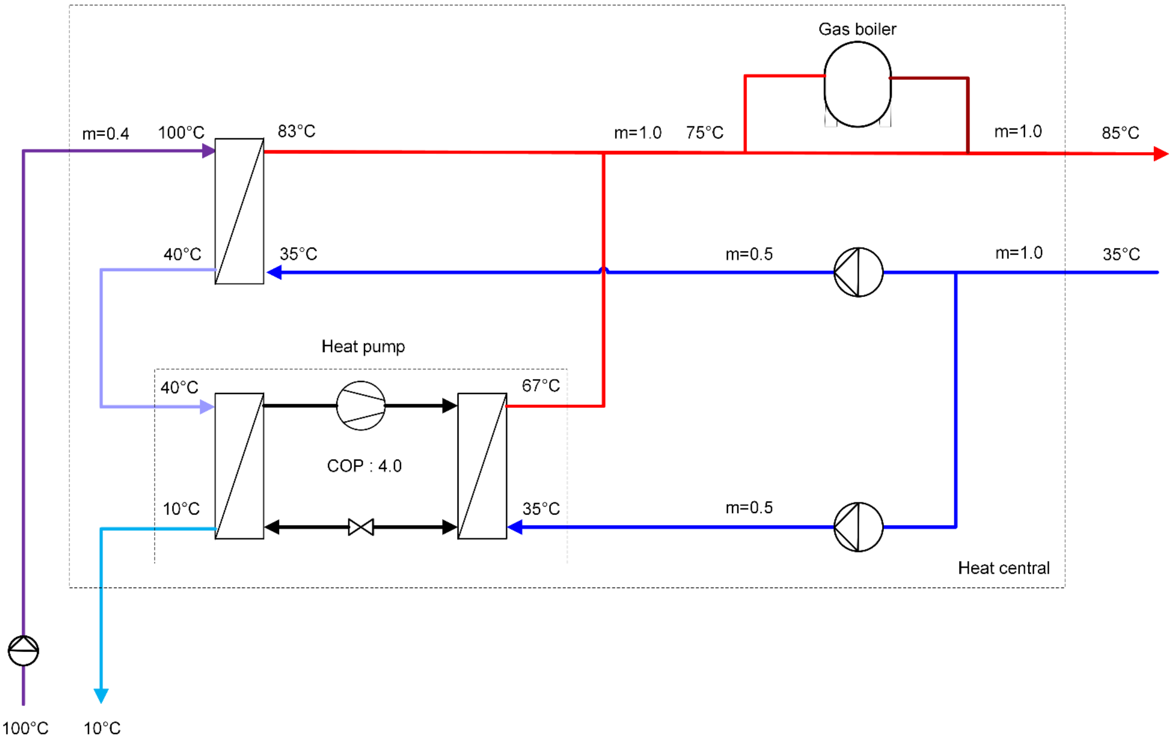

Figure 35 – Heat central concept for the district heating system in Zharkent

The proposed concept enables to make the most of the geothermal wells without compromising the sustainable use of the resource. The gas boiler is only intended for the coldest weather period, to boost the temperature of the system without increasing the amount of geothermal fluid extracted from the system. Return temperature of a district heating system cannot be much lower than 30-35°C but the installation of a heat pump on the return pipe main enables to optimise the energy extraction from the geothermal fluid and return it to the geothermal system at about 10°C. The main goal of such a setup is to squeeze as many degrees from the geothermal fluid as possible before reinjecting it.

It should be noted that on top of the load and energy calculated in the section 5.2.1 for the users, the heat central will have to be able to cover the heat losses in the distribution system. The heat losses have been assumed to be 12%, a rather high value compared to other places in the world mainly because of the extreme local weather conditions. The maximum power is thus 78.5 W/m^2 at heat central level, or **314 MW** for Zharkent. Based on this, the circulation flow is thus about 1 500 kg/s.

In general, a geothermal district heating system will be optimal from the economical point of view with an installed geothermal power ranging from 40 to 80% of the total peak power. This mainly depends on the type of additional energy and on the local conditions (drilling costs among other things). Nevertheless, since geothermal energy is always used for the base load, the share of energy provided by the geothermal system can turn out to be rather high, from 70 to 90%, depending on the shape of the load duration curve.

For the present case, the authors have assumed that the geothermal production system will be able to cover about 70% of the power demand. Table 10 presents the values obtained for the Zharkent geothermal district heating as proposed in this study.

Table 10 – Power and energy at heat central level in Zharkent

	Heating power, W/m²	**% of power**	**Energy kWh/m²**	**% of energy**
Primary geothermal loop (Temperature drop: 100°C to 40°C)	37.8	48	133	73
Secondary geothermal loop (Temperature drop: 40°C to 10°C)	18.9	24	31	17
Electrical energy from heat pump	6.3	8	10	6
Peak load boiler, gas	15.4	20	6	4
Total	**78.4**	**100**	**180**	**100**

At maximum power the geothermal covers 225 MW or 72% of the 314 MW in total, resulting in a maximum geothermal flow of 600 kg/s.

It should be pointed out than the annual energy from geothermal is (133+31) 164 kWh/m^{2}or 91% of the total amount of energy provided to the district heating system. For a system supplying energy to 4 Mm^2 as suggested for the Zharkent city, this equals to about 656 GWh (564 000 Gcal) per year or 2 360 TJ. The remaining energy is from electricity and gas.

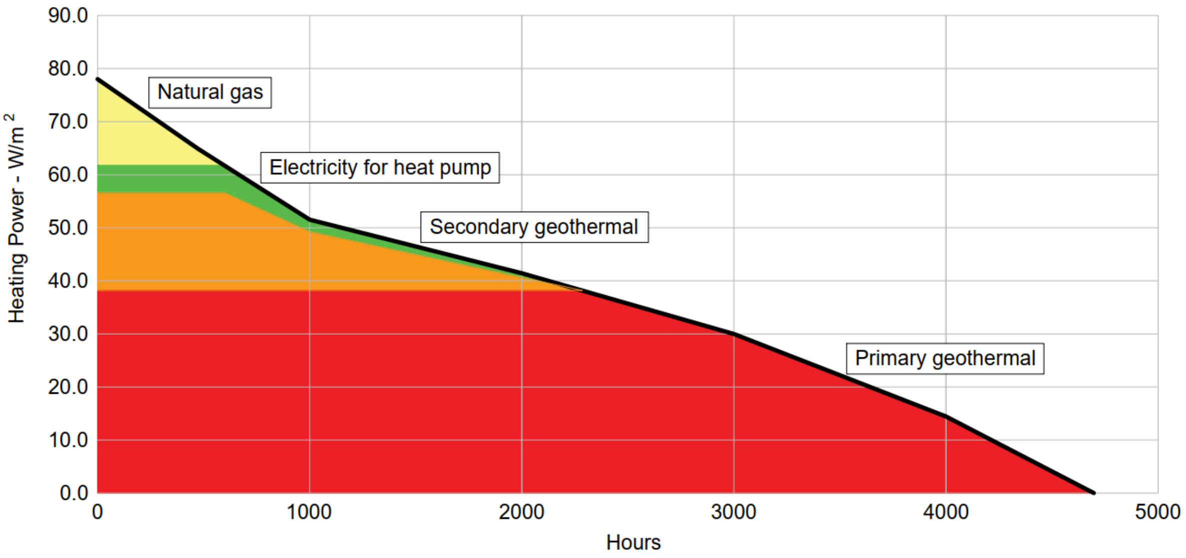

Figure 36 - Estimated power duration curve and energy input for a heat central in Zharkent.

Figure 36 shows graphically the heating power per m^2 of heated floorspace as a function of the duration in hours over the year, the so-called power duration curve. The area, shown below the power duration curve represents the annual heating energy.

Adjustment of the share between geothermal, electricity and gas is in fact an optimization exercise, based on actual price of electricity and gas, cost of drilling etc. The mix of energy input for heating as set forth in Figure 36 is not necessarily the most optimum combination but is an educated guess based on the consultant's experience from similar projects. Low gas cost will most likely reduce the geothermal share and in some cases rule out the heat pump share. Such adjustment would have to be done on a case by case basis depending on basic project parameters such cost of drilling and resource characteristics.

5.2.3 Cost estimates

Based on the cost information provided in section 4.4.1, preliminary cost estimates of the proposed geothermal district heating in Zharkent is set forth in Table 11.

Table 11 – Preliminary Capex for the proposed geothermal district heating in Zharkent

	Units	Quantity	Unit price, MUSD	Total cost MUSD
Geothermal production[1]	Number of doublets	5	8.25	41.3
Pipe main/transport[2]	km	5	2.2	11.0
Heat centrals	MW	314	0,12	37.7
District heating system	ha	2 000	0,05	100
Total				**190**

[1]: Drilling production and re-injection wells including resource gathering system for 600 kg/ of 100°C geothermal fluid assuming large wells at 3 600 m depth.

[2]: Transport of fluid from well field to heat central(s)

The total investment cost is estimated to be 190 MUSD for the whole system. This results in 47.5 USD per square meter of heated floorspace or 5 000 USD per household.

As discussed before, there are two major variable operational cost parameters involved, electricity and natural gas. Peak load boilers using conventional sources of energy such as natural gas or coal are well known technologies. In terms of investment, they are among the cheapest technologies available on the market today to produce heat at large scale. Their maintenance cost is usually low. However, their operational cost will highly depend on the gas price that may fluctuate depending on the international market. the same goes for heat pumps assumed to be powered by electricity. It is assumed here that the electricity price and gas price are according to information provided by MoE.

Table 12 – Annual Opex estimate for the proposed geothermal district heating in Zharkent

	Units	**Quantity**	**Unit price, USD**	**Total cost MUSD**
Gas for peak load boilers	kWh/year	24 000 000	0.018	0.43
Electricity for heat pumps	kWh/year	40 000 000	0.054	2.16
Electricity for well pumping	kWh/year	5 000 000	0.054	0.27
Electricity for DH pumping	kWh/year	3 000 000	0.054	0.16
Maintenance cost, 2 % of CAPEX	2.0%	-	-	3.80
Other cost, billing etc	-	-	-	1.00
Total annual Opex				**7.82**

5.2.4 Cost of space heating with geothermal for Zharkent town

No detailed financial and economic analysis is available for the time being. However, it is possible to establish a preliminary estimate based on the following:

- Capital cost in year 1: 190 MUSD;
- Annual operating cost: 7.2 MUSD, starting from year 2 for 24 years;
- Annual energy sold to end-users: 160 kWh/m^2 x 4 Mm^2= 640 GWh;
- Energy price 4.5 US¢/kWh (calculated based on the below IRR);
- 10% project IRR requirement over 25 years.

The energy price of 4.5 USD US¢/kWh sold to the end users is provided here for the sole purpose of giving an order of magnitude of the geothermal energy district heating energy price.

It should be noted that this value is comparable to the price of local house heating with gas. Heating with gas locally costs 1.80 US¢/kWh according to MoE.

Geothermal has the advantage of being a cleaner and local source of energy, with minimum impact in terms of greenhouse gases than gas and contributing to enhancing energy independence of the local community.

5.2.5 Cost of Geothermal only (not distribution)

If a developer is to only harness the energy and operate the heat central, i.e. the responsibility of the distribution system is not in his scope, the preliminary estimate based on the same assumptions as before will be the following:

- Capital cost in year 1: 90 MUSD;
- Annual operating cost: 5.42 MUSD, starting from year 2 for 24 years;
- Annual energy sold to Distribution company: 180 kWh/m^2 x 4 Mm^2= 720 GWh (Including DH losses);
- Energy price 1.9 US¢/kWh (calculated based on the below IRR);
- 8% project IRR requirement over 25 years.

Resulting energy price to the distribution system company is 1.9 US¢/kWh. Note that 8% IRR is used instead of 10% because the operation and selling heat to all customers in the town is now not the developer's responsibility. The buyer of the energy is now only one, the distribution company, possibly a public entity and therefore the financial operational risks are lower.

It should be noted that this value is comparable to the price of powering a district heating heat central with gas only. Gas for the developers costs 1.8 US¢/kWh according to MoE. This means that harnessing geothermal to supply heat centrals for district heating system is in a similar price range as in the case of a system fuelled with natural gas based on current price.

5.3 Binary power generation

5.3.1 Power plant concept

The authors of the report suggest having the binary power generation case study as follows:

- Net installed power of 10 MW$_e$; and
- Resource temperature: 125°C.

Based on a conversion factor of 10.4% as indicated in Table 9, the geothermal heat input needed for such a power plant would be 96 MW x 8 760 hours = 840 GWh per year, or about 3 000 TJ/y.

Based on the available information on the geothermal resource, a temperature of 125°C would be available at 4 000 meters depth. The plant would require three large geothermal doublets at 4 000 m depth and able to supply altogether 330 kg/s of 125°C geothermal fluid. The fluid would be cooled down to 57°C in the process before reinjection.

5.3.2 Cost estimates

Table 13 below presents a preliminary cost estimates for the proposed geothermal power plant.

Table 13 – Preliminary Capex for the proposed 10 MW_e geothermal power plant in the Zharkent basin

	Units	Quantity	Unit price, USD	Total cost MUSD
Geothermal production[1]	Number of doublets	3	10	30
Power plant	MW (net)	10	3.0	30
Total				**60**

[1]: Production and re-injection wells including resource gathering system for 330kg/ of 125°C geothermal fluid to at least 4 000 m depth.

Regarding the operation cost, it is foreseen that the geothermal loop will require pump of 330 kg/s at a depth of 200 m, resulting in a power request of 1.3 MW. Other operation and maintenance costs are as discussed in section 4.3.3. The estimated operation and maintenance costs are shown in Table 14.

Table 14 – Annual Opex estimate for the 10 MW_e geothermal power plant in the Zharkent basin

	Units	quantity	Unit price, USD	Total cost MUSD
Maintenance cost, 3% of CAPEX	3%	-	-	1.8
Other cost, billing etc	-	-	-	0.5
Total annual Opex				**2.3**

5.3.3 Cost of electricity to the grid

It is not relevant to conduct a detailed financial and economic analysis at this stage. However, it is possible to establish a preliminary estimate based on the following premises:

- Annual net energy from the Binary Cycle: 83 GWh/year;
- Annual electricity for well pumping: 11 GWh/year;
- Annual electricity sold to the grid: 72 GWh/year;
- Discount period 25 year;
- 8% project IRR;
- Calculated energy price: 11 US¢/kWh.

The minimum energy price resulting from this preliminary estimate is 0.11 USD per kWh and is provided here for the sole purpose of giving an order of magnitude of the price of electricity from geothermal with the setup proposed here.

Note that the such project could receive additional income from selling residual heat from the brine at 60°C to users such as greenhouses or aquaculture.

5.4 Conclusion on potential utilisation case studies

From the technical point of view, the feasibility of the case studies presented here will highly depend on the characteristics of the geothermal resource. Nevertheless, based on assumptions that are deemed prudent compared to the information readily available, the case studies show that the cost of energy for heat and electricity is of the following order of magnitude:

- Heat price for end users at district heating level: 4.5 US¢/kWh;

- Heat price for heat central: 1.9 US¢/kWh;
- Electricity price: 11 US¢/kWh.

It should however be pointed out that the prices shown here would appear to be high compared to various energy price information collected via the Internet most likely due to the current energy policy and energy subsidy. This issue is further discussed in chapter 6.

The implementation of a geothermal district heating will also be highly dependent on the ability to have an energy density as high as possible with a massive connection to the users nearby the distribution system. This is considered a critical issue together with the energy efficiency of the buildings and their modernization. With this regard, the authors consider that metering and tariff will be critical tools to promote sustainable use of the resource and ensure that a large part of the community can be supplied with energy from the geothermal system.

Regarding the electricity production case study, it should be borne in mind that geothermal energy is considered a baseload, available all year long at stable price irrespective of the weather or fossil fuel prices. Very few renewable energy sources present such advantage.

6 Strategy for implementation of geothermal utilization

6.1 Benefits

There are various known benefits associated with the harnessing of geothermal energy. In Kazakhstan these would relate to environmental issues as well as the economy of the local areas involved. The below highlights the main benefits presently identified.

6.1.1 Air quality

The reduction of air pollution due to the production of energy for space heating and for the heating of domestic hot water is one of the main advantages of a geothermal district heating system.

Fuelling of district heating systems with oil or coal results in release of air pollutants such as carbon monoxide, sulphur dioxide, particulate matters and other organic and inorganic air pollutants. The implementation of a geothermal district heating system will contribute to achieve significant reduction of local air pollution.

6.1.2 Greenhouse gases

Another environmental benefit associated with the geothermal utilization is associated with the fact that geothermal energy is classified as a renewable energy resource that can replace production of energy by conventional energy systems emitting greenhouse gases. Greenhouse gases (GHG), such as CO_x, CH_4, CFCs (list non-exhaustive) have a potential for negative impacts on global climate and are the object of international agreements for the reduction of their emission. Part of those gas emissions comes from the energy production from fossil fuels such as coal, oil and gas.

Some geothermal systems contain various gases, but their composition varies from one resource to the other. Using a geothermal doublet with full reinjection, as is introduced for both the binary power generation and the district heating system case studies, will in most cases allow for full reinjection of the gases, resulting in a project free from greenhouse gas emission.

GHG emissions are usually given in equivalent tons of CO_2. Carbon credits may be a source of income in the future although this market is currently weak. Depending on the economic feasibility of a project, it is possible to consider calling for extra credit via the Clean Development Mechanism in place in the framework of the Kyoto Protocol. Certified Emission Reductions, tons of avoided CO_2 emissions per year, could possibly be sold and contribute to the economical attractivity of the project.

6.1.3 Local source of clean energy

Geothermal energy is an indigenous source of clean energy and can contribute as such to “clean energy” independence of Kazakhstan.

As previously mentioned, geothermal energy is an excellent candidate to provide baseload, available all year long at stable price no matter the weather or the fossil fuel prices. It is therefore important to consider this source of energy in the energy mix of Kazakhstan.

Finally, geothermal energy could contribute to strengthening the supply of energy close to populated areas and avoid high transmission losses over long distances. Although power transmission losses are quite comparable with other countries, with about 7% of power output in 2018[19], the scattered population and size of the country makes it challenging to transport electricity in an efficient manner. Developing a geothermal power project in the Zharkent basin, close to a populated area, could e.g. be an efficient way to strengthen the power sector.

6.1.4 Value creation

As previously mentioned regarding the “Geothermal Resource Park” model, there is more to geothermal than just the energy. A carefully planned geothermal project aiming at integrating the resource exploitation activities in the community can potentially create more jobs than just the jobs of the power and/or district heating operators. Planning for instance for an eco-park close to a geothermal project will create further jobs and can sustain a whole economic ecosystem at the community scale by enabling all kinds of complementary activities such as food production and food processing, tourism, well-being industry, etc. The diversity of activities that may result from the utilisation of geothermal resources is an important factor to be considered by policy makers and project developers.

From the industry sector viewpoint, using geothermal resources in an industrial process or in general as part of the business activities is a way to develop “green products” and “green services” and can be also seen as a selling point, giving a competitive edge.

Finally, an important factor is the enhanced quality of life with, as previously mentioned, improved air quality but also access to a source of energy that, if used in a sustainable manner, will have a stable price.

6.2 Barriers

In addition to the benefits of geothermal utilization, various identified barriers exist. It is crucial that these be addressed and analysed prior to large scale harnessing as mitigation will increase the likelihood of success. The main barriers to utilization in Kazakhstan are considered to be those described below.

6.2.1 Resource risk

Because of the nature and location at great depth in the Earth’s crust, there is considerable risk associated with the development of geothermal resources. This resource risk is greater than the risk associated with other renewable energy resources but outweighed by the 100% availability of geothermal. This risk is variable depending on the nature of specific geothermal systems and on the stage of development. The risk is often higher in fracture-controlled systems than in sedimentary systems (see Chapter 2). It is also much greater during the initial stages of development than during later stages when much more information has been collected, through comprehensive exploration and deep drilling. This risk can be minimized by comprehensive research, both prior to drilling and during the drilling phase of the development of a geothermal project.

A big part of the resource risk is the actual drilling risk, which e.g. involves whether wells encounter the permeability (and hence well flow-rates) and reservoir temperature expected. This risk is minimized again by comprehensive research, and especially by incorporating new data and lessons learned from each new well drilled. It can be mentioned that in the case of the sedimentary geothermal resources of Kazakhstan that once the first exploration wells have been drilled, and they have located productive sedimentary reservoir layers, the drilling risk declines significantly because of the horizontal continuity of the sedimentary layers (applies especially to sandstone layers). The

---

[19] https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS?end=2014&start=1991&view=map

International Finance Cooperation has published a comprehensive study of worldwide drilling success in the geothermal industry (IFC, 2103), which constitutes a useful reference.

There are also risks associated with the well-drilling itself, just as in the petroleum industry, e.g. well collapse to name the most serious risk. This risk is minimized by using qualified and experienced drilling contractors, as well as by learning from previous drilling operations in a given area.

There is also considerable risk associated with assessments of the capacity of geothermal resources (see Chapter 2). Initially, the capacity can only be approximately assessed (e.g. by volumetric assessment), while later in the development, when wells have been drilled and the reservoir tested or even utilized, the capacity can be assessed much more accurately (e.g. by numerical modelling).

Finally, it should be emphasised that the best way to avoid overexploitation associated with the resource risk is stepwise development. i.e. developing a resource in relatively small steps over a longer period. The first step should be well below the estimated capacity as well as providing essential information on the resource capacity as the first step progresses.

6.2.2 Legal framework for geothermal utilisation

To our knowledge, there is currently no specific legal framework in Kazakhstan concerning the utilisation of geothermal resources. This could be a serious barrier for investors wishing to develop projects in this field in the country due to the resulting uncertainty on issues such as ownership, licensing, fees, monitoring, etc. On the other hand, a carefully designed legal framework will protect the interest of the country by setting clear rules on utilisation, providing guarantees on use rights, determine price mechanism, tax issues as well as environmental and monitoring issues.

These aspects have not been investigated in the framework of the present Study but are considered paramount for promoting the development of geothermal in Kazakhstan without jeopardizing its future.

6.2.3 Market environment for enabling district heating

District heating is often a viable solution for communities because its scale allows for more efficient energy supply and reduced operation cost. In the case of a geothermal district heating system, it will additionally reduce air pollution and CO_2 emission, compared to individual conventional systems.

It is however important to note that a key parameter for the success of a district heating system is the energy density of the area served and accordingly the heated area connected. With this regard, one should in most cases aim at connecting as many users as possible. This issue can be tackled at local level in different ways, for instance either in the urban plan or in agreement with local stakeholders.

Further to this, most of the issues already pointed out in the recent study on “Modernization and Financing Mechanisms for DH Sector and Other Municipal Services” (The World Bank, 2015) are also valid for enabling geothermal district heating projects.

6.2.4 Space heating issues

The end-users are a critical component of direct utilisation of geothermal resources, especially in the perspective of designing an economic and sustainable system that will be available to the local community in the long term. Energy efficiency of the buildings and of the heating systems will be an issue.

Four aspects should be mentioned here that will require specific attention:

- Buildings must be reconstructed in terms of thermal insulation parallel with implementation of modern geothermal district heating;
- The heating devices used should be designed to obtain a return temperature to the resource as low as possible with the aim of optimizing its utilization;
- The metering and tariff systems should encourage both energy-saving behaviour and optimum energy extraction; and
- Energy prices must be reasonable to secure the development of the latest geothermal technology and enhance energy savings at customer level.

In practice, this means that development of a district heating system in an already existing neighbourhood might imply modification of the heating equipment of the users. Also, incentives to change habits related to the use of conventional fossil fuels will have to be created. Objectives of such incentives would be to promote sustainable utilisation of the resource, for instance via a special metering and tariff system. For further details, see discussion on these issues in section 4.4.1.

6.2.5 Price of thermal energy

The case studies evaluated suggest that, although the prices remain indicative at this stage, heat from geothermal could be competitive with heat from other sources of energy with a price of 1.9 US¢/kWh at heat central level, comparable to the current price of thermal energy produced from gas, sold at benchmark price.

Heating price of 4.5 US¢/kWh to individual end users connected to a geothermal district heating system is high compared to conventional district heating in Kazakhstan but comparable to international benchmark prices.

The authors of the report have received indication on district heating energy prices at end user level in Almaty, in the range of 1.0 – 1.5 US¢/kWh, which appear to be very low and must be heavily subsidised. This energy price is even not high enough to pay for the transportation and distribution cost of the heat (district heating water) in the city.

Although the prices calculated for the Zharkent case study compare well with benchmark values outside of Kazakhstan, the current low price of conventional district heating energy in Kazakhstan could be a barrier to the development of a geothermal district heating projects.

High upfront cost is often pointed out as a disadvantage for the implementation of geothermal direct use projects. However, such projects usually have during their lifetime much lower operation and maintenance cost, mainly because, unlike in conventional projects, there is almost no need for buying energy. Geothermal projects are furthermore almost non-dependent on the fluctuation of the energy market for the operation.

6.2.6 Price of electricity

With an estimated price of electricity to grid of 11 USD US¢/kWh determined in the case study, the price of electricity from a binary power plant appears to be in the upper range of the electricity prices seen in the various regions of Kazakhstan. One of the main advantages of electricity from geothermal compared to other renewable sources of energy is that it is a baseload, able to produce energy at almost constant level, no matter the weather or other external factors.

Compared to recent wind projects in Kazakhstan where offered price of electricity was around 5 US¢/kWh, geothermal electricity looks unattractive. However, one must keep in mind that the capacity factor for geothermal electricity is 90% compared to 35% for wind projects. In this regard, geothermal power is attractive as part of the renewable energy mix of a country.

Harnessing the geothermal resources in Kazakhstan for electricity production is technically feasible. The case study presented indicates that if the Government of Kazakhstan decides to put geothermal energy on the agenda as part of its electric energy mix, it will most likely have to put in place incentives and mechanism to compensate for the lack of competitivity that has been identified in this preliminary assessment.

6.2.7 Knowledge and capacity building

As may be expected in a country with few projects in operation, that there are currently very few clearly identified players in the field of geothermal in Kazakhstan.

For comparison, it is estimated that about 1 500 to 2 000 people work directly or indirectly in the field of geothermal in Iceland, a country with a population of about 350 000. The activities related to geothermal span various types of companies or entities such as energy companies, services companies, suppliers, contractors and various institutions (Íslandsstofa, 2016). The professions involved are various and form a complete chain of knowledge from legal to technical, education and social sciences. This illustrates how diverse the activities related to geothermal utilisation can be. It took Iceland many decades to get there by developing the 2.4 GWh_{th} district heating systems and 700 MW_e geothermal power plants. This can give an order of magnitude of the impact such sector might have on a society. However, such process may take time, following a certain learning curve and it requires a vision at national level.

6.2.8 Social acceptance

Sometimes social acceptance is a big issue in geothermal activity, mainly when harnessing from high temperature areas. But there is also some concern for low-temperature utilization as well. Earthquakes due to re-injection and risk of water pollution, mistakes, general acceptance of new projects and source of energy unknown to local people. Such issues are easily avoided with appropriate communication and implementation of the sector’s best practices.

6.3 Recommendations

Based on the results of this Study the following recommendations are made, regarding the next steps towards comprehensive understanding of the geothermal resources in Kazakhstan and their future large-scale utilization.

6.3.1 Further resource assessment

- A comprehensive country-wide compilation and evaluation of data, existing in the archives of Kazakhstan, from wells drilled in Kazakhstan having hydrothermal indications. These will mostly be petroleum exploration wells, but also other deep wells with some drilled specifically as geothermal wells. The emphasis should be on temperature conditions, types of reservoir rocks, rock permeability, tectonics (faults, fractures and their nature), pressure conditions, flow-rates and chemical composition. The compilation should also include compilation of surface exploration data, i.e. seismic exploration data collected by the petroleum industry as well as other surface exploration data (geology and geophysics) collected for petroleum exploration and hydrogeological research. Such a comprehensive compilation is comparable to what has e.g. been done in Hungary, where geothermal conditions are comparable to those in Kazakhstan[20]. Even though the compilation should be country-wide, and without a-priori assumptions, the efforts may prioritize the Ustyurt-

---

[20] Tulinius et al., 2010

Buzashin, Mangyshlak, Almaty and the Zharkent regions, as well as possibly the Aral region, as indicated by the results of this Study.

- Following this compilation further exploration should be planned[21,22] to fill gaps in the existing data for selected resource areas, e.g. MT resistivity surveying (is often helpful in geothermal exploration) as well as other geophysical surveying (gravity, magnetic, etc.), geological mapping/exploration and geochemical studies. Here the IFC Geothermal Exploration Handbook[23] can be of valuable help as well as the ESMAP Geothermal Handbook[24].
- It is, furthermore, recommended that a data base specific to geothermal resources in Kazakhstan be set up incorporating geothermal conditions and likely resource potential.
- Following these steps conceptual models should be developed through the integration of all available data/information across all disciplines of science and engineering involved[25], both generally on a basin-wide scale and more detailed conceptual models for selected locations, which are of greater interest and where information is sufficiently detailed.
- Consequently, drilling of exploration wells (either slim-holes or full-scale wells), and later production wells should be planned[26].
- Once wells have been drilled they should be subjected to logging, testing, monitoring and resource assessment and modelling (see chapter 2). Resource capacity assessment is a critical part of any utilization plans, where data from surface exploration, exploration drilling and testing is used, based on an accurate conceptual model.
- The relevance/importance of reinjection for future sustainable utilization should also be studied at each location. This will depend on local hydrological conditions (recharge, i.e. boundary conditions), chemical content of the geothermal water, etc.

6.3.2 Enabling environment (legal, market and institutional)

Legal framework

An evaluation of present legal-, institutional-, regulatory- and permit-framework with suggestions for improvements is recommended. This should also involve an evaluation of possible support and tariff-framework as well as data management.

The development of geothermal utilisation may need review of components of the legal and regulatory framework such as:

- National Energy Policy

---

[21] Steingrímsson, B. (2014): Phases of Geothermal Development in Iceland from a Hot Spring to Utilization. Presented at “Short Course VI on Utilization of Low- and Medium-Enthalpy Geothermal Resources and Financial Aspects of Utilization”, organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, March 23-29, 2014. https://orkustofnun.is/gogn/unu-gtp-sc/UNU-GTP-SC-09-01.pdf

[22] Richter, B. et al. (2014): Geothermal Exploration Associated Cost in Iceland. Presented at “Short Course VI on Utilization of Low- and Medium-Enthalpy Geothermal Resources and Financial Aspects of Utilization”, organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, March 23-29, 2014. https://orkustofnun.is/gogn/unu-gtp-sc/UNU-GTP-SC-18-32.pdf

[23] Geothermal Exploration Best Practices IGA Service GmbH 2013

[24] ESMAP Geothermal Handbook: Planning and Financing Power Generation

[25] Axelsson, 2013

[26] NZS 2403:2015 Code of practice for deep geothermal wells

- Regulatory provisions on (list non-exhaustive): electricity, district heating, environment, water and agriculture, rural development, finance, land and property, mining, procurement and foreign investment.

The Geothermal Transparency Guide (BBA Legal, 2016) provides an overview of the legal and regulatory framework governing exploration, exploitation and production of electricity from geothermal resources for 16 countries where geothermal resources are being harnessed or are available for harnessing. It outlines key issues to be taken care of when designing the legal framework for geothermal, but each setup is adapted to the local particularities. A thorough review of the legal and regulatory framework in Kazakhstan is necessary to set-up clear game rules for potential project developers, protect the country's interest and make sure that geothermal is an option for electricity and district heating in line with the national objectives.

Geothermal Management Authority

GoK should consider having an entity with the authority necessary to manage permitting and licensing as well as monitoring. Specific attention should be paid to the management of concessions and the decisions related to electric production.

Because of the great areal extent of most sedimentary geothermal resources, several concessions may be granted to different developers once development and utilization starts, covering the same geothermal system. This will ultimately cause problems as production in one concession will cause a water-level draw-down in other concessions near-by and vice-versa. For long-term sustainable utilization of geothermal resources in such situations, comprehensive resource management must be applied. This includes, to name the most significant aspects:

- Comprehensive monitoring of mass extraction and reservoir response (water-level and temperature changes).
- Limiting extraction through government initiatives/regulations.
- Providing exclusive rights to experienced/responsible companies.
- Applying reinjection (which limits interference between concessions, if close to 100%).

Local governments should dictate this management through various means, both on local and countrywide scales.

Energy market and existing infrastructure

With about 60% of urban population currently serviced by district heating, there appears to be a strong tradition of using such systems. However, this sector seems to be rather weak with inefficient operation and current state of the installation in poor condition (The World Bank, 2015). Pricing is a key issue, not an easy one in a context of energy poverty and where existing systems may benefit from subventions. The case of geothermal utilisation for space heating should be integrated in the overall country energy policy to ensure that its implementation is not blocked due to prevailing subsidies or under-pricing of input energy sources when in competition with another source of energy benefiting from subventions. In this regard, estimation of cost of services for heating and electricity, assessment of direct or indirect energy subsidies, and review tariff policy are recommended.

Renewable energy resources appear to be unevenly distributed over the country. With a scattered population and a large country, the strength of the transmission grid may be an issue for electricity. Geothermal energy could contribute to strengthening the grid in area where it is available. Such projects should be assessed on a case by case with regards to the role in the regional energy security scheme.

General risk assessments should be conducted on the different aspects of geothermal development, e.g. on risks associated with public or private sector development, risks associated with tenders for international markets, etc.

Pricing policy for electricity from geothermal

It is critical for the Government of Kazakhstan to design a pricing mechanism that attracts investors and is enables at the same time affordable energy prices for the users. Various mechanisms are currently used for electricity from geothermal such as Feed-In Tariff, energy auction tariffs, negotiated prices, etc. There are pros and cons for each method and the design of the pricing policy will depend on the Government of Kazakhstan's objectives in terms of renewable energy targets, price to users, attractivity of the sector and so forth.

It is not possible to opine on the best mechanism at this stage without assessing thoroughly the context in Kazakhstan. This issue should be investigated and tackled as part of the legal and regulation framework design.

Feasibility of a project will not only depend on the construction and development cost but also on the operational cost and of course on the amount of energy that can be sold to the grid and at what price.

Regarding the price, many countries tackle this issue with specific tariffs for electricity from renewables, including a tariff for geothermal. There are however many other ways to determine the price of electricity from geothermal as is presented in the "Geothermal transparency guide" (BBA Legal, 2016) . In some cases, developers must reach a power purchase agreement (PPA) with relevant authority to secure the remuneration of the energy produced in the mid and long term.

Attracting investors

In the early stages of establishing a geothermal energy market, such as the potential one in Kazakhstan described in this report, it is considered to increase the likelihood of success if investors are selected on a competitive basis and not through unsolicited proposals.

Apart from the issues mentioned above concerning the creation of an environment favourable to investment in the geothermal sector and aimed at reassuring investors that their project will be viable in the medium and long term; various policy aspects require careful consideration:

- Technical and financial capacity of the geothermal players: it is not enough that the geothermal investors have financial capacity to successfully implement geothermal project, technical capability and proven record of projects in this fields are also important factors;
- Purchasing power of the users, such issue is critical to the success of the energy transition policy of Kazakhstan in general. This means that whenever geothermal energy is less attractive than an existing conventional system in the current context, it should be assessed based on long term price forecast, bearing in mind that geothermal is rather stable in terms of price. In practice, the Government of Kazakhstan should investigate financial tools such as subvention, tax reduction or other incentives to promote renewable energy in general and geothermal in particular;
- Political issues: the decision to undertake implementation of renewable energy projects is often initiated from a political will because it requires vision to follow such path. It is crucial that it is supported widely by the society, possibly following its leaders. Another highly sensitive issue on the political agenda is the implication of the public entities, how much access to the natural resources is granted to private companies and under what conditions.

Creating a framework for private investment is a matter of policy at national level, i.e. whether energy companies should be public and/or private, whether Public Private Partnership (PPP) setup is feasible or not and under what conditions, etc. Should partners external to Kazakhstan be an option for the Government of Kazakhstan, various criteria such as experience, track record, social and environmental policy, should be taken into account apart from the usual financial capability.

- Licensing and use of national resources: the length of exploration permits should be determined in the legal framework to make sure that once developers obtain an exploration licence, they swiftly undertake necessary steps to assess the resource. Also, exploitation licence and financial framework for granting of a licence are critical aspect to setup a fair and encouraging framework for exploitation of geothermal.

6.3.3 Capacity building

Speeding-up development of geothermal utilization is easier today because this sector has grown quite a lot in the past decades and both experience and knowledge are available among the current players in this sector. However, the set of basic competence required for developing geothermal projects includes major scientific and technical competence in disciplines such as geology, geochemistry, geophysics, reservoir engineering, environmental science, geothermal drilling and geothermal engineering. Although the authors have not been able to see any figures on trained people in these fields, the lack of currently ongoing projects indicates that there may be just a few people trained and experienced, currently working in Kazakhstan.

The authors highly recommend designing the strategy for implementation of geothermal utilisation in such a way that the Government of Kazakhstan receives support and training from experienced partners in this field worldwide. Such training should not only concern the public partners but also potential developers willing to go into geothermal. Also, when attracting private investors in the geothermal projects, it is critical to select them based on criteria such as track record, social and corporate responsibility, environmental health and safety policy, to name examples.

7 Conclusions

The main results of this study can be summarized as follows:

1. Kazakhstan holds considerable geothermal resources, only assessed to a limited extent, mainly in some of its fifteen deep sedimentary basins. This is confirmed by wells drilled, mainly as petroleum exploration wells, which have intersecting permeable structures yielding hot water. This is also supported by similarities with geothermal conditions in other countries where sedimentary geothermal resources are utilized on a large scale, such as in France, Germany, Hungary and China, to name a few well-known examples.

2. Considerable research has been conducted to assess the likely energy production potential of these sedimentary resources, even though such research has not been extensive during the last 2-3 decades. Information made available for this study demonstrating the potential, has to some extent been fragmented, incomplete and not always consistent. Comprehensive data related to the geothermal resources exists in the archives of Kazakhstan and should be compiled, data both from wells having hydrothermal indications, as well as surface exploration data.

3. Further analysis of a countrywide assessment by (Boguslavsky, 1999), which is considered reliable, has been further expanded in this study to estimate extractable energy density (TJ/km^2/yr) and yearly extractable energy per basin for four of the most significant basins. The most concentrated potential is estimated to be in the Ustyurt-Buzashin and Manguyshiak basins in SW-Kazakhstan and in the W-Ily (Almaty) and E-Ily (Zharkent) basins in SE-Kazakhstan. The first two are also amongst the basins with the greatest extractable energy per basin, by virtue of their relatively great surface area.

4. Initially this Study was to bring special focus on the Ily Basin and its Almaty and Zharkent sub-basins. During the October 2018 site visit to Kazaksthan, greatest emphasis was placed on the Zharkent sub-basin, as an initial example or case study. It also became clear that there was also specific interest in the Arys sub-basin of the Syr-Daria Basin as well as the Almaty sub-basin, because of potential geothermal resources within, or near, heavily populated urban centres. Even though the focus of this study was on the geothermal resources of SE-Kazakstan it may be pointed out that great geothermal potential is also expected in the Ustyurt-Buzashin basin in SW-Kazakhstan where petroleum exploration wells have demonstrated resource temperature as high as 150 – 160°C at 4 – 5 km depth, to name the most obvious example outside SE-Kazakhstan.

5. The Arys and Almaty sub-basins clearly hold extensive geothermal resources, albeit at relatively low temperature suitable for direct use, specifically space heating. Incomplete information indicates that well-head temperatures up to 75°C have been measured in producing wells in the Arys sub-basin and up to 85°C in the Almaty sub-basin. Corresponding reservoir temperatures are correspondingly higher. In the Arys sub-basin the geothermal water appears to contain relatively little dissolved solids (~1 g/L), while in the Almaty sub-basin the solid content appears to be much higher (up to ~ 15 g/L, or even higher). The potential of these sub-basins warrants comprehensive further studies.

6. According to available information, the geothermal resources in the Zharkent sub-basin appear most interesting because of higher resource temperature than in e.g. the Arys and Almaty sub-basins, low concentration of dissolved solids and powerful natural recharge. It is therefore suitable for demonstration projects. The Zharkent geothermal resources were also the focus of a recent, comprehensive geothermal assessment study, during which 11

exploration wells were drilled. Thus, more geothermal information/data is available for the Zharkent sub-basin, than for other locations in Kazakhstan. It should be pointed out, however, that even though the Zharkent basin appears most promising now, further research may locate other promising geothermal resources.

7. In addition to the relatively high resource temperature (depth), and low dissolved solids, geothermal conditions in the Zharkent sub-basin are in further ways favourable compared to other sedimentary resources in Kazakhstan and worldwide. The reservoir formations discovered reaching great depth outcrop at the surface in mountainous regions on the margins of the sub-basin and are provided with natural recharge through precipitation. This recharge is also demonstrated by high well-head pressure and artesian flow. Available information also indicates that this well-head pressure and artesian flow have not declined with time, which is generally the case in geothermal systems, sedimentary ones in particular.

8. The estimated extractable energy for the Zharkent basin is in the range of 20 to 160 TJ/km^2/yr, depending on resource temperature, and assuming a utilization period of 50 years. Hypothetically each km^2 could thus provide space heating for 200 to 1,600 inhabitants. The whole basin could similarly provide heat for roughly 1.5 million inhabitants. These numbers should not be taken literally, however, they're only presented to demonstrate the potential.

9. Because of the closed nature of most sedimentary geothermal reservoirs, reinjection is essential for their sustainable use. Otherwise water-level in the reservoirs will decline continuously with time and the hot water extraction can't be maintained in the long-term. This may not be immediately necessary in all locations in the Zharkent sub-basin, because of the natural recharge, but will become so with time and increased geothermal development. It will certainly be required from the beginning of large-scale utilization in most other sedimentary geothermal resources in Kazakhstan.

10. Reinjection is associated with some risks and challenges, with the main risk being possible cooling of near-by production wells. The most efficient way of assessing the danger of cooling of production wells due to reinjection is to perform so-called tracer tests and associated cooling modelling. The main challenge associated with reinjection into sedimentary geothermal reservoirs is the clogging of sandstone layers next to reinjection wells. A solution to this problem was developed in Germany/Denmark in the 1990's. An updated version of the European solution is e.g. successfully being adapted on a large scale in China.

11. Geothermal resources in Kazakhstan are low- and medium temperature resources. Large scale electrical power production is not expected to be competitive to other energy sources. Although at specific sites, where temperature is reasonable high, small scale geothermal electrical power may be installed and in combination with heat production to increase economic viability of such projects. The economic feasibility of such co-generation plants needs to be studied further for each instance under consideration.

12. Low and medium temperature geothermal resources are local energy heat sources and should therefore primary be used locally; as it is not possible to transport heat over long distances.

13. Kazakhstan should therefore primarily aim for direct use of geothermal resources; house heating, greenhouse heating, fish farming and other direct use applications.

14. The development of an efficient and comprehensive regulatory framework for geothermal utilization and district heating in Kazakhstan should be given highest priority.

15. Two hypothetical case studies in the Zharkent sub-basin are presented and analyzed. One involving space heating for the 35 000 inhabitants of Zharkent town and the other involving a 10 MW_e. binary electrical power plant utilizing the deepest part of the sub-basin, containing the hottest resources (125°C assumed). The 2 300 TJ/year needed to heat the town would require a drilling area of about 15 km^2 (2 300 / 155), which is somewhat less than the area of the town. A similar drilling area can be estimated for the 10 MW_e electrical plant. About 3 000 TJ/yr will be needed or an area about 14 km^2 (3 000 / 210).

16. From the technical point of view, the feasibility of the case studies presented here will highly depend on the quality of the geothermal resource. Nevertheless, built on assumptions that are deemed prudent based on information readily available, the heat price with geothermal district heating at end-user level is estimated at 4.5 US¢/kWh and the electricity price from a geothermal binary plant at 11 US¢/kWh. It should however be pointed out that the prices shown here would appear to be high compared to energy prices in Kazakhstan, as far as they were available for this Study, likely due to the current energy policy.

17. The implementation of a geothermal district heating will also be highly dependent on the ability to achieve an energy density as high as possible with a massive connection to the users nearby the distribution system. This is considered a critical issue together with the energy efficiency of the buildings and their modernization. In this regard, the authors consider that metering and tariff will be critical tools to promote sustainable use of the resource and ensure that a large part of the community can be supplied with energy from the geothermal system.

18. Regarding the electricity production case study, it should be borne in mind that geothermal energy is best used as a baseload, available all year long at a stable price no matter the weather or the fossil fuel prices. Very few renewable energy sources present such an advantage.

References

2017 The World Bank, Solar resource data: Solargis. (án dags.). Sótt frá https://solargis.com/maps-and-gis-data/download/kazakhstan/

Axelsson, G. (2012). Role and management of geothermal reinjection. *Papers presented at "Short Course on Geothermal Development and Geothermal Wells", organized by UNU-GTP and LaGeo*, (bls. 21). San Salvador.

Axelsson, G. (2013). *Conceptual models of geothermal systems – Introduction.*

Axelsson, G. (2016). Nature and assessment of geothermal resources. Santa Tecla, El Salvador: UNU-GTP and LaGeo.

Axelsson, G. S. (2005). *Sustainable utilization of geothermal resources for 100 – 300 years.* Proceedings World Geothermal Congress 2005, Antalya, Turkey, 8 pp.

BBA Legal. (2016). *Geothermal transparency guide.* Sótt frá https://issuu.com/bba3/docs/geothermal-transparency-guide_web?e=23738478/43095423

Bertani, R. (2010). *Geothermal power generation in the world – 2005–2010 update report. .* Proceedings World Geothermal Congress 2010, Bali, Indonesia, 41 pp. .

Boguslavsky, E. V. (1999). *Geothermal resources of sedimentary basins in the Republic of Kazakhstan.* Bulletin d'Hydrogéologie, 17, 123-131.

Energy. (2018). *Energy*. Sótt frá https://energyplus.net/weather

Fridleifsson, I. B. (2008). *The possible role and contribution of geothermal energy to the mitigation of climate change.* Hohmeyer, O., and Trittin, T. (eds.), Proceedings of the IPCC .

IFC. (2103). *Success of Geothermal Wells: A Global Study.* International Finance Corporation.

IRENA. (2013). *IRENA Case Study 2013 - Wind atlas Kazakhstan.* Sótt frá https://globalatlas.irena.org/UserFiles/casestudies/IRENA_Case_Kazakhstan.pdf

Íslandsstofa. (2016). *Mapping the Icelandic Geothermal Energy Sector.* Sótt frá https://smidjan.islandsstofa.is/media/2/mapping-the-icelalandic-geothermal-energy-sector.pdf

Kan, S. M. (2017). *Geothermal water Zharkent artesian basin and prospects creation on their based complex of thermal and power production.* News of the national academy of sciences of the republic of Kazakhstan. Series of geology and technical sciences,.

Kasymbekov, D. A. (2006). *The Pilot project on exploration on geothermal waters, including the examination of 40 wells that penetrated the geothermal waters and preparation of a feasibility study their use. Program 013 - "State geolog.*

KazEnergy Association. (2015). *The National Energy Report 2015.*

Lopez, S. H. (2010). *40 years of Dogger aquifer management in Ile-de-France, Paris Basin, France.* Geothermics, 39, 339–356. .

Lund, J. F. (2010). *Direct utilization of geothermal energy – 2010 worldwide review.* Proceedings World Geothermal Congress 2010, Bali, Indonesia, 23 pp.

Saemundsson, K. A. (2009). *Geothermal systems in global perspective.* Santa Tecla, El Salvador: UNU-GTP and LaGeo.

Sarmiento, Z. S. (2013). *Volumetric assessment of geothermal resources.* Papers presented at "Short Course on Conceptual Modelling of Geothermal Systems", organized by UNU-GTP and LaGeo, Santa Tecla, El Salvador, 15 pp. .

Stefánsson, V. (2005). *World geothermal assessment.* Proceedings World Geothermal Congress 2005, Antalya, Turkey, 5 pp. .

The Ministry of Energy and Mineral Resources of the Republic of Kazakhstan. (2016). *Committee of Geology and Subsoil Use "Kazakh Institute of Oil and Gas"Exploration on the Geothermal Groundwater in the Area Zharkunak Zharkent Basin Almaty". Report, 40.*

The World Bank. (2015). *Modernization and Financing Mechanism for DH Sector and Other Municipal Services.*

Uyzbayeva, A. &. (2015). *Towards Achieving Energy Efficicency in Kazakhstan. .* World Academy of Science, Engineering and Technology.International Journal of Energy and Power Engineering, Vol:9, No:2.

Verkís, ÍSOR. (2018). *Preliminary review of geothermal resources in Kazakhstan - Inception report (ID 47272).*

Williams, C. (2007). *Updated methods for estimating recovery factors for geothermal resources.* Proceedings of the 32nd Workshop on Geothermal Reservoir Engineering, Stanford University, California, USA, 7 pp. .

World Bank. (2018). *Unlocking Energy Efficiency Potentials in Cities in Kazakhstan - Synthesis report.*

[14] ESMAP, the World Bank (1997): Kazakhstan and Kyrgizstan. Opportunities for renewable Energy Development. Report No. 16855 KAZ, 130 pp.

[15] Azhgaliev, D.K. & Karimov, S.G. & Isaev, A.A. (2018): Regional Study is the next Important Stage in Evaluation of Oil and Gas Industry Potential of Sedimentary Basins of Western Kazakhstan. Georesursy. 20. 16-24. 10.18599/grs.2018.1.16-24.

[16] Ulmishek, G.F. (2001): Petrolium Geology and Resources of the North Caspian Basin Kazakhstan and Russia. US Geologial Survey Bulletin, 2201-B, 25 pp.

[A] Creation of Energy Potential Atlas - Geothermal Energy. *Summary of geothermal energy in Kazakhstan with focus on regional aspects, heat capacity and thermal gradient map*.

[B] Status of geothermal waters and prospects for their utilization. *Description of basins and geothermal potential.*

[C] Geological Works summary note. *Description of roles and definitions for hydrogeological studies.*

[D] Kazakhstan Water Code – specific characteristics. *Description of roles and definitions for permits and monitoring of hydrogeological studies.*

[E] Geothermal waters of southern Kazakhstan. *Summarized results of thermal waters in Southern Kazakhstan and survey results from wells in Arys, Almaty and Zharkent basins.*

Appendix A: Information Documents Provided for this Study

Reference Name	Authors	Year	Description	Presentation
Report 2016 Zharkunak Zharkent Basin Almaty	Kazakhstan Authorities	2016	Report on exploration for underground geothermal water on Zharkunak portion Zharkent basin Almaty region to assess the performance of thermal groundwater reserves for use in heat power purposes	English translation
Report on "Pilot project on exploration on geothermal waters, including the examination of 40 wells that penetrated the geothermal waters and preparation of a feasibility study their use"	Ministry of Energy and Mineral Resources, Republic of Kazakhstan	2006	Report on well examinations, 7 wells in Zharkent basin	English translation
Creation of Energy Potential Atlas - Geothermal Energy	Kazakhstan Authorities	?	Summary of geothermal energy in Kazakhstan with focus on regional aspects, heat capacity and thermal gradient map	English translation of a report/chapter, origin unknown
Status of geothermal waters and prospects for their utilization	Kazakhstan Authorities	2018	Description of Basins and Geothermal potential	English translation of a report/chapter, origin unknown
Geological Works summary note	Kazakhstan Authorities	?	Description of roles and definitions for hydrogeological studies	English translation of a report/chapter, origin unknown
Kazakhstan Water Code – specific characteristics	Kazakhstan Authorities	2018	Description of roles and definitions for permits and monitoring of hydrogeological	English translation of a report/chapter, origin unknown
Geothermal waters of southern Kazhakstan	Kazakhstan Authorities	?	Summarized results of thermal waters in Southern kazakhstan and Survey results from wells in Arys, Almaty and Zharkent basins.	English translation of a report/chapter, origin unknown
Geothermal resources of sedimentary basins in the Republic of Kazhakstan	Boguslavsky, E., Vainblat, A., Daukeev, G., Movchan, I., Pevzner, L., Smyslov, A. & Khakhaev, B.	1999	Bulletin d'Hydrologie No. 17 (1999)	Paper
Kazakhstan and Kyrgizstan. Opportunities for renewable Energy Development	ESMAP	1997	Report No. 16855 KAZ	Report
Petrolium Geology and Resources of the North Caspian Basin Kazakhstan and Russia	Ulmishek, G.F.	2001	US geologial survey Bulletin 2201-B	Report
Regional study is the next important stage in evaluation of oil and gas industry potential of sedimentary basins of Western Kazakhstan. Georesursy. 20. 16-24. 10.18599/grs.2018.1.16-24.	Azhgaliev, D.K. & Karimov, S.G. & Isaev, A.A..	2018	Sedimentary basins	Paper
Towards Achieving Energy Efficicency in Kazakhstan.	Uyzbayeva, Aigerim & Tyo, Valeriya & Ibrayev, Nurlan	2015		Paper

Appendix B: Various Cost Related Information and Assumptions

Energy prices in Kazakhstan for a district heating company

Electricity price:	20 KZT/kWh = 5.4 US¢/kWh (Based on information from MoE)
Natural gas price:	60 KZT/Nm^3 = 16.2 US¢/ Nm^3 (Based on information from MoE)
Gas heat price	60 / (36,000 x 0.9) = 0.00185 KZT/kJ;
	6.66 KZT/kWh
	1.80 US¢/kWh
	1.55 €¢/kWh

KazTransGaz gas exports to China to 10 Billion Nm^3/year will bring in more than 2 Billion USD/year in revenue, (whole sale) 20 US¢/Nm^3. Price of natural gas for households in China is 40 US¢/Nm^3

Price of natural gas for households in selected countries based on information from the National Energy Authority of Iceland and others is as follows:

Country	€¢/kWh
Kazakhstan	0.6 (Not confirmed)
Russia	0.7
USA	3.1
Moldova	4.0
Estonia	5.7
Latvia	6.2
UK	7.9
Denmark	10.0

Cost estimates

Cost estimations set forth in this report should be evaluated as **Class 5** estimates, based on AACE International Recommended Practice No. 18R-97. Class 5 estimates are applied for project concept screening where the cost estimate methodology is based on i.e. parametric models, judgment or analogy. Typical variation in high and low ranges are as follows:

Low:	-20% to -50%
High:	+30% to +100%

Economical evaluation and feasibility assumptions

To pay back the investment through difference between operational cost and annual energy sale the assumption is that all capital spending will happen in year 1 and the energy sale and operation will start in year 2 and onward for 25 years as shown in the simplified cashflow table below.

Table 15 – Simplified cashflow values with 10% IRR and 5 US¢/kWh energy price

			Year											
Cost:			1	2	3	4	5	6	7	8	9	10	24	25
Construction	1000	USD	1000.0											
Annual operation	4	%		40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Cost			1000.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Sold Energy pr y	3	MWh												
Revenue	50	USD/MWh	0.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
Cash flow			-1000.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0
Simple Project Cashflow	10	%												
Simple payback	10	y												

Based on experience from geothermal district heating projects a simple 10% project IRR, resulting in zero Net Present Value (NPV), is very likely to secure high enough return on say 25% equity and normal interests' rate on loans covering 75% of the investment. Taxes may have an impact but in general companies serving as utility companies for local communities do not pay high taxes. A simple payback method for the investment during year 1 – 10 will give similar results.

Table 15 shows a simplified cash flow for a hypothetical project. Note that the years 11-23 are hidden.

If the IRR is reduced to 8% the annual revenue will decrease 10% for the same example as above. A simple payback method for the investment during year 1 – 12 shows similar results.

Table 16 – Simplified cashflow values with 8% IRR and 4.5 US¢/kWh energy price

			Year											
Cost:			1	2	3	4	5	6	7	8	9	10	24	25
Construction	1000	USD	1000.0											
Annual operation	4	%		40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Cost			1000.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Sold Energy pr y	3	MWh												
Revenue	45	USD/MWh	0.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0
Cash flow			-1000.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Simple Project Cashflow	8.0	%												
Simple payback	12	y												

Net project cashflow IRR benchmark

- Private infrastructure heating project, geothermal drilling, heat centrals, district heating network, many customers, cost estimate +/-35% - **Net project cash flow IRR 10%**
- Private infrastructure heating project, geothermal drilling, heat centrals, one customer (public utility, owner of the DH), cost estimate +/-25% - **Net project Cash flow IRR 8%**

Public infrastructure project, geothermal drilling, heat centrals, district heating system, many customers, cost estimate +/-35% - **Net project cash flow IRR 6%**