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Moving beyond Gas: Can Bangladesh Leapfrog and Make the Energy Transition Just by Exploring the Role of Geothermal Energy and Gas Infrastructure?*

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Abstract – *How a natural gas rich developing economy like Bangladesh growing at ~7% annually in the pre-pandemic period can envision a roadmap for Sustainable and Just energy transition using the investments in gas infrastructure is discussed in the article. Bangladesh is caught up in a complex combination of likely risks of rising stranded assets, redundancy of jobs in the fossil fuel sector, need for cleaner available innovation and technology through global partnership to meet the inevitable increase in energy service demand. We make a case for the new use option of Bangladesh drilling wells and the infrastructure dedicated so far to extract and use domestic natural gas reserves. Utilization of gas exploration wells and depleted wells for the generation of geothermal heat and power can help in leapfrog with a drastic reduction in the cost of installation of geothermal plants and without job loss. This article provides learnings based on other country experiences related to the use of depleted wells for geothermal production. Available data from one of the gas reservoirs for three wells in Kailashtila gas field has been used to assess the potential. The simulation result shows that using existing wells as a geothermal heat source with heat pumps is not the best option for cooling only applications. Absorption chiller would be a better choice for heat-based cooling. However, a combination of seasonal cooling and heating with heat storage in geothermal wells during hot periods and heat utilization for space heating during cold periods presents a very attractive energy solution option. But more detailed systematic studies including detailed calculation of geothermal energy generation potential for Bangladesh with feasibility assessment can be conclusively done with site specific data access and are necessary to fully explore the technical and economic potential.*

Keywords – *Bangladesh, geothermal energy, just energy transition, leapfrog, natural gas.*

1. INTRODUCTION

In 2015 the world has achieved consensus in the declaration of a few global agenda. Interestingly a wide variety of scientific efforts at various contexts, levels and scale started to give shape to these agenda in reality. This article sits at the intersection of two such agendas. First, is the adoption of the Paris Agreement at the COP21 and the other is the adoption of the Sustainable Development Goals (SDG) framework. Three years later in 2018 IPCC special report [1] on Global Warming of 1.5°C presents the assessment based on available scientific literature that accelerated deep decarbonization is at the core of mitigation strategy consistent with 1.5°C warming compared to the pre-industrial level. The same report also presents the high agreement and robust evidence of consequences evaluated by the scientific community in faster and deeper mitigation strategies through possible threats to multiple social and economic dimensions of sustainable development for countries currently having a high dependency on fossil fuels for income generation, contribution to national income, economic development and generation of employment. The same concerns are coming from those which are representing voices around possible job loss, loss of investment flow despite new resource identification, high risks of stranded assets, lower revenue earning with fluctuating oil and gas prices, dwindling reserves [2]. The literature on solutions and policy instruments talk of need for diversification of economy and energy sector to ease these adverse consequences of transition and need for creating enabling conditions [3]. The diversification discourse is mostly dominated by focus on new investment opportunities limited to wind and solar energy sectors. Also, the countries at risk discussion get dominated by GCC (Gulf Countries Council) countries. All these discourses ignore multiple challenges and realities in many small but fast emerging developing countries' perspectives. Bangladesh which is growing at more than 7% and is aiming for developed country status before middle of the century needs special attention.

The objective of this study is to answer the research question, how can Bangladesh take advantage of the

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accelerated need for global transition while addressing the 'trilemma in energy transition'? The trilemma is: how an oil and gas dependent country can potentially leapfrog to new sustainable energy form without job loss, asset loss and by using international cooperation under Sustainable developmental goal (SDG 17). So, this study presents the basic hypothesis within an analytical frame of 'energy transition trilemma' in section 2. Section 3 describes the current and future challenges for sustainability of Bangladesh energy sector to set the scene. Section 4 represents how geothermal energy technology can use gas/oil infrastructure and how is it happening in other countries to inform technical feasibility issues for Bangladesh, section 5 illustrates geothermal exploration status and potential in Bangladesh. Section 6 uses simulation methods to assess geothermal potential of gas wells in Bangladesh using actual well level data and represents preliminary results from the modeling and simulation for geothermal energy utilization. Last section 7 adds concluding remarks with emphasis on scope for practical way forward with possible international partners for cooperation.

2. ANALYTICAL FRAMEWORK

We consider that national circumstances will continue to influence energy transitions paths within overarching global commitments and narratives of sustainable development. Primary energy resources are all transformed to deliver final energy service demands such as cooling/heating, illumination, mobility, electricity *etc.* [4]. We argue that a country like Bangladesh which has made a historically huge investment in gas infrastructure, human capacity building and institutions [5] have created some kind of technological and institutional lock-in effect in fossil fuel based energy sector creating barriers for shifts to other energy sources. To make the transition to happen Bangladesh can explore ways and means to minimize direct economic and social costs of transition by exploring geothermal sources that can continue to use the same available gas infrastructure and human capacity with some reskilling and supplementary innovation through international cooperation (SDG 17). IPCC special report on 1.5°C [1] talks about the benefits of a portfolio approach in mitigation technology and strategy selection. Multiple technologies, policies and subsystem transitions need to be searched for instead of one size fits all kind of solution. We name this as 'trilemma of energy transitions' with reference to oil and gas based fossil fuel energy systems, which are caught up in a complex combination of problems due to likely uncertainty and redundancy of human resource currently engaged in the sector, sunk costs and stranded asset due to prospective early retirement of infrastructure and projected reduction in investment and need for finding a cleaner substitute for fossil-based energy carrier [6].

Our basic premise is energy system transition needs to be guided and requires innovation, large scale investment and long period of time with long term developmental goal. So, any transition plan needs urgent energy transition strategy management plan and institution to start early on conceptualizing a new innovation plan, piloting the same to understand feasibility and challenges to overcome them gradually in a demonstration project. The commercialization stage takes much more challenges as enablers need to be in place to guarantee commercial success, such as: policy, finance, human resource with new skill and public acceptance. History of energy system transition has seen many failures, slow down, trapped in valley of death in innovation chain in the absence of systems approach and enablers [7].

We represent the current transition challenge for countries like Bangladesh by Figure 1 currently endowed with gas reserves and infrastructure to use it and with matching high domestic human skill. We hypothesize that one of the sustainable energy transition path can be to make use of geothermal energy resources to diversify the energy supply portfolio to meet demand for cooling purpose and/or if feasible for power generation. Geothermal energy resource based system in Bangladesh can use the gas drilling infrastructure, wells, human skill and help in leapfrog in renewable energy path with strategically chosen international partners. The same infrastructure with additional innovation can play an important role in Hydrogen based economy also but that is kept outside the purview of this article.

The Government of Bangladesh adopted the Renewable Energy Policy in 2008 and the subsequent power sector master plan in 2010 and 2016 have objectives of developing renewable energy resources to harness the existing potential and adoption of renewable energy technologies wherever possible. The policy also aims at scaling up renewable energy share in electricity generation as the country is fast depleting domestic natural gas reserves. However, current national discourse makes no reference to geothermal in renewable energy potential portfolios as a part of the solution.

3. BANGLADESH ENERGY SECTOR: CURRENT AND FUTURE CHALLENGES

Bangladesh economy is growing currently with 7.86% annual growth in GDP with per capita income moving up to USD 1751 in 2017-18 from USD 843 in year 2009-10 [8]. The success story of Bangladesh is unique. Studies show that, the larger part of this economic transformation has been supported by the growth of the power sector, social changes, especially women empowerment, girls' education, children's health improvements (life expectancy is now 72 years), population growth reduction, NGO participation in development sector and microcredit program stimulating social interactions and involvement of rural women in economic activity [9], [10]. Now maintaining and advancing this decade long remarkable success in a sustainable and equitable manner is an opportunity as well as challenge and the focus should be given to the removal of the bottlenecks in infrastructure and challenges in energy sector, and response to climate change.

In Bangladesh, current installed capacity in power sector is around 20 GW, but actual generation is less than 12 GW, which falls short of current demand [11]. The government projects demand to reach at least 60 GW by 2041[12]. Lack of reliability and intermittency of grid supply is another major obstacle for development in Bangladesh. World Bank survey indicates power outages are major obstacle, with businesses experiencing several hours of outages per day. Bangladesh is overwhelmingly reliant on heavily-subsidized domestic sources of natural gas (61% of total generation). Domestic gas reserves are slowly being depleted, which is leading to import of much more expensive LNG, requiring either significant new subsidies or price increases. The majority of new power supplies coming online include coal, imported LNG, nuclear, and regional trading. Due to seasonal water flows and limited land area, conventional renewables are not seen as a primary contributor. Gas production is still government-controlled. Bangladesh intends to import power from India, Bhutan, Nepal, and Thailand (via Myanmar). Progress on this front is already underway: Bangladesh is doubling the capacity of its interconnection with India to 1 GW, and the government has begun exploring with neighbors' potential co-investments in hydroelectric power plants [13], [14]. But these are not going to be sufficient for securing energy supply going forward. So, search for new energy sources which can provide long term self-reliance and sustainable non-intermittent source and security of supply is important for Bangladesh energy sector.

Fig. 1. Energy transition trilemma: Possible solution for leapfrog.

4. GEOTHERMAL AND OIL AND GAS DRILLING WELLS: OPPORTUNITIES AND CHALLENGES

This section deals with how technologically geothermal energy can use existing gas/oil infrastructure and how is it happening in other countries to justify technical feasibility. What is the resource potential global /for some countries? Where is the technology in terms of

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commercialization/ demonstration scale? The share of intermittent renewable energy from solar and wind in the grid has increased globally rapidly during the last decades. Technology development, cost reduction and supportive policy decisions have made this transition possible. However, the issue of intermittency of the renewable power already cause difficulties for grid stability and grid control.

Different from solar and wind, the geothermal energy is dispatchable and therefore, it could be a strong contributor to full transition to decarbonized energy system by supporting the grid. Geothermal energy has been steadily utilized for heat and power generation for many years, although not with a major share in total global energy generation. The main reason for the limited utilization of geothermal energy has been the high cost of infrastructure installation of such plants, where the drilling and well construction stands for the major part of the total investment cost. Therefore, reducing the drilling and well construction costs for geothermal installations have been discussed for years, without a major breakthrough. Utilization of oil and gas exploration wells and depleted wells for generation of geothermal heat and power has gained attention recently, since this would result in long desired drastic reduction in cost of installation of geothermal plants for clean energy supply. There are some obvious advantages with reusing the existing wells, such as reduced cost, but there are also challenges related to use of depleted wells for geothermal production, which need to be understood and handled accordingly to enhance growth of this dispatchable renewable energy source.

There have been several studies reported by researchers over the globe where the potential of geothermal energy generation from depleted wells have been investigated experimentally and theoretically (please see references [15] to [26]). These studies have demonstrated the readiness level of the technologies as well. To better understand the possibilities and challenges of reusing the existing depleted wells, the readers need to have a general understanding of the physical well construction and the legislative framework concerning ownership, use and finally plug and abandonment (P&A) of the wells. So, there are both technological and institutional, legal, economic and management issues that can impact the energy generation potential from depleted wells. Some of the opportunities and the challenges are discussed below:

- From an energy generation point of view, the main parameters impacting the energy generation capacity of the wells are the available temperature and the flow rate of the working fluid at the well head (at the surface level). Higher flowrate means higher energy generation capacity, which requires wells with large diameters. However, keeping the diameter large to the target depth would result in very high cost of drilling and well construction. It could be mentioned here that the wells drilled for oil and gas production are usually ending with a diameters between four and seven inches at the final section of the well, which is not exactly the optimum size from the geothermal energy generation point of view.
- From the remaining lifetime and well integrity aspect, one needs to understand the construction of the petroleum wells, which at each section and depth is presented by the following layers from outside in; the formation, the cement layer and the casing (steel piping inside the well). Utilizing existing wells for geothermal energy production requires sufficient remaining lifetime of the well, which motivates additional investments in geothermal energy. The well casing might have been exposed to erosion and corrosion at different sections of the well, which will limit the useful remaining life of the well. The quality of cementing job and the condition of the cement in place are also important factors for the remaining lifetime of the well. An important step in utilization of the existing wells for geothermal production is assessment and qualification of the wells for geothermal production. Programs for systematic analysis and evaluation of the existing wells, as well as identification of measures that provides safe and secure operation of the geothermal plants will be necessary to start now for an affordable and large scale utilization of existing wells for geothermal energy production.
- From a legislation point of view, one should consider the responsibility for plugging and abandonment of the wells (P&A), since P&A stands for considerable capital costs followed by the long-term responsibility associated with well monitoring. When the allowances for exploration and production of petroleum is given to a company, the P&A responsibility for the wells is also given to the petroleum producing company. Thereby, the petroleum company is responsible for closing and monitoring of the wells so that no unexpected events take place even after the P&A. So, transaction cost economics would favor petroleum companies to become geothermal energy generation companies. However, if another company/organization would take over the depleted wells for geothermal energy generation the issue related to P&A will assume a new dimension. It might become a problem if the petroleum company is not ready to accept the responsibility for P&A after the years of geothermal production. Therefore, one of the major showstoppers for using existing wells for geothermal energy production in some countries are around the P&A and the legal responsibility issues related to it. However, flagging this issue at this initial stage of discourse is useful as they need deeper and newer attention as opportunities and challenges are new.
- There are plenty of depleted and exploration wells

over the globe, but the legal and economic issues for the abandoned wells need to be revised in new paradigm of sustainable development and climate action to enable geothermal production from these wells. The rules and regulations concerning wells to be operated by more than one company/organization in not clear today. Therefore, there is a need for clarification of technical, economic, legal responsibilities for the involved companies when using existing wells for geothermal energy generation and social and political issues for the country under consideration

4.1 Other Country Experiences

The use of existing infrastructure for transport of equipment and distribution of the energy from the wells is a major advantage of the existing wells, which further reduces the total cost of the geothermal energy from abandoned wells. Several pilot studies have been carried out in various countries to evaluate the energy generation potential of the depleted wells. The results show that between 3 and 5 MW electricity can be produced from one depleted and sealed well with electrical efficiencies of about 10-15%, when using double pipe heat exchanger (coaxial tubing in the well with injection between existing well and outer pipe and production from the inner pipe with sufficient isolation between the inner and outer pipes). However, the amount of energy generated and the cost of it will be different depending on location, depth and other circumstances. Beside heat and power, which have been in focus for energy service generation, there are also examples where the geothermal heat has been utilized for poly-generation with several useful products/services as outcome (*e.g.* desalinated water, *etc.*) [17], [18]. The economic viability of the geothermal energy is under researched and needs to be investigated for different markets and locations to help find the optimal solution selected contextually.

Assuming electrical efficiency between 10% and 20%, a temperature difference of 30°C to 55°C between inlet and outlet, and a mass flowrate of 10 to 60 kg/s, one can estimate the power output [kW], using water as working fluid (see Figures 2 and 3). For more detailed mathematical calculations, the readers are referred to the publications in the reference list [15] to [24].

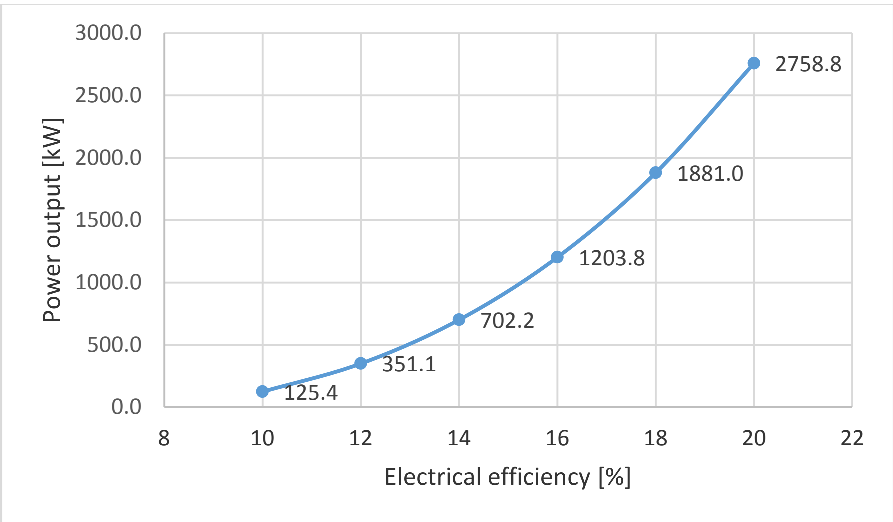


Fig. 2. Power output as function of electrical efficiency.

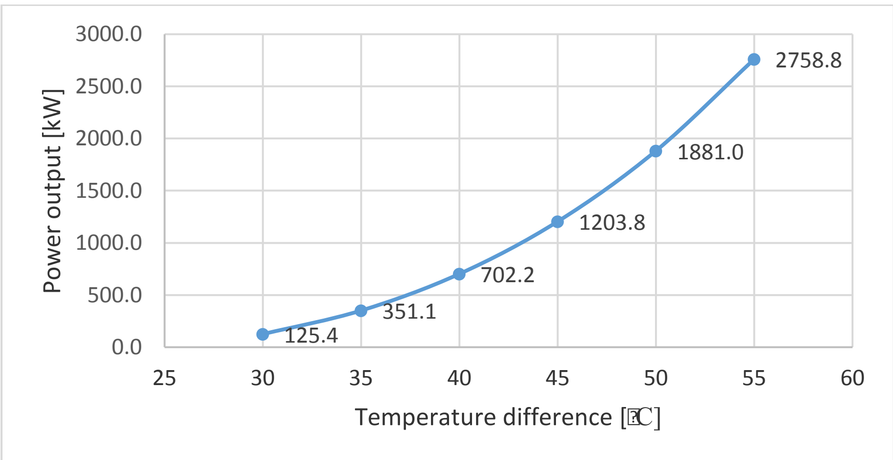


Fig. 3. Power output as function of temperature difference.

5. GEOTHERMAL EXPLORATION STATUS IN BANGLADESH

Several studies [27]–[37] identify the prospects of geothermal energy and concluded that there are several potential site for the geothermal energy extraction in Bangladesh but more detailed systematic studies including detailed calculation of geothermal energy generation potential with feasibility assessment are necessary to fully explore the geothermal potential. Geological survey of Bangladesh drilled an exploratory well for geothermal resource at Thakurgaon districts in 2011 and the recorded temperature gradient was 44.75°C at a depth of 560 m [33]. In 2011, a private company, Anglo MGH Energy, was declared to build the first geothermal plant in Thakurgaon district with a capacity of 200 MW [38], but the project did not commence finally for reasons unknown to the researchers.

5.1 Potential Geothermal Area in Bangladesh

Based on the geo-tectonic setup, the potential area for geothermal energy is divided into two different sections: (1) Northwest shield area (2) southeast deep sedimentary basin [37]. The northwest area has an average temperature gradient of 30°C /km, whereas the southeast deep sedimentary area is 20°C /km [36]. Tectonically, northwest shield area is subdivided as (a) Sub-Himalayan Foredeep (b) Rangpur Saddle (c) Bogra shelf and the southeast deep sedimentary basin is subdivided as (a) Deep Sedimentary Basin (b) folted belt [30].

The southern part of Bangladesh lies on Sub-Himalayan foredeep area. The average thermal gradient is only 22.5°C. One well (Salbanhat-1) was drilled in Tetulia where 79°C at a depth of 2500 m was recorded [30]and 110°C at a depth of 4000 m [33] was projected.

Concerning the Rangpur Saddle area, currently hard rock has been collected from Madhyapara and coal from Barapukuria. High temperature was detected at these coal bearing zone and hard rock structure. Below the coal seams of Barapukuria mine, there is a sandstone called Gondwana sandstone where 50°C was observed at a depth of 400 m. The coal seams work as an insulator for increasing the temperature of the basement. Besides, in this area, warm water with a temperature of 36°C was observed in irrigation wells at a depth of 80 m at Thakurgaon. In coal mine, observed temperature was 50°C at 400 m, 40.5°C at 380m and 52°C at 440m. The author concluded that if a well is drilled in this area, there is chance of getting enough temperature for electricity production. As hard rock and coal mine are in the same geological structure then there might be a need for fracturing to penetrate into the low permeability region [30].

Bogra shelf is the transition zone of Rangpur saddle and Bengle foredeep. Magnetic and seismic survey of these zones were done by Stanvac Oil Company in the mid nineteen fifties. Four deep wells were drilled in this area (Singra, Kuchma and Bogra) and the temperature gradient of 35°C /km were obtained in these wells. The most promising one, Singra-1, recorded a temperature higher than 150°C at the bottom of the well. Thus, the deep wells at Singra, Kuchma and bogra have high potential for geothermal energy generation [30], [33].

Deep sedimentary basin consists of the area between hinge line tending SSW-NNE from Sylhet-Mymensing-Pabna and Arakan Yoma Folded System called Bengal Foredeep region. The area has several troughs and highs namely Faridpur Trough, Hatiya Trough, Sylhet Trough, Modhupur high [28]. In the Hatiya trough, shahbajpur 1 well has a significant temperature gradient of 29.5°C /km that might be a potential location for geothermal energy extraction [27]. But cool sediments are continuously loaded in this deep sedimentary basin and very low thermal gradient (average 20K/km) was observed. Thus, although there are some deep abandoned wells, the area has limited potential for electricity production [30], [37].

The most prominent tectonic element, parallel to Arakan Yoma Fold, is the folded belt. The western part of the folded belt is the most prospective oil and gas area of Bangladesh with 12 gas fields. Several hot springs were observed in Sitakund anticline structure at Barapkundo and gobindachara with a temperature gradient of 35 k/km. Besides, wells at Bakhrabad and Saldanadi have the thermal gradient of 30°C /km and 27.2°C /km respectively [30], [33]. As there are many high deep, dry and abandoned wells available in this area with significant thermal gradient, these could be a prospective geothermal energy source.

5.2 Thermal Gradient of Deep Exploratory Wells

To explore and develop oil and gas reserves, a number of wells were drilled over the years in the eastern part of Bangladesh. The measured subsurface temperature of these wells are available [29], [37], [39]. The drilling depth of these wells ranges from 2100m to 4977m. Using the temperature data, a thermal gradient map of Bangladesh was developed as shown in Figure 5. The most prominent zone for geothermal energy was obtained at Singra 1 well location in northwest shield area with more than 150°C bottom hole temperature. Whereas, in the Southeast deep sedimentary basin area, potential thermal gradient was obtained at Shahbajpur 1 well at a rate of 29.5°C /km located in Hatiya trough followed by Saldanadi 1 well at a rate of 27.2°C/km.

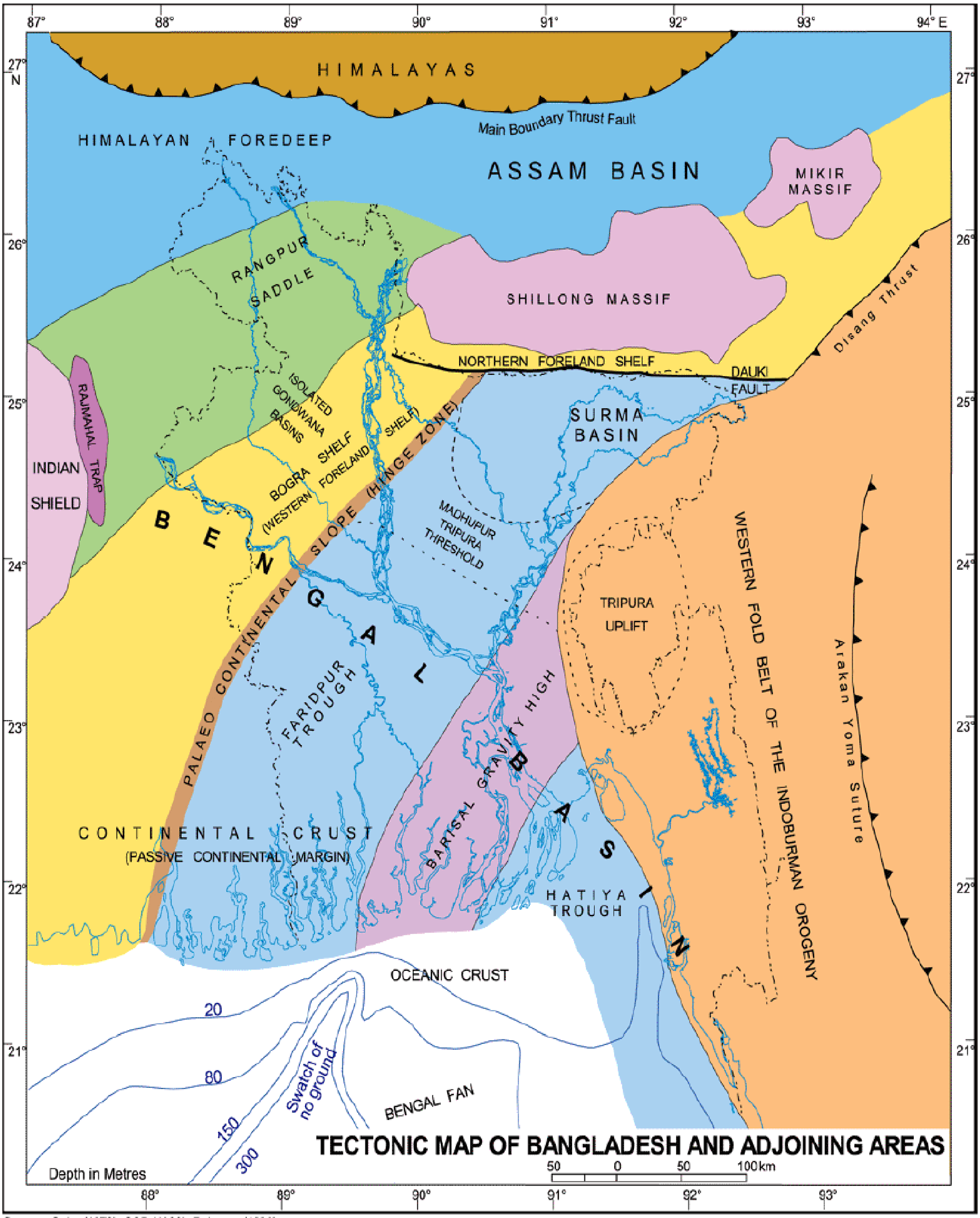


Fig. 4. Tectonic map of Bangladesh.
(Source: [28])

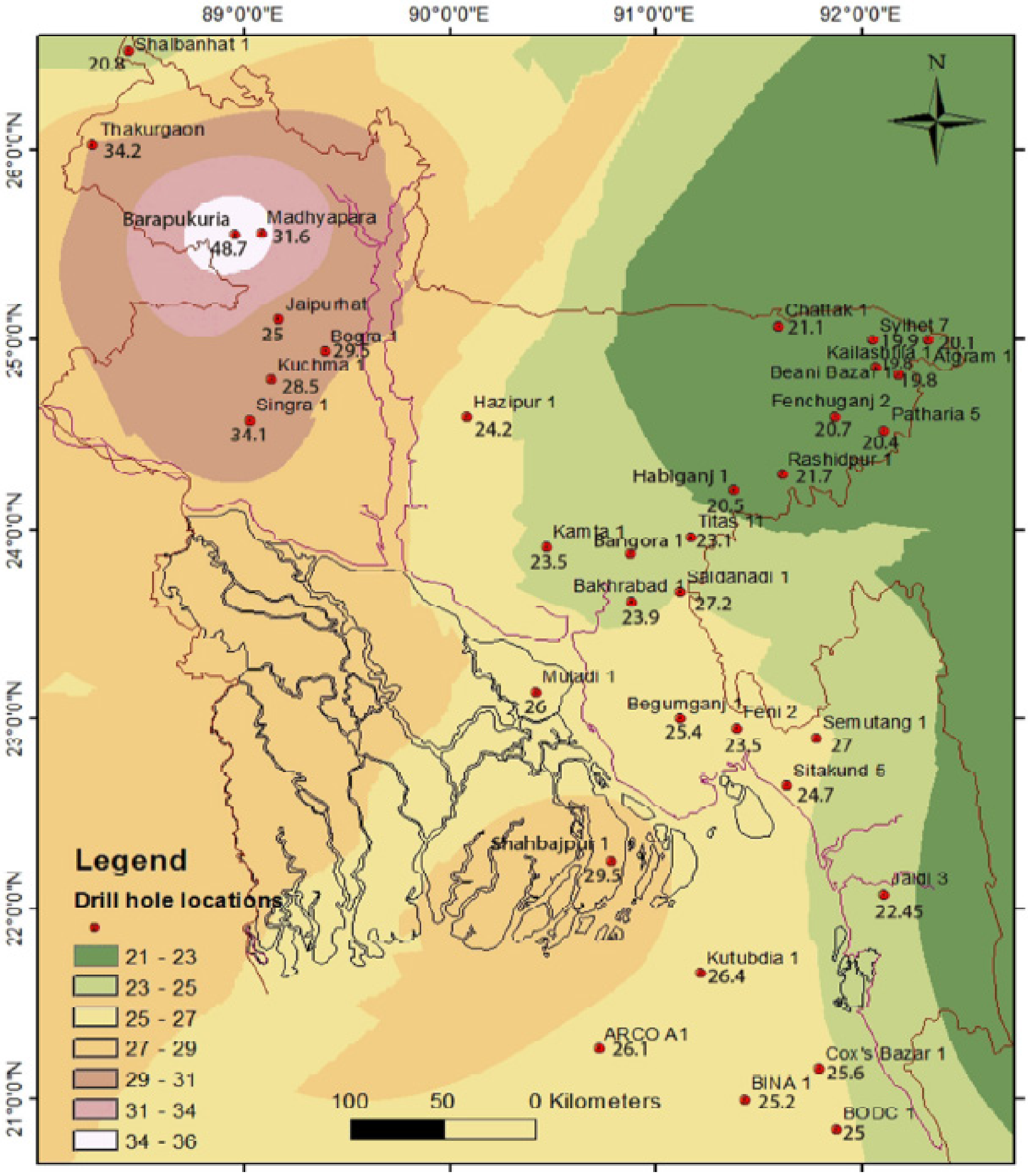


Fig. 5. Well wise temperature gradient of Bangladesh.
(Source: [37])

6. THE CASE STUDY: KAILASHTILA GAS FIELD'S WELLS FROM BENGAL FOREDEEP REGION IN NORTHWEST REGION OF BANGLADESH

6.1 Design and Simulation in IPSEpro

To understand potential of geothermal energy, a case study of one possible site to utilize wells in Bangladesh has been used to derive implications. The choice has been driven by data access. Three deep gas wells from Kailashtila Gas Field (Table 1) with reservoir temperature of about 63°C and surface-wellhead temperature of 42°C were used for the modeling and simulation work. Cooling application using heat pump was studied and the results of the parameters studies carried out are presented here. One of the wells was considered as production well and the other two as injection wells. Design and Simulation in done by IPSEpro Software system.

IPSEpro, a commercial simulation tool, was used for modelling and analysis. The parameter values used for simulation are shown in Table 2. The environmental temperature range of 25°C to 40°C was used for system performance analysis. The system setup as IPSEpro model is represented in Figure 6 with the state properties at specific points. The properties represent specific enthalpy, temperature, pressure and mass flow rate.

The cooling system consists of 4 main elements, condenser, expansion valve, evaporator and compressor. As working fluid used R134a refrigerant in cycle. It is worth mentioning that selection of the working fluid plays a significant role for the system performance. Saleh *et al.* [44] showed that 31 pure component working fluids are suitable for use in Organic Rankine Cycles (ORCs). In these studies the critical temperature, normal boiling temperature, and critical pressure for the working fluids were arranged in specific order to give an indication of their suitability as working fluids for ORCs. Lee *et al.* [45] carried out parametric analysis on an energy recovery system. They concluded that the ORC system efficiency depends on the normal boiling point, the critical pressure and the molecular mass of the working fluid.

Since the properties of the chosen working fluid have a significant impact on the performance of the ORC cycle, appropriate thermodynamic properties of working fluid can result in higher cycle performance and low costs. According to [46], the ideal organic working fluid should have high molecular weight, small heat content (low enthalpy), high critical pressure and temperature, low operating pressure to avoid danger of explosion or rupture, small specific volume high condensing pressure to prevent air inflow into the system, low cost, low heat latency and being nonflammable, corrosive or toxic.

Table 1. Well data of Kailashtila gas field upper gas sand.

Particulars	KTL2	KTL3	KTL6
Well diameter	354.33 mm	354.33mm	508mm
Well depth: MD (TVD)	3260(2259)m	3522(2273.4) m	(2302) m
Product flow rate- kgs-1	0.628 kgs-1	0.628 kgs-1	0.628 kgs-1
Reservoir pressure	3221 bar, at	3232.1 bar, at	3241 bar, at
Reservoir fluid temperature	63.16 °C	62.78 °C	62.78 °C
Reservoir fluid heat capacity kJ/kg.K	21.009 W/m2/K	15.9 W/m2/K	-
Reservoir fluid density kg/m3	0.628 kg/m3	0.62 kg/m3	0.63 kg/m3
Ambient temperature	25-32 °C	25-32 °C	25-32 °C
Surface temperature, ºC	42.22 °C	42.22 °C	-
Surface wellhead pressure, bar	176 bar	171.7 bar	182.36 bar

Data source: [40]-[43]

Table 2. Main fixed parameters of organic Rankine cycle.

Parameters	Value
Wellhead/surface temperature of geothermal fluid, °C	42
Requested cooled environment temperature, °C	22
Evaporator inlet temperature from environment, °C	25-32
Evaporator heat transfer area, kW/K	0.80
Condenser heat transfer area, kW/K	46.33
Pressure ratio	20
Compressor efficiency, %	80

Table 3. R134a refrigerant properties used in this study.

No	Properties	R-134a
1	boiling point	-26.1°C
2:	auto-ignition temperature	770°C
3	ozone depletion level	0
4	solubility in water	0.11% by weight at 25°C
5	critical temperature	122°C
6	cylinder color code	light blue
7	global warming potential (GWP)	1200

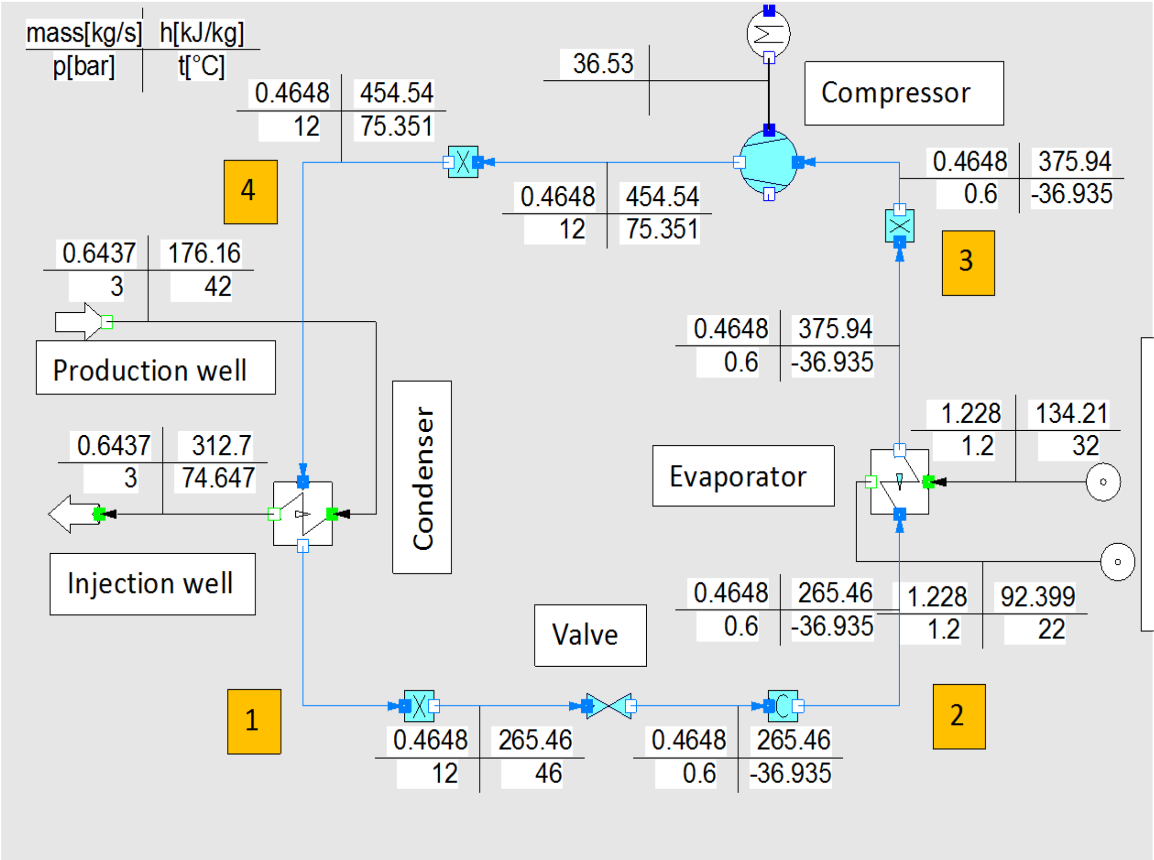


Fig. 6. IPSEpro simulation model.

6.2 Results and Discussion

The objective of the simulations conducted was to study the potential of using existing wells as geothermal source for cooling purposes (being a temperate country Bangladesh has high space cooling demand). The settings for simulations carried out were indoor temperature of 22°C, outdoor temperature between 28 and 40°C, and a wellhead temperature of 42°C. The product heat transfer area and the heat transfer coefficient for the evaporator and the condenser were kept constant through all simulations. The overall cycle performance depends mainly on the isentropic efficiency of the compressor. Table 4 shows the example for simulation results for outdoor temperature of 32°C.

For thermodynamic calculations and performance analysis a suitable working fluid is required, mainly considering the heat source temperature. For this purpose, the refrigerant R134a was selected as working fluid for IPSEpro simulations. Figure 7 shows the Pressure-Enthalpy diagram of R134a, containing necessary thermodynamic properties of the working fluid.

Simulation results for parameter studies within a temperature range between 28-40°C outdoor temperatures are shown in Table 5. Research target for 22°C indoor temperature at existing environment temperatures has reached. According to the results in Figure 8, environment temperature has not significant impact to design cycle data.

The properties of the working fluid at different states are marked on the P-h diagram in Figure 7.

Table 4. Simulation result for 32°C outdoor temperature.

Phase	State	P, bar	T, °C	h, kJ/ kg	s, kJ /kgK
Saturated liquid	1	12	46	265	1.21
Liquid +vapor	2	0.6	-36.94	265	1.29
Saturated vapor	3	0.6	-36.94	375	1.76
Supercritical gas	4	12	75.35	454	1.80

Table 5. Parameter study results for outdoor temperature of 28 to 40°C.

$N_{simulation}$	T_{env}, °C	Tgf, °C	W_{comp}, kw	$Q^{co}l$, kw	m_{gf}, kg/s	m_{col}, kg/s	m_{ref}, kg/s	COP
1	28	74.706	35,39	49,749	0.6224	1,983	0,4503	1,41
2	30	74.677	35,96	50,552	0,6330	1,511	0,4576	1,41
3	32	74.647	36,53	51,355	0,6437	1,228	0,4648	1,41
4	34	74.622	37,00	52,010	0,6524	1,037	0,4708	1,41
5	36	74.593	37,53	52,762	0,6624	0,902	0,4776	1,41
6	38	74.563	38,07	53,508	0,6724	0,800	0,4843	1,41
7	40	74.534	38,59	54,248	0,6823	0,721	0,4910	1,41

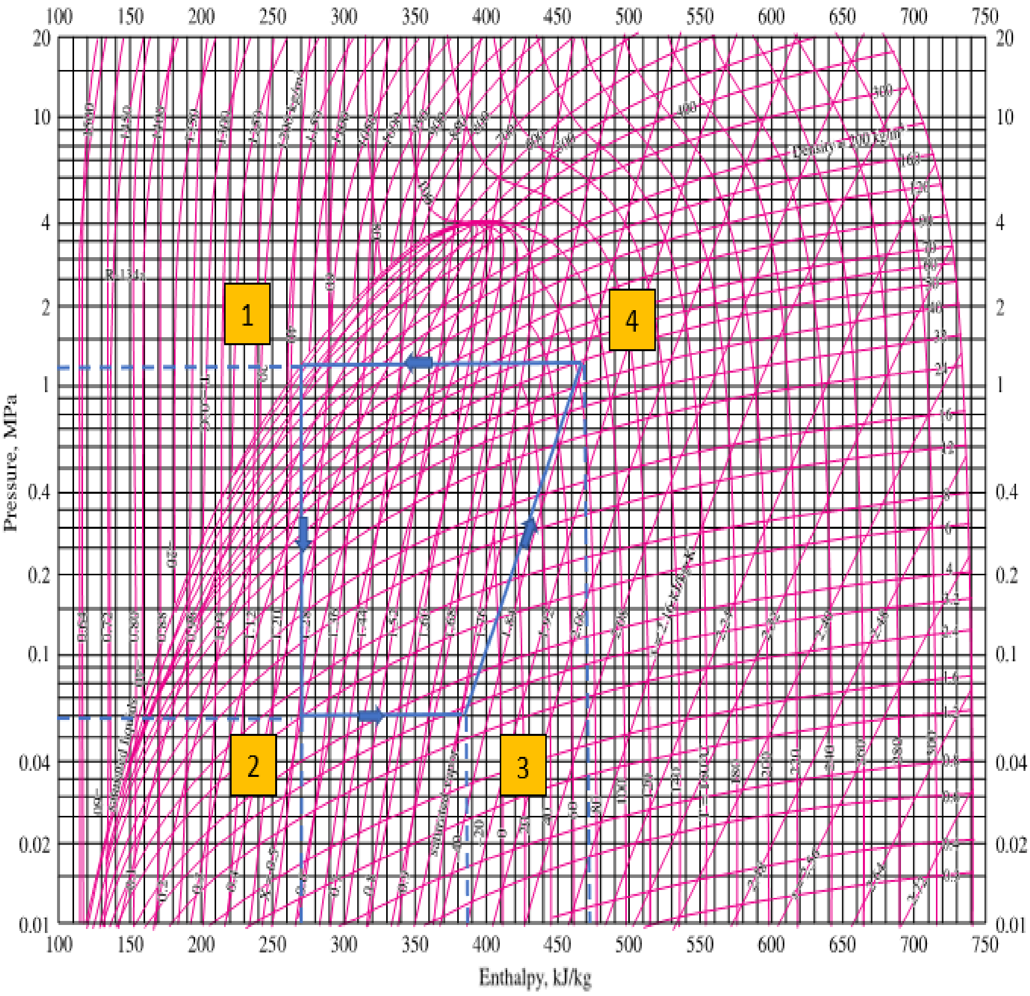


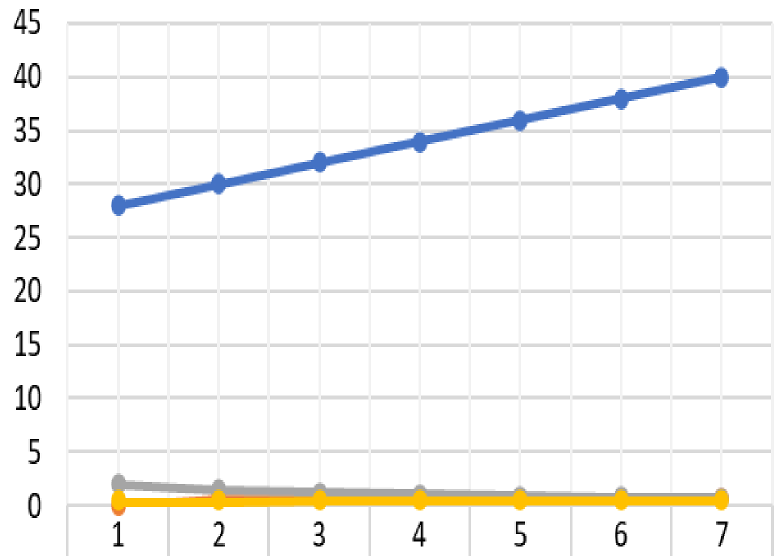
Fig. 7. Presure versus enthalpy diagram for refrigerant R134a.

Figure 8 shows that the mass flow rates of the well (mgf), coolant (mcol) and refrigerant (mref) do not change significantly with change in the outside temperature (Tenv) varying between 28 and 40°C.

Figure 9 shows the variations in geothermal fluid temperature (Tgf), Compressor power consumption (Wcomp) and rate of heat transfer to the refrigerant passing through the Evaporator (Qcol)Relation between environment temperature (Tenv) when the outdoor temperature is changing between 28-40°C The net power consumption increases from 35.39 kW to 38.59 kW (8.6%).

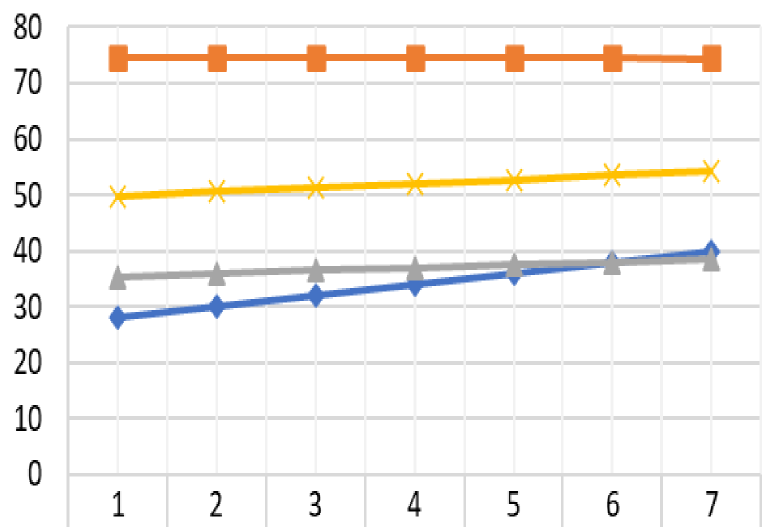
Figure 10 shows that the changing outdoor temperature has marginal impact on various parameters listed on the figure.

The study carried out shows that using existing wells as geothermal heat source with heat pumps is not the best option for cooling only applications. Absorption chiller would be a better choice for heat based cooling. However, combination of seasonal cooling and heating over a year, with heat storage in geothermal wells during hot periods and heat utilization for space heating during cold periods presents very attractive energy solution option.



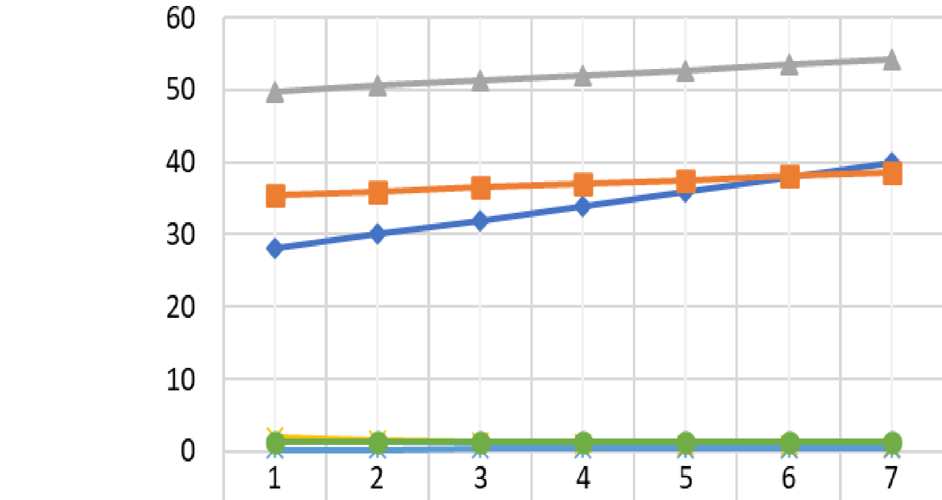
	1	2	3	4	5	6	7
Tenv, °C	28	30	32	34	36	38	40
mgf, kg/s	0	0.63	0.64	0.65	0.66	0.67	0.68
mcol, kg/s	1.98	1.51	1.23	1.04	0.9	0.8	0.72
mref, kg/s	0.45	0.45	0.46	0.47	0.47	0.48	0.49

Fig. 8. Relation between T_{env}, m_{gf}, m_{col} and m_{ref}.



	1	2	3	4	5	6	7
Tenv, °C	28	30	32	34	36	38	40
Tgf, °C	74.71	74.68	74.65	74.62	74.59	74.56	74.53
Wcomp, kW	35.39	35.96	36.53	37	37.53	38.07	38.59
Qcol, kW	49.75	50.55	51.36	52.01	52.76	53.51	54.25

Fig. 9. Relation between T_{env}, T_{gf}, W_{comp} and Q_{col}.



	1	2	3	4	5	6	7
Tenv, °C	28	30	32	34	36	38	40
Wcomp, kW	35.39	35.96	36.53	37	37.53	38.07	38.59
Qcol, kW	49.75	50.55	51.36	52.01	52.76	53.51	54.25
mcol, kg/s	1.98	1.51	1.23	1.04	0.9	0.8	0.72
mref, kg/s	0.45	0.45	0.46	0.47	0.47	0.48	0.49
COP	1.41	1.41	1.41	1.41	1.41	1.41	1.41

Fig. 10. Relation between Tenv, Wcomp, Qcol, mcol, mref and COP.

7. CONCLUSION

This paper starts with three major challenges for Bangladesh with increasing depletion of domestic gas reserves, how to make a transition to a new energy sector scenario with adequate social justice and less or no fossil fuel share over time and what will happen to the large gas infrastructure. A way forward towards solution has been built on the argument of leapfrogging to geothermal energy as a potential alternative source. Hydrogen can also be seen as a solution for leapfrog but this article does not cover hydrogen. The prospective locations of geothermal energy resource based on information available from official data sources is presented in the maps after considering past efforts within the country. But we realize it needs to be updated through new exploratory studies. Other country experiences in similar lines serve as an encouragement to explore the case of Bangladesh. However, it becomes clear that technical feasibility and institutional feasibility need to be understood well given the prospect. To understand technical feasibility simulation is designed by IPSEpro to study the potential of using existing wells as a geothermal source for cooling purposes, and real-world data for renewable applications are used for performance analysis. The modeling results contribute to the enhancing of further utilization of the existing depleted wells. We are aware of the limited data access and use in this study. Therefore, to understand full potential future research need access to more data on existing wells in Bangladesh. It is expected that this article will generate interest to explore geothermal potential in Bangladesh and will attract companies and businesses to provide technological cooperation. As an example we cite the case of Norway which is oil-gas producing country and is expanding its geothermal energy share. Like Bangladesh, in the same decade of seventies Norway emerged as a major petroleum producing country but unlike Bangladesh, Norway used its oil and gas mainly for export to Europe and accumulated huge rent over the years and invested the same for R&D in energy sector. The mature petroleum fields on the Norwegian continental shelf are reaching the end of their economic lifetime in the North Sea and will soon be subject to P&A. Utilizing the depleted fields for energy generation and energy storage have been reviewed carefully in Norway lately and there are certain opportunities identified for reuse of the existing wells. However, the Norwegian petroleum fields are mostly at deep water area and thereby the costs related to reuse of the existing wells might be considerably higher than *e.g.* for the countries where all or a majority of the wells are drilled onshore [47]. In comparison, Bangladesh used domestically the drilling activity and gas withdrawal for early phase of economic development of the economy. This is still acting as a major source of energy for the country's economic development. But as the country grows towards targeted middle income by 2021 and by 2041 towards high income status as envisaged by political leaders of the country, new innovation needs to enter into the developmental action agenda very fast. Moreover, our observation is that Bangladesh with all on shore wells have advantage for exploring the possibility of geothermal technology rather easily compared to Norway. Norway has been very successful concerning development of petroleum exploration and production technologies. Therefore, the accumulated Norwegian knowledge, supported by the modern and state of the art technologies available can be seen as a scope for potential technological international partnership development to enhance further utilization of the existing depleted wells for energy generation in Bangladesh. If successful this transition to geothermal option will alleviate the uncertainty around social justice in energy sector transitions. This will also enable to reduce national risk of stranded asset in the form of abandoned gas infrastructure and trained manpower arising from depleting gas reserves. This at the same time will also help in leapfrogging through diversification of the current monolithic dependence on gas as primary energy sources of energy and to expand the renewable energy portfolio beyond solar and wind based technologies. Latter two cannot fulfil the expected growth of demand of reliable electricity in Bangladesh given the scarcity of unfertile land mass. In Bangladesh the regulation debars shift of agricultural fertile land for solar energy project. As most of its land is fertile and provide food security through agricultural activities, unused non-agricultural land is difficult to find in densely populated country for solar and wind projects [48].Therefore, a careful socio-technical and economic-environmental assessment would be required to evaluate the energy production and storage capability, by reusing existing wells. Since gas sector is still government controlled and with high international cooperation it may be easier for Bangladesh to overcome well ownership and closer deal for used up wells compared to many other countries. If we follow the various criteria for successful transition [49] then political, social, environmental feasibility indicators are compatible with geothermal energy pathway for Bangladesh. However, a demonstration stage pilot project for feasibility assessment in all the dimensions is necessary for learning local context better to manage transitions. This cannot happen in Bangladesh without global cooperation. Timing of urgency of national need to solve energy transition trilemma match with the timing of urgency of global climate change mitigation response need (SDG 13) and opportunities under SDG 17 for international cooperation in implementation. This study demonstrates the need and method of assessment to enhance focus on geothermal energy generation and use strategically in Bangladesh in fast economic growth phase (SDG 8) through smooth and peaceful transition in the longer run (SDG 16). This will not only build a sustainable energy future for Bangladesh (SDG7) with justice in transition assured but will also act as an energy sector development model for oil and gas rich many developing economies with necessary global partnership development (SDG 17) in innovation (SDG 9) and knowledge transfer.

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NOMENCLATURE

m_{gf}	- geothermal fluid mass flow, kg/s
m_{ref}	- refrigerant R134a mass flow, kg/s
m_{col}	- cooling fluid mass flow, kg/s
T_{env}	- cooling environment fluid temperature, ^{0}C
T_{gf}	- geothermal fluid temperature, ^{0}C
T_{ref}	- R134a fluid temperature, ^{0}C
W_{comp}	- compressor net power consumption, KW
Q_{col}	- evaporator heat transfer, KW
CoP	- coefficient of performance

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