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Financial and Environmental Analysis of Geothermal Heat Pump Utilization in Shiraz City of Iran

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ABSTRACT

Due to the shortage of fossil fuel resources and the environmental issues caused by carbon emission, significant attention is being attracted to renewable energy resources. Among these sources, the geothermal resource is specifically useful in regions with underground potential due to low operational costs and high system efficiencies. Ground source heat pump (GSHP) utilized for building heating and cooling is a system commonly employed in this field. This paper aims to evaluate the overall environmental and financial benefits of GSHP employment in Shiraz, a major city in Iran, to supply heating and cooling demand for residential buildings constructed in 2017. The result demonstrates that in case of system substitution for 2725 apartments with GSHP systems, an approximate annual amount of 26 million cubic meters of natural gas is saved and consequently, 208'500 tons of yearly carbon emission is reduced. Furthermore, the country can export the natural gas to its neighbours which benefits 8'774'067 $.

1. INTRODUCTION

Due to a reduction in fossil fuel reserves and its environmental problems, renewable energies have become the greatest alternative for many countries. Renewable resources can be used for water desalination, heating and electricity generation. The absorbed solar energy by ground surface has a great energy resource. This energy can be utilized by ground source heat pumps (GSHPs) and reduce air pollutants and greenhouse gasses (GHGs).

The heat pump idea was developed by Lord Kelvin in 1852 and Robert Webber completed the idea by considering ground as a heat source in the 1940s. Due to the lack of oil resources in 1970, all renewable sources of energy, including GSHP, have been considered more. More than 500'000 GSHP systems for cooling and heating have been installed in United States and Canada, and 400'000 of these systems are using in European Union.

Iran has many oil and natural gas resources and the energy price is considerably low in comparison with other countries. Fossil fuel consuming power plants were generated 95% of Iranian electricity demand in 2017. Figure 1 illustrated the final fossil fuel consumption proportion in 2017.

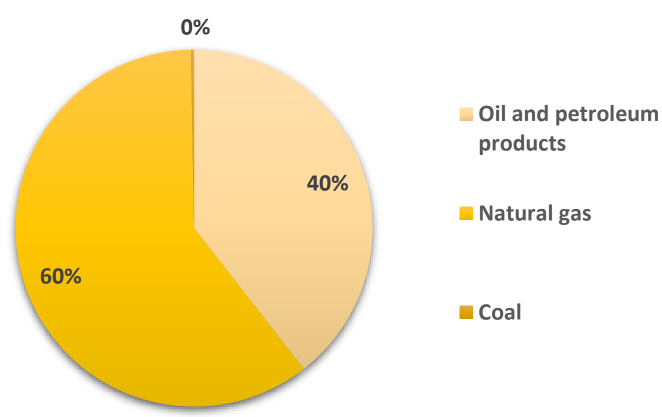

Figure 1: The final fossil fuel consumption in 2017

As it is obvious, natural gas was the greatest energy resource in Iran and 707 mtoe of this resource was consumed in 2o17. Figure 2 demonstrates the natural gas consuming sectors in Iran. Clearly, the residential, commercial and public sector is the most natural gas consuming sector (more than 55%).

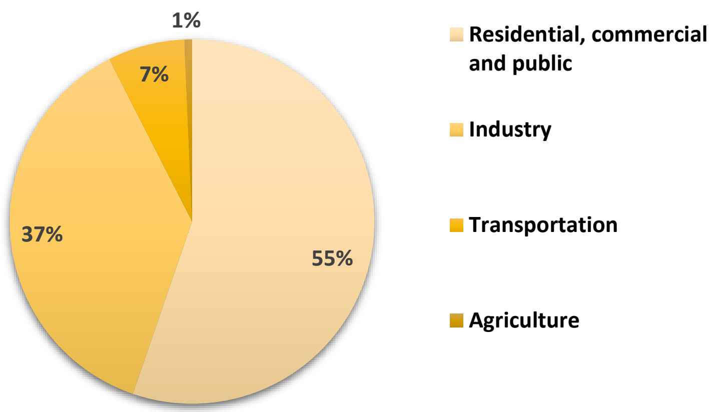

Fig. 2: Natural gas consuming sectors

Shiraz is one of the most populated cities of Iran with 1'781'707 residents. The Iranian government put a great amount of subsidy on natural gas and environmental problems caused by natural gas consumption is a growing concern.

In this paper, new building under construction in 2017 in Shiraz are considered as a case study and GSHP systems are selected to supply heating and cooling demand of these buildings. Financial and environmental analyses were conducted to obtain a reasonable amount of subsidy by the government to use GSHPs instead of common systems

2. MATERIALS AND METHODS

Considering the fluctuation of ambient and underground temperature (Figure 3), it can be obtained that, the greater the depth, the less the temperature changes. So, at a depth of 3 to 4 meters from the surface of the ground, temperature variation is negligible. Therefore, underground can be considered as a good source of heating and cooling for buildings.

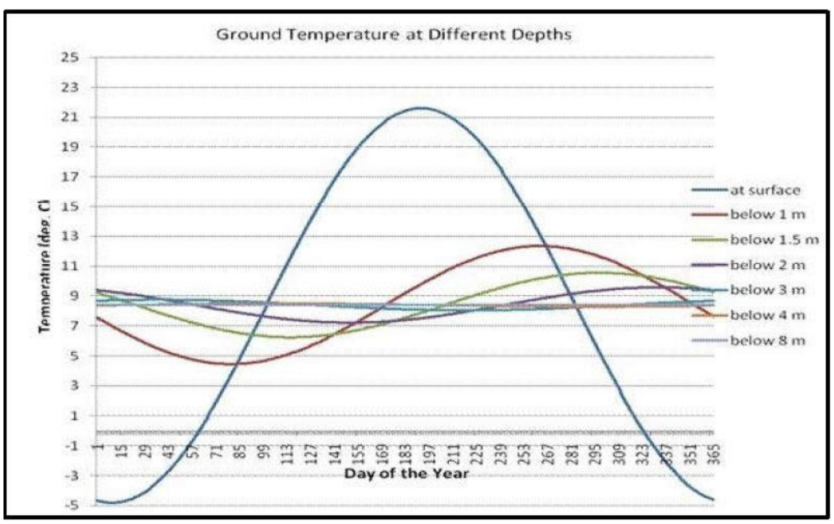

Figure 3: Ground temperature profile compared with surface temperature

In GSHP system, the heat is extracted from underground and transferred to the building by the fluid inside the pipe and used as a source of heat in the winter, or in the summer, the warm air inside the building is transferred to the ground through the pump. Also, the source of heat in Heat pumps can be underground or surface water.

In general, ASHRAE has divided heat pumps into 3 categories:

1. Groundwater Heat Pumps (GWHP)

2. Surface Water Heat Pumps (SWHP)

3. Ground-connected heat pumps (GCHP)

Ordinarily, the geothermal heat pumps have two main parts, including a heat pump inside the building and a pipe circuit outside the building. This plumbing circuit can be an open or a closed cycle. In the open cycle, the exchange of heat is carried out with a large source of water which has a constant temperature such as groundwater.

On the other hand, in closed cycle heat pumps the heat exchange takes place with the ground through a ring pipe and another underground coil. The ground coil can be designed vertically (Figure 4) or horizontally (Figure 5).

Figure 4: Vertical GSHP

Figure 5: Horizontal GSHP

2.1 Financial analysis

The city of Shiraz is one of the major cities in Iran, with an area of 1268 square kilometres. According to the Statistical Center of Iran report, the area of under construction buildings in 2017 was 2'588'289 square meters. According to the same report, the number of buildings constructed in the mentioned year was 2'725, which is equal to 19'906 apartment units. As an assumption in this research, the number of each building unit residents was considered 3 people.

According to the Iranian Energy Balance sheet of 2016, annual natural gas consumption per person in the residential, commercial and public sector in Shiraz is 613 square meters . Since 71% of the building energy is consumed to supply cooling and heating demands, the annual savings in a building unit is:

$$3 \times 613 \times 0.71 = 1306 \text{ m}^3$$

If all under construction buildings in Shiraz are equipped with GSHPs, the annual natural gas reduction would be:

$$1306 \times 19'906 = 25'997'236 \text{m}^3$$

The thermal value of each cubic meter of natural gas in Iran is 8905 kcal. Therefore, 269 million kilowatt-hours of energy will be supplied by GSHPs, annually. If the natural gas is exported to Turkey and sold at 0.35 cents per cubic meter instead of domestic consumption (sold 0.0125 cents per cubic meter to citizens) by governmental subsidies, the country would earn $ 8'774'067.

$$(0.35 - 0.0125) \times 25'997'236 = 8'774'067 \text{ \$}$$

2.2 Environmental analysis

One major shortcoming of fossil fuel consumption is Greenhouse gas emission as well as air pollution. Fig. 6 shows the contribution of fossil fuels to carbon dioxide emission in 2017.

Although natural gas has the least amount of pollution as compared to other fossil fuels, approximately 61% of carbon dioxide emission in Shiraz is caused by natural gas consumption .

Hence it is deduced that geothermal heat pumps significantly reduce carbon dioxide emission while saving natural gas resources. The external costs resulting from preventing the emission of 6 air pollutants (namely CO_2, SPM, SO_2, CH_4, and NO_X) are listed in Table 1.

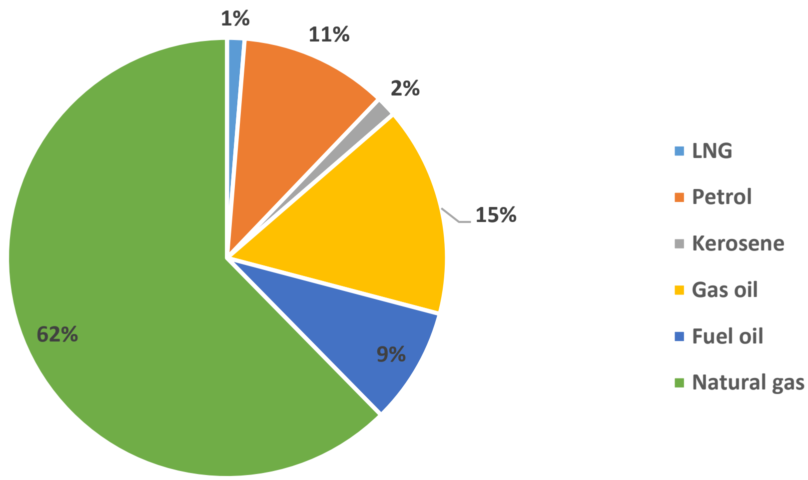

Figure 6: The contribution of fossil fuels to carbon dioxide emissions

Table 1. Environmental cost reduction

Air pollutant	Air pollutant emission index (gr per kWh)	Reduced air pollutant (Ton)	External costs of Pollutants ($/Ton)	Amount of external costs Reduction($)
CO2	767.48	206’452.12	2.86	590’453
SPM	0.154	41.43	1228.57	50’894
CO	0.694	186.69	53.57	10’001
SO2	3.887	1045.6	521.43	545’209
CH4	0.02	5.38	60	322.8
NOX	793.13	778.49	171.43	133’456

Also, the logarithmic tons of emission reduction caused by utilizing GSHP is illustrated in Fig.7.

The annual profit rates of the government due to natural gas selling and pollutants' emission prevention is equivalent to:

$$1'330'336 + 8'774'067 = 10'104'403\ \$$$

The maximum required cooling load for a building unit with 100 square meter area in Shiraz is 40’000 btu/h, which is equal to 3.4 cooling tons. Similarly, the maximum required heating load is 30’000 btu/h, equivalent to 2.5 cooling tons. Therefore, the maximum required load for a building is 3.4 cooling tons per year.

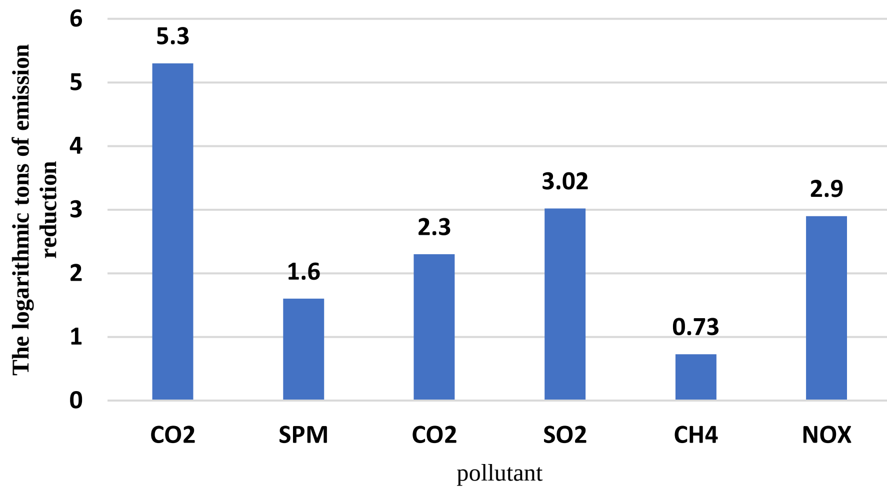

Figure 7: The logarithmic tons of emission reduction caused by utilizing GSHP

The cost of heat pump installation per cooling tons equals \$3900. Therefore, the GHP installation cost for a building with 8 units is estimated to be

$$8 \times 3.4 \times 3900 = 106'080\ \$$$

According to the reports of the central bank of Iran, the inflation rate in 2016 was 11.9% and the discount rate was assumed to be 21% (equal to 2016 minimum benefit in long time deposit).

Hereby, the capital investment return period is estimated by conducting economic calculations for replacing conventional systems with GSHP for different government subsidization support percentages. The acquired results for the number of capital investment return period for various percentages of government support is illustrated in Fig.8.

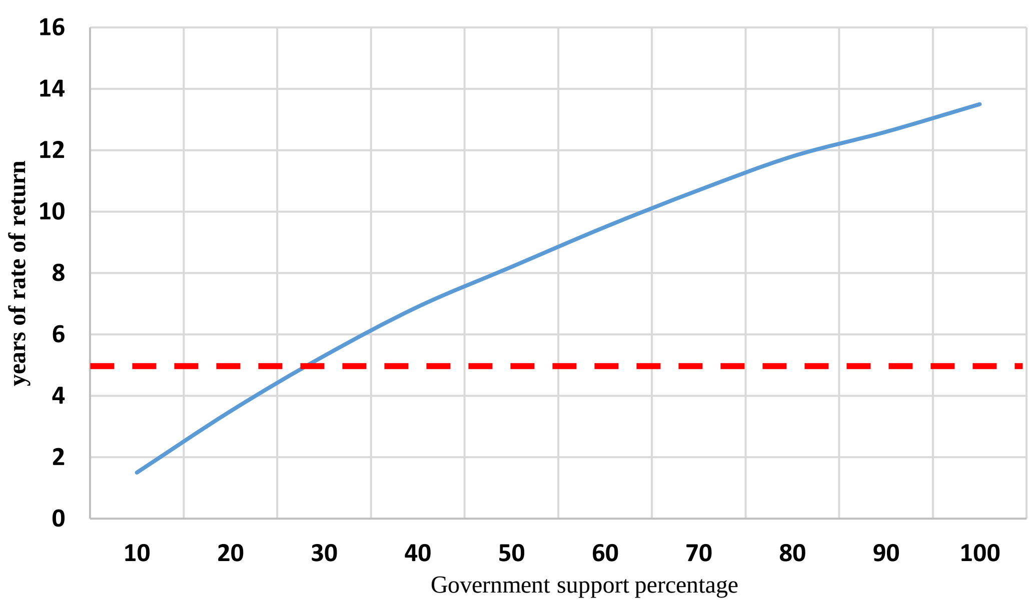

Figure 8: The effect of government support on the return of capital

In case the reasonable capital investment return period is considered to be 5 years, the government must provide 30% of the GSHP cost for the citizens for an economic action plan.

3. CONCLUSION

This paper aims to investigate the geothermal heat pumps and their feasibility to be utilized for natural gas consumption reduction along with consequent pollutant emission prevention.

Iran has enormous potential for renewable energy, being able to provide substantial amounts of its energy demand relying on these sources. On the other hand, Iran is also capable of exporting natural gas to countries like Turkey and Iraq. In this paper, the effects of replacing the conventional natural gas-based systems with geothermal heat pumps are investigated regarding the previously mentioned aspects.

If all buildings under construction in Shiraz in 2016 are equipped with GSHP, an annual amount of 25’997’236 cubic meters of natural gas will be saved. Exporting this amount of natural gas produces 8′774′067 $ annual cash flow for the country. Consequently, 208500 tons of yearly carbon emission is reduced.

If the government provide 30% of the GSHP cost for the citizens, the reasonable capital investment return period is 5 years.

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