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Geothermal Energy for Natural Gas Compressor Stations; an Environmental and Economical Assessment

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Abstract
Iran's environmental condition is critical, since it is experiencing desertification, unsustainable development and overpopulation. The objective of this study is power source replacement in natural gas stations that operate with natural gas compressors, through using electrical motors, which can be fed by a 160 MW geothermal power plant, as an alternative to gas turbines. Application of such alternative power source will decrease greenhouse gas emissions, lower environmental costs and reduce natural gas consumption. Two economic scenarios are analyzed, with either the state or private sector act as investors of the proposed geothermal power plant. Since the new system requires 580 Million USD capital investment, if the government fully invests the project, it reduces government's massive annual costs about 130% and turns it from more than $80 Million/year to an income about $24 million/year. Furthermore, if the private sector invests the project and the state's incentive regulations be taken into account, this project will be beneficial, since its IRR is about 14%; in addition to more than 20% governmental annual cost reduction. This system can be also an economic competitor for liquid natural gas (LNG) cycles and geothermal power can also be a clean power source for LNG plants.

Keywords: Greenhouse gases; environmental costs; compressor station; gas turbine; geothermal power plant; HVDC transmission

Introduction

In the last two decades, energy crisis, global warming, and climate change concerns have been raised globally. The final sample was the 2015 United Nations Climate Change Conference in Paris. In 2013, Climate Accountability Institute (CAI) claimed that two-thirds of the greenhouse gas (GHG) emissions have been caused by just 90 companies, since the industrial revolution. One of these companies is National Iranian Oil Company (NIOC). Presence of this company on the list implies that NIOC should improve its approaches towards climate issues(Goldenberg 2013; Heede 2014). Adding to this, Iran's ranking according to Environmental Performance Index has not promoted noticeably in this decade (Anon n.d.). The number of days with clean and healthy air is declining in most industrial cities of Iran. Besides, no evidence exists to show that Iran has increased its share of renewable energies while such increase cannot be expected in the forthcoming years.

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Based on EIA (Energy Information Administration) and IEEJ (Institute of Energy Economics, Japan), energy consumption will have an increase by 50 % worldwide by 2035 and the developing economies share the greatest parts. Considering this fact, along with the daily reduction of fossil fuel resources, it can be predicted that there would be a significant increase in prices of oil and gas, in the next decades (EIA 2009; Matsuo, Aoshima, and Kako 2012). Thus, choosing a wise approach towards these global issues could save the future for the people of next generation residing in gas and oil producing countries, like Iran. Iran has 18.2% of natural gas resources of the world and is the world's second largest gas owner on this basis(IEA 2015). Moreover, Iran has 7 land border neighboring countries, which creates a distinctive potential of enhancing its position as a hub or a trans-exporter of natural gas (OPEC 2013) . Meanwhile one of the most considerable issues regarding to the oil and gas is their transmission system. In Iran, transmission of natural gas is generally enabled by pipelines that originated from the south of country (upstream section). There are several natural gas compressor stations (CS) located on each main pipelines. The CS pressurize natural gas to recover its pressure drop at the pipeline. Energy demand of the compressors can be provided using grid electricity or directly from gas turbine (GT) shafts (Sadrnejad, Noorollahi, and Sadrnejad 2016). Almost all CSs in Iran use a gas turbine which burns a portion of interring natural gas to the station. Clearly, this process leads to high amount NG consumption and GHG, e.g. CO2, production and emission.

This study focuses on replacing the power source of Polkalleh’s CS compressors as one of the major CSs in Iran from shaft work of GTs, to electrical motors fed by a proposed geothermal power plant, from environmental, technical and mainly economic perspectives. The main reason of concentrating on Polkalleh CS is its capacity factor which is one of the highest among Iran’s CSs. Therefore, if this project is economically feasible, it will prevent burning large amount of natural gas each year, and also prevent the production of huge amount of GHGs annually. Geothermal energy also is chosen, primarily due to its reasonable rate of reliability, high ratio of energy generation relating to investment among all sorts of renewable energy resources, and finally great geothermal energy potential in Iran(Moghaddam et al. 2014; Mohammadi et al. 2017; Noorollahi et al. 2007, 2008; Noorollahi, Pourarshad, and Veisi 2017). Furthermore, when CSs are not online, i.e. some CSs are in their OFF mode in summertime, the generated electricity of geothermal power plant can be directed into the national power grid for other consumers.

Studies such as “Performance assessment of a natural gas expansion plant integrated with a vertical ground-coupled heat pump” and “Integration of vertical ground-coupled heat pump into a conventional natural gas pressure drop station” are done by other reasearchers. In both studies, a vertical ground sources heat pump system, that is ground-coupled, preheats the stream of natural gas up to moderate temperatures(Noorollahi et al. 2019). Then, the gas stream would be passed through the CS heater to reach the desired temperature and pressure(Farzaneh-Gord et al. 2016; Ghezelbash et al. 2015). However, in one of the most related topics, a group of the Iranian researchers gathered the emission data of numerous gas turbine and steam turbines (ST) of Iran (Shahsavari Alavijeh et al. 2013). The data corresponding to Polkalleh CS have been retrieved based on appointments between the authors and the R&D section of Iranian National Gas Company (INGC). This dataset includes all information associated with Iranian Gas pipeline routes and CSs; and also, detailed information regarding Polkalleh CS, which is chosen as the case study station, covering power and efficiency of the turbines, molar fraction of the consumed fuel and the CS’s capacity factor (CF).

Due to the lack of research on the pollutants in Iran's CSs, emissions in these stations are calculated through a model provided by Iranian Department of Environment and Ministry of Energy, which is called “Emission Calculating Model”. In this model, capacity factor, GT efficiency and molar fraction of fuel are used as input. The results obtained from this model are compared and verified by "Greenhouse Gas Emission Measurement & Economic Analysis of Iran Natural Gas Fired Power Plants" (Shahsavari Alavijeh et al. 2013), which as stated, collected emission data from 20 STs and 30 GTs in Iran.

In the next step by using NO_X, CO_2 and CH_4 amounts and costs, environmental costs of emitted GHGs from Polkalleh CS are calculated according to (Alireza Baghban, Jafar Sasanipour, Pouya Haratipour, Mehdi Alizad 2017; Smekens and van der Zwaan 2006; Tol 2003; Waldhoff et al. 2014).

Annual Polkalleh CS costs including total Operation and Maintenance (O&M), consumed natural gas cost and environmental externality costs are calculated for the existing condition. In the next step, the geothermal reservoir that is closest to this CS is selected; and based on its specifications, the most economically proper power plant is designed and its costs are computed based on Hance, 2005 (Hance 2005) and Salas, 2012(Salas n.d.).

Finally, with comparison of these two systems (Conventional and Proposed) from an economical point of view, results are analyzed and stated. All these steps are taken believing that:

- Global warming has irreversible effects on all living species and environmental impacts are very important to address. Also, one of the influential factors on global warming is greenhouse effect.
- As a consequence of global warming, all the greenhouse gasses have externalities and governments need to capitalize these costs toward sustainable energy development projects.
- Most prices, currency exchange rates and regulations are based on the average prices, conditions and Iranian government budget reported in 2015 and 2016.

It must be noticed that there are numerous inefficient and old systems of energy, currently operating in Iran. The 8-years imposed war on Iran in the 1980's and numerous sanctions which cause trade difficulties from 1980's to 2015's are the main reasons for it. Thus, as long as these outdated energy systems are operating, so much room would exist for further developments and improvements in different energy sections of Iran. Therefore, outcomes of evaluations like this study, can potentially be implemented in energy systems which consume fossil fuels, to calculate any hidden cost, e.g. environmental costs and the price of natural gas wasted in old gas turbines, as a benchmark for economic comparisons.

Above all, not only geothermal energy as the power source of compressor stations, could be a serious economic competitor for off-shore gas transmission as liquefied natural gas (LNG), but also geothermal energy can operate as a clean power source for on-shore LNG plants, too.

Gas Transmission Pipelines and Compressor Stations

Currently, natural gas is transportaed in two major ways:

- LNG Carriers; which is transportation done by ships in liquid state.
- Pipeline transportation in gas state; which in this transmision method, there must be several CSs located at every 50 to 150 km distance. While in every CS due to the compressors energy demand, 5 to 15% of its inlet natural gas is burned to supply the energy to make up for pipeline pressure drop. Therefore, this type of transportation is not logical for distances more than 2000 km.

Generally, when natural gas enters into a CS, it moves to dryers and scrubbers and then is pressurized by compressors, before finally getting cooled and leaving the CS. Typically centrifugal type of compressors is used.

As aforementioned, compressors' energy can be provided by GTs shaft work which is totally independent of the surrounding or electrical motors (providing electricity via an electric grid).

Nevertheless, power generation efficiency in power plants (combined-cycles for instance) is mostly higher than GTs, particularly when natural gas burns in both. So not only power plants burn less natural gas, but also capturing carbon in their stack are much easier than capturing it from stacks of many small and distributed GTs. Another advantage of electric motor to remote GT is its availability of operating in variety of speeds, which makes the system more flexible to demand changes; however, these kind of CSs are much more sensitive to power faults. So this last issue is addressed in this project with choosing geothermal power transmission system, in HVDC mode.

The first Iranian gas pipeline was established in 1965 by the Soviet Union, according to an agreement in which 10 billion cubic meters of natural gas were shipped from Iran to Russia, annually. In exchange, Russia constructed gas pipeline, its CSs and two major Iranian companies (Steel Company of Isfahan and Machinesazi Arak). The IGAT (Iran Gas Trunk Line) 1 pipeline was 42" in diameter and 1100 Km in length which transports NG from Bidboland plant in south of Iran to the Astara city in north west. Currently, Iran has more than 10 IGATs, which are 33,000 Kilometers long. In addition, two-third of the prosperities of Iranian National Gas Company is located in Iranian Gas Transmission Company. The Iranian gas pipelines characteristics are summarized in Table 1.

Moreover, Iran has about 76 compressor stations while the number of CSs is going to be increased to above 100 CSs, in the next decade, because of increased total energy demand. All these CSs are online and fully loaded for about 5 months of each year, from November to March. With a good estimation made in Table 2, the total power supply of GTs of CSs can be assumed to be about 6000 MW. About two-thirds of this power is transmitted to compressors by shaft and total power requirement is about 4,000 MW. Nonetheless, CSs' demand and supply do not follow any rule and vary only as a function of natural gas demand.

Table 1. General Information about Iran Gas Pipelines

Pipeline Name	Path and Destination	Length (Km)	Diameter (inches)	Capacity (Mm^3/day)	Number of CSs
IGAT 1	Bidboland refinery to Astara city,	1100	40& 42	40	10
IGAT 2	Kangan refinery to Qazvin city for consumption and export	1040	56	90	9
IGAT 3	1^{st} to 5^{th} phases of South Pars and Kangan refinery to Iran central and northern provinces of Iran for consumption	1195	56	90	10
IGAT 4	1st to 5th Phases of South Pars and Parsian Refinery to Saveh and export lines of Qazvin	1145	56	110	10
IGAT 5	6th to 8th Phases of South Pars and Fajr refinery to Khouzestan for injection to oil wells	540	42 & 56	95	5
IGAT 6	9th and 10th phases of South Pars to the Western provinces for consumption and export	610	56	110	5
IGAT 7	Asalouyeh to the South-Eastern provinces for consumption and export	900	56	50	Under Construction
IGAT 8	Asalouyeh and Parsian refinery to the central provinces for consumption	1050	56	110	10
IGAT10 (Loop)	Fajr refinery to the central provinces and pipelines	600	56	70	4
Azarbaijan 3rd line	From Saveh to the North-Western provinces for consumption and export	500	40 & 48	50	3
North and North-East 2nd line	From central provinces to eastern provinces for consumption	900	42 & 48	60	5

Table 2. General information of Iran's natural gas compressor stations

Property	Quantity
Number of CSs	76
Total Power Supply (MW)	6000
Total Power Demand (MW)	4000
Annual Capacity (Months per Year)	5~6

Polkalleh CS and Its Annual Costs

Polkalleh CS, located in Isfahan territory, is among the primary CSs in Iran (illustrated in Figure 1) which works completely loaded around a half of the year. As it is expressed in Table 3, this CS is exactly comprised of three sub-stations:

1. CS number 1, i.e. CS3 on IGAT 1: this CS consists of five Nevskiy GT units each is 10MW GTK-10-3 which constructed by Russia. These GTs and also IGAT 1 were included in the specified agreement amongst Iran and USSR, in 1965. Basically, these GTs have been employed beyond their economic life, yet they are being used around 3 months/year. IGAT 1 is also confronting numerous technical difficulties and outflows. Hence, right now, this pipeline often operates at the peak demand to store natural gas for other pipelines.
2. CS number 2, i.e. S4 on IGAT 2: This CS involve five devices of 16MW UGT-16000 GTs made by Zorya Mashproekt and set up by Sumi "Frunze" NPO who were both from Ukraine. These arrangement of Gas Turbines are online for about 6 months of year.
3. CS number 3 on IGAT 4: It is the most up to date among these three, containing four GT units of 25MW SGT-600 Siemens, and is online over half a year.

In this research, Polkalleh CS, cost calculation has been done according to the INGC data. It's also taken into consideration that the GTs that are on standby mode are OFF and out of utilization. Only operational GTs are considered ON.†

As declared, annual cost of a CS is sum of O&M, natural gas consumption and environmental costs. The experts and technicians of INGC believed that the operational cost of the principal CS is about \$0.750 million/ year while the maintenance cost is around \$2 million/ 20,000 h.

Annual maintenance cost of each GTK-10_3 is deliberated about \$0.18 million, each UGT-16000 nearly \$0.40 million and each SGT-600 is around \$0.43 million. By adding the outlined operational cost to this value, total annual O&M cost would be \$4.4 million.

To calculate the environmental costs, firstly, the amount of GHG emissions ought to be calculated. Though, since the INGC neglects environmental issues, there has no longer been any studies or records about them. On natural gas also, there is no concerns about the amount consumed NG in GTs, mainly because the INGC does not pay for the consumed natural gas to the Iranian government; however, we did not exclude it. Consequently, in this research, calculation is done based on GT capacity factor and efficiency. Molar fraction value of the natural gas entering into the Polkalleh CS is demonstrated in Table 4. Also, in Table 5, actual and theoretical amount of air for combustion, heat value, molecular mass and density of the fuel are shown. Additionally, according to GTs' performances and capacity factors, their fuel consumption are computed and shown in Table 6.

† For being ready to meet the demand, CS GTs are ON most times and they circulate natural gas over the CS via the by-pass lines. This cycle continues until the demand peaks. At this time, the exit valves open, the recycling natural gas flows through the main pipelines and leaves the CS. This cycle facilitates prompt action of the CS and provides faster gas supplement compared to turning the GTs ON and loading gas on an OFF GT. However, it grows energy demand. This study neglects ON mode of GTs during recycling and concerns the fully-loaded online operating of the GTs per year just. If the recycling process be considered, then the annual costs will increase.

As stated before, the extent of emissions from Polkalleh CS is calculated by Iranian Ministry of energy model called “Emission Calculating Model”. The inputs that need to be implanted in this model are attributed to the energy system, such as capacity factor, efficiency and power of GT, and also fuel information such as heat value. So as indicated by Tables 5 and Table 6 emission results of the model are presented in Table 7.

To confirm the GHG emission results, they are compared with Shahsavari et al., (Shahsavari Alavijeh et al. 2013). They collected emission data from 32 GTs of Iran, in 2008. In this study 6 out of 32 GTs are chosen, due to their identical power production to Polkalleh GTs. After that their efficiency calculation has been done and sorted in Table 8, by supposing that each of these 6 GTs burns an amount of natural gas equaling those of Polkalleh CS GTs.

GTs “number 5” and “number 8” with 9.5MW and 11MW respectively are more efficient than the Nevskiy GTs. nevertheless, the performance of gas turbines “number 2” and “ number 1” are almost equal to Zorya GTs, furthermore GTs “number 29” and “ number 32” are very similar to Siemens GTs. So considering the Table 8 and by comparison the data with the data presented in Table 7, it is clearly shown that the results of the model are acceptable.

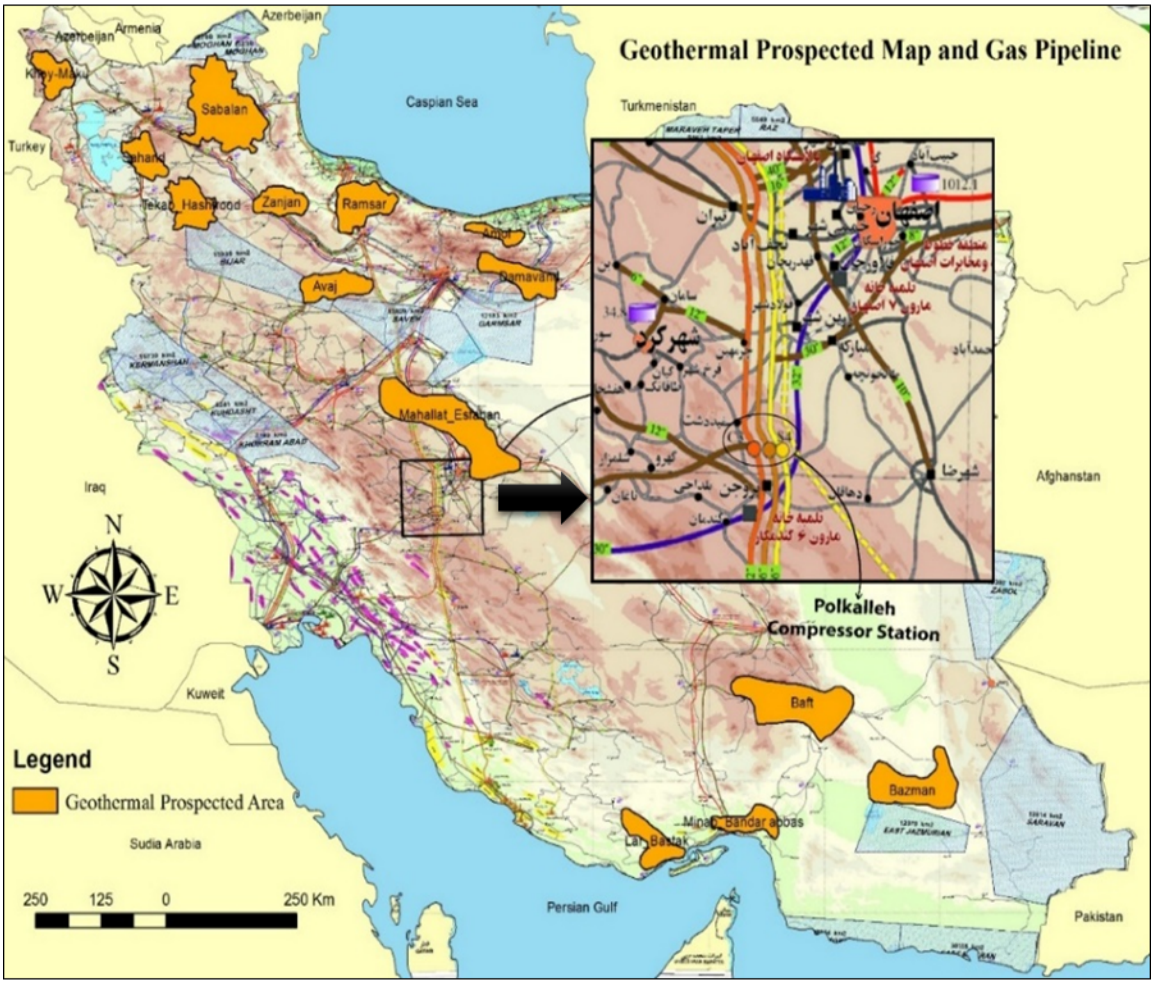

Figure 1. Polkalleh CS location on the general map of the petroleum industry of Iran (Courtesy of Iran National Cartography Center) and Iran Geothermal prospected map (Noorollahi et al. 2009)

For security reasons, additionally, O_2 has to be separated from the gas stream prior to entering into the GT. This can be carried out by filling up the pipeline with N_2 or natural gas and discharging the gas mixture entirely into the air before the process starts. Although N_2 is safer, natural gas is less expensive and more available for CSs, certainly. The amount of natural gas demanded for gas purgation can be significant, specifically knowing that CH_4 molecular volume is the largest among GHG molecules. Therefore if all the Polkalleh compressor station starts, expected 300 days per year, then around 600,000 m^3 natural gas (practically CH_4) will be wasted (Andrey 2013). So in Table 9, consumption of natural gas has been continued with the current conditions and total annual GHG emissions are presented.

Table 3. Detailed information and specification of Polkalleh compressor station

CS Name	Polkalleh#1	Polkalleh#2	Polkalleh#3
GT Manufacturer	Nevskiy	Zorya	Siemens
GT Name	GTK-10-3	UGT 16000	SGT-600
GT Arrangement	2+2+1	4+1	3+1
Supplied Power (MW)	10	16	25
Power Demand of Compressor (MW)	6	12	16
GT Efficiency (%)	8~10	23~25	28~30
Annual Working Time (Months per Year)	2~3	5~6	5~6
CS Capacity(Mm^3/day)	46	90	95
GT Max Speed (rpm)	4400	4800	7700
Compression Ratio	1.18	1.40	1.45

Table 4. Molar fraction input natural gas in Polkalleh CS

Substance	Molar Fraction in Fuel (%)	Lower Heat Value (Mj/Kg)
CH_4	90.33	50.00
N_2	3.76	-
C_2H_6	3.05	47.80
CO_2	1.01	-
C_3H_8	0.72	46.35
I-C_4H_{10}	0.26	45.75
N-C_4H_{10}	0.21	45.75
I-C_5H_{12}	0.09	45.35
N-C_5H_{12}	0.06	45.35
N-C_6H_{14}	0.06	44.75

Table 5. Chemical components of natural gas in Polkalleh CS

Component	Quantity
Theoretical Air of Combustion (Kg Air/1Kg Fuel)	16.32
Real Air of Combustion (Kg Air/1Kg Fuel)	50
Fuel Molecular Mass (g/mole)	17.61
Fuel Density (kg/m^3)	0.78
Lower Heat Value of Fuel in Mass Unit (Mj/Kg)	47.26
Lower Heat Value of Fuel in Volume Unit (Mj/m3)	37.15

Table 6. Natural gas consumption flow rate of each GT and the whole CS itself

GT Name	Power (MW)	GT Efficiency (%)	Fuel Consumption Flow Rate (Kg/s)	Annual Fuel Consumption (1000ton/year)
GTK-10-3	10	8~10	2.11~2.64	15.42
UGT 16000	16	23~25	1.35~1.47	22.24
SGT-600	25	28~30	1.76~1.89	28.76
Polkalleh CS	180	-	19.21~22.11	265.71

Table 7. Emissions of each Polkalleh CS GTs

GT Name	Specific CO_2 Emission (Kg/KWh)	Specific NO_x Emission (g/KWh)	Annual CO_2 Emission (1000ton/Year)	Annual NO_x Emission (ton/year)
GTK-10-3	2.29	3.36	41.72	61.22
UGT 16000	0.90	1.31	63.07	91.80
SGT-600	0.71	1.04	77.74	113.88

Table 8. The efficiency of correspondence GTs in Iran to the Polkaleh CS (Shahsavari Alavijeh et al. 2013)

Polkalleh GT	GT Number	GT Power (MW)	Fuel Consumption (Kg/s)	GT Efficiency (%)	Specific CO_2 Emission (Kg/KWh)	Specific NO_x Emission (g/KWh)
GTK-10-3	Number 5	9.5	1.06	19	0.87	4.06
	Number 8	11	1.08	21	0.77	1.04
UGT 16000	Number 2	15	1.62	19	0.85	3.94
	Number 1	16	1.65	20	0.81	3.40
SGT-600	Number 29	24	1.89	27	0.70	1.76
	Number 32	26.70	2.01	28	0.65	0.89

Table 9: Annual natural gas consumption and emissions of Polkalleh CS at current condition

Component	Amount
Total Gas Consumption (1000ton)	265.71
CO_2 Emission (1000ton)	652.42
NO_x Emission (ton)	953.74
CH_4 Emission (ton)	468

There are diverse numbers reported for the environmental costs of GHGs in different studies(Noorollahi 1999). As an instance for CO2 costs, costs ranging from $4 per ton to $345 per ton have been determined by authors in specific assets. This disparity, for certain has resulted from divert global warming impacts and externalities.

Therefore, according to Tol, 2003 (Tol 2003) and Waldhoff (Waldhoff et al. 2014), mainly, CO_2 costs are classified within five general viewpoints that vary from extremely conservative to strictly committed visions and three of them are involved in the cost calculations. Also, NO_x and CH_4 environmental costs come from Smekens and Van der Zwaan (Smekens and van der Zwaan 2006) and Waldhoff (Waldhoff et al. 2014) again and are presented in Table 10.

Thus, according to the environmental GHG costs and emissions in Tables 9 and 10, the annual external costs of Polkalleh CS are presented in Table 11. The related annual costs in the current condition based on three scenarios are exhibited in Table 12. However, ongoing the business with the current condition as usual, needs no further initial investment with no doubt and this could be considered as a slight economic opportunity.

Table 10: Environmental Costs of GHGs in different environmental visions (Smekens and van der Zwaan 2006; Tol 2003; Waldhoff et al. 2014)

Environmental Cost	Environmental Vision	Quantity ($/ton)
CO_2	Extremely Conservative	4
	Conservative	16
	Reasonable	30
	Committed	54
	Strictly Committed	84
NO_x	Reasonable	16000
CH_4	Reasonable	320

Table 11: Annual environmental costs of CS in different environmental visions at current condition

Polkalleh CS Condition	Annual Environmental Cost (M$)		
	Conservative Vision	Reasonable Vision	Committed Vision
Current Condition	25.85	34.98	50.64

Table 12. Economic opportunities and challenges of the government sector (INGC) at the current condition of Polkalleh CS – The 1st Scenario

The Government Sector			
Challenges			Opportunities
O&M Cost (M$/Year)		4.4	Further investments are not required
Natural Gas Cost (M$/Year)		50.00	
Environmental Cost (M$/Year)	Cons.	25.85	
	Reas.	34.98	
	Com.	50.64	

Geothermal Power and its Costs

Nowadays geothermal energy is one of the most fascinating options of investment among renewable sources of energies, and predictions claim that its production capacity would be increased significantly in the next decades(Saffarzadeh and Noorollahi 2005)(Lund and Boyd 2016; Moghaddam et al. 2013, 2014; Younes Noorollahi and Itoi 2011; Saffarzadeh and Noorollahi 2005; Yousefi and Ehara 2007). EGS (Enhanced Geothermal System) also has been represented as a breakthrough in energy technologies, as claimed that by 2050, its share in world energy basket will be up to 8% (Bertani 2015; Noorollahi et al. 2009; Yousefi et al. 2010).

Nonetheless, in Iran, geothermal projects are not as promising as it was expected. The first geothermal studies in Iran, started in 1975 and the first 100MW geothermal power plant (Meshkin Shahr Power Plant) was set to be established in 1995, yet there is no single sign of power generation in this power plant after about four decades(Hosseini et al. 2013; Noorollahi 2005; Y Noorollahi and Itoi 2011). As displayed in Figure 1, the most geographically proper geothermal reservoir near Polkalleh CS, is Mahallat-Isfahan reservoir (Noorollahi et al. 2009; Yousefi et al. 2010), and according to “Mahallat and Isfahan Geothermal Prospect Evaluation” (Y Noorollahi and Itoi 2011; SUNA 2011), its specifications are stated in Table 13.

Table 13. Mahallat-Isfahan geothermal reservoir specifications

Reservoir component	Amount
Average Wells Flow Rate (Kg/s)	80
Average Depth of Power Wells (Km)	2.1±0.8
Average Depth of Make-Up Wells (Km)	1.7±0.6
Reservoir Temperature (°C)	180±20
Well Head Temperature (°C)	140±20

Thus, according to Salas, 2012, (Salas n.d.) and Table 13, the best possible option from technical and economic aspects, is installing a double-flash power plant. The specific net power outlet of every well is also about 50 kW/(Kg/s), so power produced by every well is about 4MW. To minimize the losses during transmission of power, VSC-HVDC transmission mode is selected, for the common distance of 100 Km between Polkalleh CS and the power plant. The main reasons behind this choice are:

- In HVDC, there is no limit in grid distance. Furthermore, due to skin effect, power loss is significantly less than HVAC, which makes it a better option for bulk-power transmission (In this project, power loss is considered 1% for every 100Km). Nonetheless, power loss in HVDC switching stations and intermediate sub-stations is more than HVAC (This loss also considered 1% in every sub-station). Cables and grids of HVDC are cheaper than HVAC (about 40%), and this advantage is especially taken into account in long distances. However, HVDC sub-stations are expensive, mainly because of converters. HVDC is also environment-friendly and leaves less trace than HVAC (Bahrman and Johnson 2007; Flourentzou, Agelidis, and Demetriades 2009)

- HVDC is much more flexible and faster in controlling power flow, active/re-active powers, and also towards the demand changes in the grid. The risk of system errors and cascading outages in HVDC is also less than HVAC. So the power quality and stability are higher as well as the availability of the system. As far as a CS is so sensitive to consistency of power supply, this feature is really essential (Hammerstrom 2007).
- HVDC is able to be connected directly to electric motors which have VFD and operates in variable speeds (Baran and Mahajan 2003).

All the cables are chosen from ABB - Extruded Polymeric DC Cable types, and electric motors from ABB-Motorformer™ type (the power loss in electric motors considered 5%). All prices of the system of electricity transmission are gathered from (Alberta Energy 2009; Eeckhout1 et al. 2009; Peters, Timmerhaus, and West 2003).

As far as the maximum demand of Polkalleh CS is 154MW[3] (an emergency situation when 2 standby compressors are ON), and considering all the losses, the demand of this CS is assumed to be 160MW. So the initial investment and annual cost of a 160MW double-flash geothermal power plant, based on (Hance 2005) and (Salas n.d.) are stated in Table 14.

Since the usual temperature of Mahallat-Isfahan geothermal reservoir is not so high (as shown in Table 13) and geothermal power plant's capital cost is tightly dependent on resource temperature and depth, the capital cost of this power plant is significantly heavy. So assuming the wells' depths and average wells flow rate for Mahallat-Isfahan reservoir, about 2000 m and 100 Kg/s. Also, 100Km distance for gridline is expected. In Figure 2 a 160 MW double flash power plant' capital cost is calculated in a temperature domain from 160°C to 300°C. The figure is a useful asset to see the impact of the resource's temperature on the economic shape of this project.

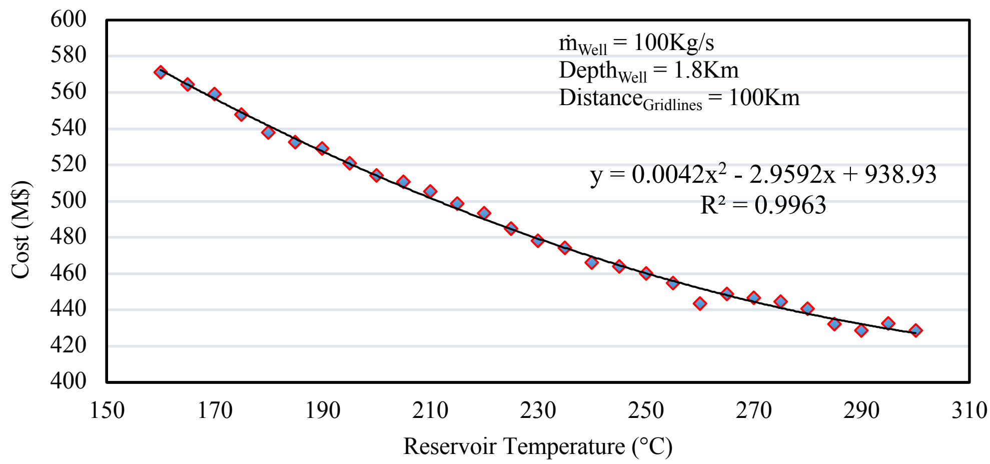

Fig 2. Capital investment in different reservoir temperatures for 160MW geothermal power plant

Economic Evaluation

Although change and flexibility are inside the DNA of all prices, the main purpose of this research is to examine and find a typical benchmark for economic feasibility of replacing cheap source of energies like natural gas in Iran with potentially expensive renewable energies. Thus, we considered standard prices of the technologies in the world, alongside the regulations in Iran's budget, neglecting the possible difficulties of trading with Iran, chiefly because of political issues or sanctions. We changed the US Dollar ($) value from all the references to the average value of US Dollar of the first six months of the year 2014.

[3] Considering the capacity factor of compressors, the annual energy consumption is also assumed 580GWh.

Table 14. Initial investment and annual cost of a160MW double-flash power plant on Mahallat-Isfahan reservoir

Title		**Specific Cost (M$/MW)**	**Final Cost (M$)**
Exploration and Confirmation		0.346 (M$/MW)	55
Drilling of Production and Make-Up Wells	1.4Km-1.9Km Depth (M$/Km)	1.7±0.3	190
	1.8Km-2.4Km Depth (M$/Km)	1.8±0.3	
Power Plant Equipment and Construction	Equipment Cost (PEC) (M$/MW)	0.560	215
	Power Plant Construction and Start Up (M$/MW)	1.93×0.560	
	Steam Gathering System and Field Piping (M$/MW)	0.260	
Power Transmission System	Electric Sub-Stations (Convertors, Switching, Transformer and etc.) (M$/MW)	(0.154±0.42)×2	120
	Overhead Transmission Line (Cables and Grid Installation) (M$/Km)	(0.699±0.143)	
	Electric Motors at the CS (M$)	0.855	
Capital Investment		3.625	580
Annual O&M Cost		0.25	40

In Iran, natural gas is considered as a national wealth; thus, it is possessed by the government, totally. In this research, the natural gas price is applied as the mean international price in 2015 equal to $4.25 per MMBtu ($0.1916/ kg) (Anon n.d.). According to the government incentive regulations, Iran Ministry of Power, have to buy every MWh of renewable power from suppliers, 4628Rials (Mansouri n.d.), while the normal power price is about 494 Rials per MWh. The government US Dollar exchange rate is also assumed 26,500Rials per $1, so the prices are equal to $174.64 per MWh of renewable power, and $18.64 per MWh of normal power (MOE n.d.).

All prices are taken out from the Iranian government budget in 2014. In another incentive regulation, the government is committed to reward the saved fossil fuel –or its equal price- to those projects, in which there are some savings from changing the energy source to renewable energies, or increasing efficiency and decreasing the losses as well as fossil fuel consumption by any means (Anon n.d.). Power plant lifetime is considered 30 years and installation period is assumed 4 years. Investment method and Iran average inflation rate for these years are stated in Table 15 (Monistry of economic n.d.).

Table 15. Investment method and the assumed Inflation rate of Iran in the project lifetime

Year	**Inflation. Rate (%)**	**Investment (M$)**
2011	22	93
2012	27	178.5
2013	35	179
2014	18	129.5
2015	15	-
2016~2045	15	-

For calculating CDM for the private investor, CO2 price is assumed $10 per ton, so based on Table 9, the annual income from CDM would be about $6.5 Million (Bank 2014). There are some different challenges and opportunities in corporation of this idea for either the government or private sectors. So we determined 2 main scenarios and discussed their different aspects. Then, in the 1st Scenario, if the private sector is the power plant investor, the main challenge will be the capital cost of the power plant, indeed. But the opportunities are selling the excess power[4] with high price to the government, selling the saved natural gas for two years, and CDM for one year. On the other hand, the government is able to sell the saved natural gas after two years and sell the power with normal price to people.

However, in the 2nd Scenario, if the government be the power plant investor and operator, the main challenges are the same, nonetheless buying high priced power from the private sector will not be needed, and the power is sold to people with normal price, adding to the saved natural gas which is sold by the government themselves from the first year. In Table 16 and Table 17 these challenges and opportunities are particularly shown. Therefore, based on Table 16, simple payback time for the private investor in the 1st scenario is little bit more than five years. Adding to this, with taking inflation rate into account and the investment method, based on Figure 3, Internal Rate of Return (IRR) for the private investor is about 14%, so the equity payback time is slightly more than 7 years. If we compare this number to the lifetime of the project (30 years), this project is economically feasible. However, comparing it with official rate of interest in Iranian Banks –from 17% up to 23%– this investment is not concluded as an economic project for the private sector.

Table 16. Economic opportunities and challenges of the private sector as power plant investor and operator (1st Scenario)

The Private Sector			
Challenges		Opportunities	
Power Plant Investment (M$)	580	High Priced Power (M$/Year)	130
O&M Cost (M$/Year)	40	Saved Natural Gas (for 2years) (M$/Year)	50
		CDM (for 1year) (M$)	6.5
The Government Sector			
Challenges		Opportunities	
High Priced Power (M$/Year)	130	Normal Priced Power (M$/Year)	14
Saved Natural Gas (for 2Years) (M$/Year)	50	Saved Natural Gas (after 2years) (M$/Year)	50

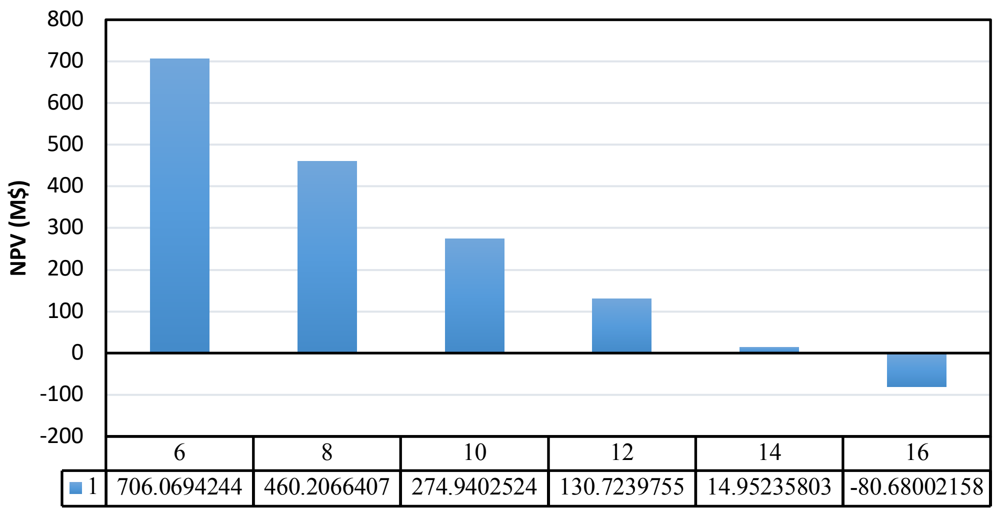

Figure 3. Net present value of project based on different interest rates

[4] The annual energy supply of a 160 MW power plant is 1330 GWh, and the energy demanded by Polkalleh CS is 580 GWh, annually. Therefore, there is a chance to sell 750 GWh high priced energy to the government for the private sector.

The current annual costs for the government were computed in the 3rd section, equal to \$80Million, \$90Million and \$105Million in three environmental visions. Looking at the yearly costs of the government in the 1st scenario, it can be observed that implementing the idea could cut its annual costs to \$66Million per year, which means this investment is able to decrease the government sector costs from 37% (committed environmental vision) to 18% (conservative environmental vision) annually.

Table 17. Economic opportunities and challenges of the government as power plant investor and operator (2nd Scenario)

The Government Sector			
Challenges		Opportunities	
Power Plant Investment (M\$)	580	Normal Priced Power (M\$/Year)	14
O&M Cost (M\$/Year)	40	Saved Natural Gas (M\$/Year)	50

It can be inferred from Table 17 that implementing this idea, with the government sector as the investor and operator, can turn the government costs to an income about \$24Million annually. However, the payback time related to the government is about 24 years which is shorter than the project lifetime; and considering the government as a non-profit organization, the investment is both logically and economically feasible.

In Figure 4, the government current costs in 3 environmental vision, the 1st scenario and the 2nd scenario are represented as a simple economic scheme. So the intersections between the lines, define the period that the costs of the scenarios become equal with each other.

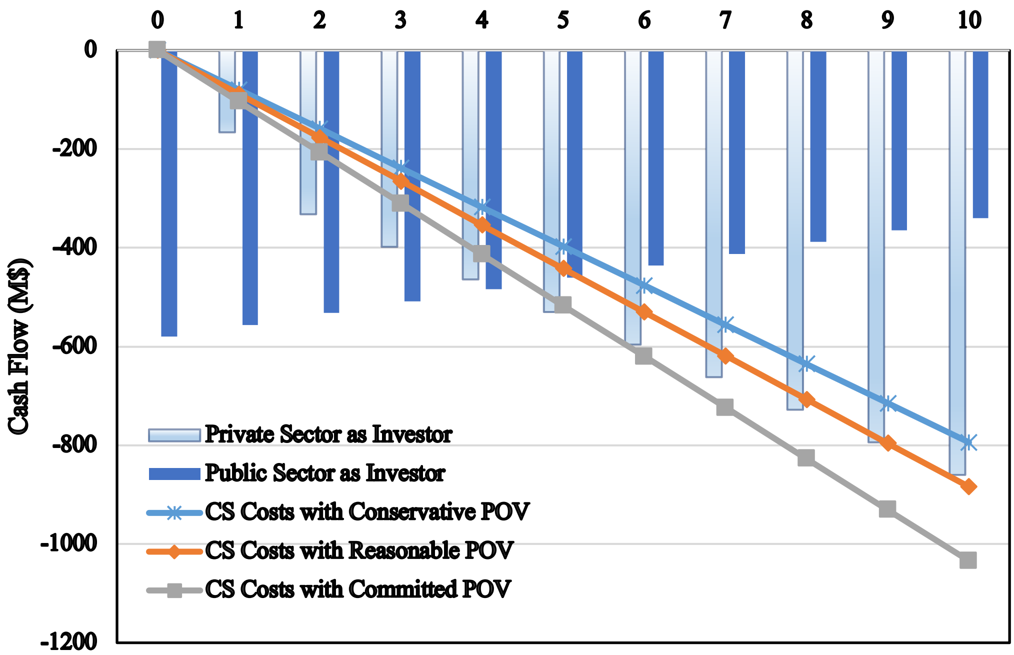

Figure 4: Simple economic chart of the government costs in current condition and two scenarios

Figure 4 implies that the cost-equal points between the 1st scenario and the current circumstance is between 5 to 12 years. The cost equal points between the 2nd scenario and current condition lies between 4 to 6 years. So it can be stated that although the 1st scenario can decrease the government costs and is profitable for the private sector as well, the 2nd scenario is the best possible option for the government, since it is associated with shorter cost-equal points, and turns the yearly costs to an annual income indeed.

A simple macro-economic analysis of all CSs replacement

In this section, a general estimation is made and the result of imposing this concept on all the Iranian CSs is investigated. Firstly, it should be noticed that, since there is no clarity within the INGC, gathering the specific statistics of all numerous Iran CSs is not possible. Thus taking advantage of a number of the INGC specialists, a general however close to-truth estimation of all CSs in Iran is chosen. Hence, 20% of the 76 CSs of Iran are taken into consideration in an approach similar to the CS of Polkalleh, 45% with half capacity of Polkalleh CS, and 35% with one-tenth capacity of Polkalleh CS. Table 18 presents the simulation results.

Table 18. Current condition of Iran CSs

Number of CSs	Total Power Supply (GW)	Total Power Demand (GW)
15	2.70	1.80
34	3.06	2.04
27	0.48	0.32
Total	6.24	4.16

While Polkalleh CS's total power capacity is 180 MW, the specific costs related to this CS are calculated. Therefore, considering the yearly costs of Polkalleh CS, i.e. \$81.25 Million, \$90.38 Million and \$106.04 Million according to the outlined visions, the yearly costs of this CS are \$0.45 Million per MW, \$0.50 Million per MW and \$0.59 Million per MW, respectively. So referring to the total production of power by all Iran CSs, Table 18, according to the cut-expenses ratios of every scenario which revealed in the last section, the total yearly cost of the CSs for INGC and therefore for the Iranian government, are computed and reported in Table 19.

So it can be stated roughly that implementing the 1st scenario for all CSs of Iran can save from \$500Million (conservative environmental vision) to \$1.5Billion (committed environmental vision) annually. However, the 2nd scenario has the potency to turn the government costs to about \$800Million income annually. Adding to this, should the 2nd scenario be implemented only on the 15 major CSs (which are online more than the other CSs and consume gas more), with an investment around \$6.5 Billion, it is able to turn \$1.3 Billion the government costs to \$75 Million income annually.

Table 19. Economic impact of replacing all CSs power demand with geothermal power

Environmental Vision	Total Annual Cost of Iran CSs (B\$/Year)		
	Current Condition	The 1st Scenario	The 2nd Scenario
Conservative	2.81		
Reasonable	3.12	2.28	0.83 (income)
Committed	3.68		

Conclusion

It is clear that the newer and more efficient power production systems are more preferable in compare to the old inefficient ones while they are more expensive. In this research, the CS of Polkalleh is selected as the case study and it is investigated as an energy system, which performs on a common basis, currently. Initially, the information regarding this system is collected. Then, based on these data, the current annual expenses of the CS consisting of the costs O&M, natural gas consumption in GTs and GHG emission costs are determined. After that, instead of using natural gas, the concept of using a geothermal power resource –as a clean and renewable source of energy– is evaluated from techno-economical perspective.

Current condition of Polkalleh CS, where is one of the most crucial and predominant CSs of Iran, is imposing significant costs on the INGC and therefore the Iranian authorities, since it owns two series of old and inefficient GTs that result in massive amounts of annual expenses, generally from environmental attitude. Alternatively, this system can be replaced by a 160MW double-flash geothermal power plant which is transmitted in HVDC mode and demands for $580 Million investment. Then, considering two economic scenarios, with either the private sector or the government sector as the power plant investor and operator, the results are promising.

In the 1st scenario with the private sector investment, IRR is about 14%, adding to 7 years of payback time. Whereas, there is 18% (conservative environmental vision) to 37% (committed environmental vision) drop in the government annual costs. However, the 2nd scenario influences the annual costs of the CS for the governmental sector greatly, as the CS can turn the government annual costs to $24 Million income and provides a 4 to 6 years of cost-equal period. In the end, it should be stated that the idea of using renewable geothermal power as the power source of CSs is not only an accepted option that can be a great economic competitor for gas transmission in liquid state or LNG, but also it is a clean power source that can be employed in on-shore LNG plants.

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