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Economic and Environmental Analysis of Replacement of Natural Gas Heating System with Geothermal Heat Pump in District 11 of Tehran

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ABSTRACT

Considering the fact that fossil fuels resources with their extreme environmental contaminants are coming to an end, clean and renewable energy utilization is taken into account. One of the simplest renewable energy resources which can also be used for heating and cooling is ground source heat pump (GSHP).

Iran is one of the developing countries with high energy consumption per capita, but major part of energy consumption is spending in Consumable sectors which do not increase GDP. Not only natural gas utilization is very costly because of subsidies for Iranian government, but also imposes massive amount of air pollution into the atmosphere and causes external costs as well.

In this paper, by modeling the buildings which are having construction permission in district 11 of Tehran city by 2014, the exchange of GSHP's with common systems by government support is studied. The results showed that by using GSHP in each year, more than 100'568 tons of air pollutant is prevented to be spread and the amount of reduced environmental costs due to contaminant is estimated to be 641'364 $. Besides, 12'931'360 $ cubic meters of natural gas can be saved annually. Regarding to gas exportation price in 2014, 3'232'840 $ profit will be gained from gas exportation. After all, Iranian government strategies to encourage households in order to apply this system is discussed. It is found with government supports for using GSHP's, the rate of return will be changed from 18 years (with no governmental support) to less than 2 years.

1. INTRODUCTION

Iran is one of the developing countries in the Middle East. It has a high energy consumption per capita due to high energy sources such as oil and natural gas and low cost of energy. The energy per capita in 2013 was 1.91 tons of crude oil, which is 65% more than the global average. However by using energy in industrial sectors Iran can reach developments and economic growth, the major part of energy consumption is used in low efficiency sectors which do not increase GDP. The below diagram displays the energy consumption sectors in Iran; It's clear that almost 50% of Iran energy consumption have been used in the domestic and commercial sectors in 2012, while in the United States of America energy consumption is less than 30% in the residential and commercial sectors (EIA, 2016).

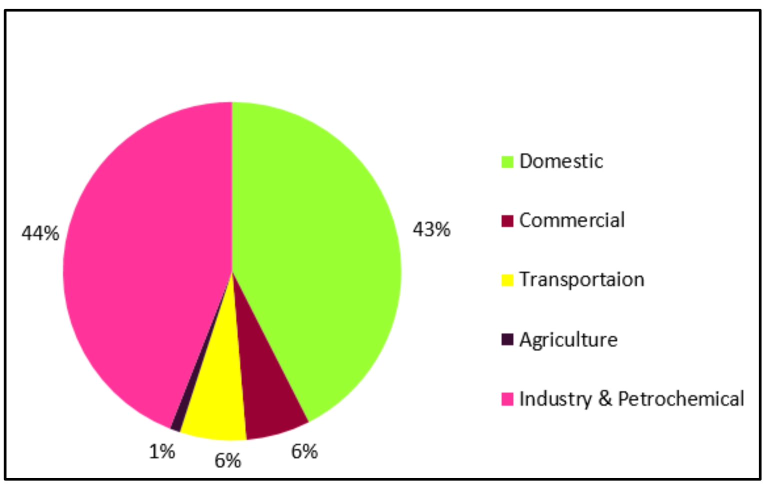


Figure 1: Iran energy consumption sectors in 2012 (Yousefi et al., 2015)

Tehran city has more than 8'500'000 residents which makes Tehran the most populated city in Iran. Providing its resident energy needs is the responsibility of government. Tehran's current development program is based on the use of natural gas in future construction projects. The natural gas consumption per capita in Tehran is 1257 m^3 per year. Not only natural gas utilization is very costly because of subsidies for Iranian government, but also imposes massive amount of air pollution into the atmosphere and causes external costs as well (EIA, 2015).

Widely, developed countries use renewable energies technology in residential sector in order to supply energy demand. One of these technologies is ground source heat pump utilization. This technology can be used both for heating and cooling. Unlike other renewable energy, geothermal heat power is available all hours of the day and in all geographic areas so it doesn't need energy storage like other renewables (Yousefi, et al., 2015). Successful examples of GSHP technology have been implemented around the world, for instance designing and implementation projects between 2009 and 2014 in southern Europe countries. In this projects 8 buildings with different applications have used heat pumps to supply cooling and heating demand. The performance coefficient of 3- 5 demonstrates this system's appropriate capability (Mendrinos and Karytsas, 2015), (Sarbu and Sebarchievici, 2016).

Moreover, the sample study carried out in northern Tunisia showed that use of GSHP system can be the solution to high energy consumption in domestic sector (Naili et al., 2016). Other than domestic, it can also be used for other consumption sectors. The use of GSHP in a Pig house center during 3-weeks lead to reduction of electricity 750 KWH and 405.39 kg in CO_2 emission (Isalm et al., 2016). GSHPs do not directly produce CO_2, but the amount of CO_2 production depends on it's efficiency and the way power generation is used (Blum et al., 2010). Typically, rate of return for GSHP system is between 6 to 20 years if the external cost does not considered (Hanova and Dowlatabadi, 2007). In a production cost comparison during 20 years period with other conventional heating systems such as air heat pump, electric and gas heaters, GSHP technology is more economical (Stuart et al., 2013).

In order to optimize the rate of return and performance of the GSHP system during its operational life, minimization of primary energy consumption regarding to design parameters (heat pump and generator capacity, size, number and geothermal heat exchanger position, flow rate in ground loop and load share in GSHP systems and alternative strategy control system) considered as objective function (Conti et al., 2015).

Another GSHP feature is the ability to combine with photovoltaic systems. In this combination, required power is supplied through solar energy. A system has introduced which uses solar energy and ground source heat pump with phase change in converter to save solar energy in summer and gives it back in winter (Xin-Guo et al., 2010). Lately, the Renewable Energy Organization of Iran (SUNA) is working on a project for installing 5 GSHPs in 5 different regions in order to determine technical and economic impacts of different climate with the performance of GSHPs. Statistics demonstrate 50-70% decrease in energy consumption by using GSHPs (Porkhial and Sheydae, 2015).

In this paper, Considering the buildings which are having construction permission in district 11 of Tehran city by 2014, the exchange of GSHP's with common systems by government support is studied. Due to the lack of contaminants by using this technology, it is expected that considerable amount of emissions reduction take place. Also with regard to the ability of exporting natural gas, Iran would use the natural gas export benefits.

2. MATERIALS AND METHODS

GSHP is a system that is used for cooling, heating and also supplying hot water demand of residential buildings, offices, industrial environments. GSHPs are growing rapidly because of multiple reasons such as producing clean energy and the ability of reducing greenhouse gas emissions, low cost of repairs and maintenance and reduction of power consumption (Sarbu and Sebarchievici, 2016).

Ground source heat pump is an exchanger that collects heat underground and transfers it to buildings by fluid into the tubes by using electricity. This heat doesn't make of combustion so it does not produce pollutant emissions resulting from combustion. In fact in this system, source of hot water is geothermal energy that is replaced with fossil fuels in common powerhouses. Due to temperature fluctuation under ground is less than ambient air, GSHPs consume less power than air heat pumps at the same performance coefficient. Also the performance coefficient of GSHP is higher than air-source heat pump and because of more stable compressor performance, GSHP compressor can work longer than air source heat pump's.

As specified in the figure 2, ground temperature is relatively constant during the year in depth of 7 meters. Therefore, it is always a difference between air temperature and ambient one which can be used for building cooling and heating (Aydın et al., 2015).

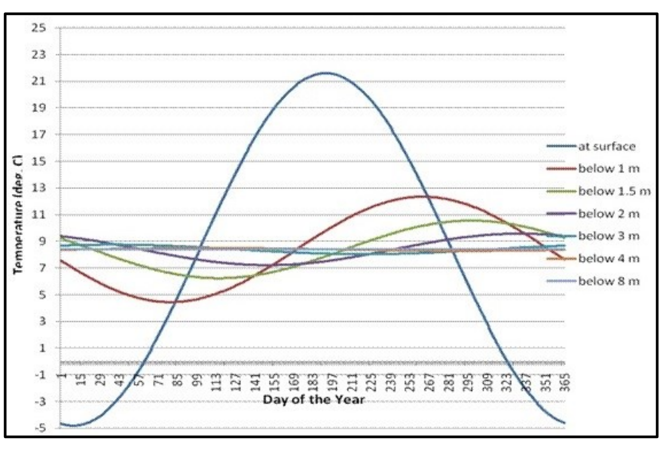
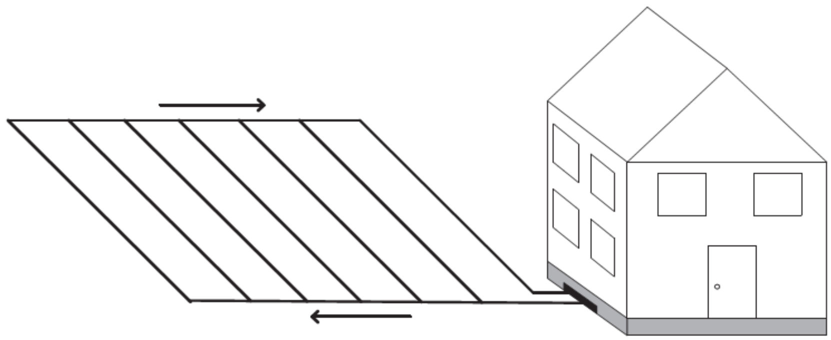


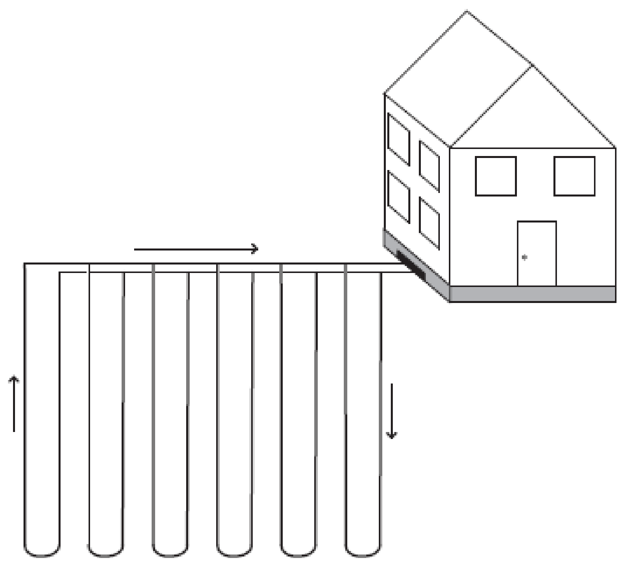
Figure 2: ground temperature profile compared with surface temperature (Yousefi et al., 2015)

GSHPs are divided into two categories; opened-loop and closed-loop. In a closed-loop cycle, heat is extracted from the ground using water flow in a continuous loop of special pipes buried in the ground. In this system, a constant volume of water is circulating through a closed u-tube loop. Closed-loop system is better than the open-loop type because of using just one well and also no need to use cleaning filter for input water from ground to pump (Yousefi et al., 2015). GSHPs classified into two classes Based on the drilling depth and number of tubes used in the system to collect heat; Horizontal and vertical which are illustrated in figure 3.

According to results vertical type has lower initial costs and also easier to install but the problem is that they need more space. By comparison of widely popular models it is found that the spiral exchanger type is the best (Aydın et al., 2015).



(a)



(b)

Figure 3: Ground source heat pump system (a) horizontal and (b) vertical

Due to lower occupancy levels and limited need for space, vertical closed loop system is applied in this project.

District 11 is one of the 22 districts of Tehran that is mainly residential - commercial context. This area is about 12’060 square meters which contains 8/1% of the total area of Tehran. The population of this area based on the latest population census in 2011, is 495,720 people. Figure 4 shows where the district 11 is located between the 22 district of Tehran metropolitan city.

A building is modeled by replacing GSHP systems instead of existing systems. The building has 5 floors and each floor contained 2 units. Total area of this building is 2077 m^2 while Base area is 360 m^2 . It is located in northern part of district 11. The residents of each flat considered as 2. By entering the information of the building in HAP Carrier 4.51 the building heating and cooling loads are calculated as 60.8 and 64 KW respectively.

The flowchart of energy consumption, natural gas savings, environmental benefits, and economical efficiency estimation in the building is shown in Figure 5.

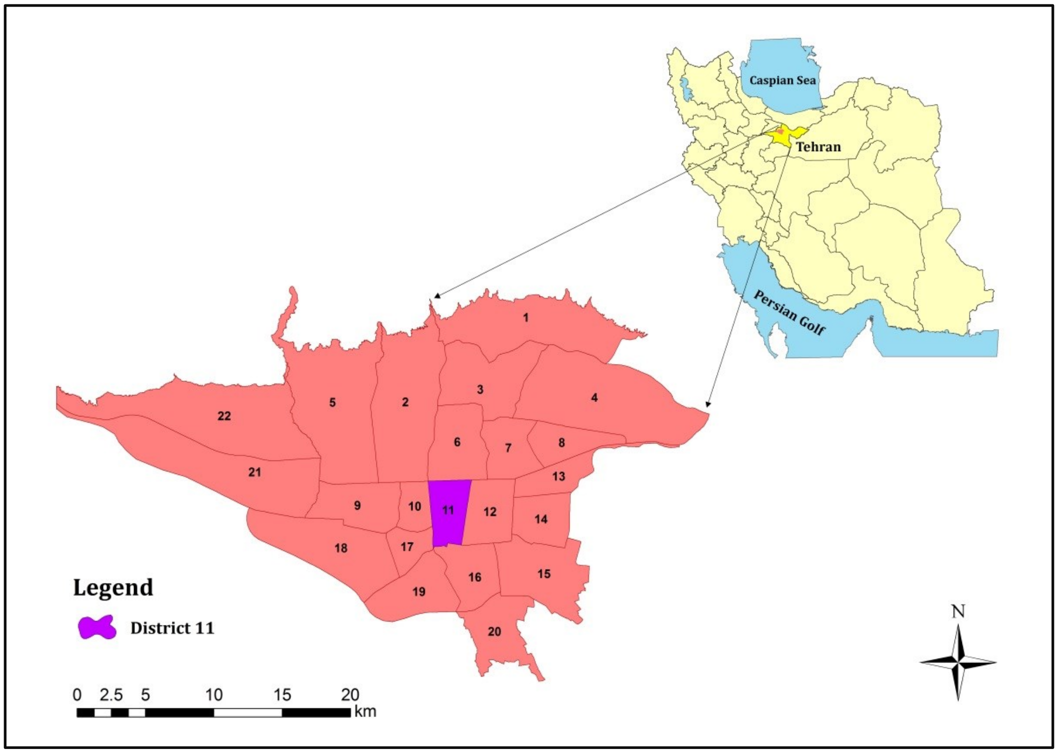


Figure 4: Location of district 11 of Tehran

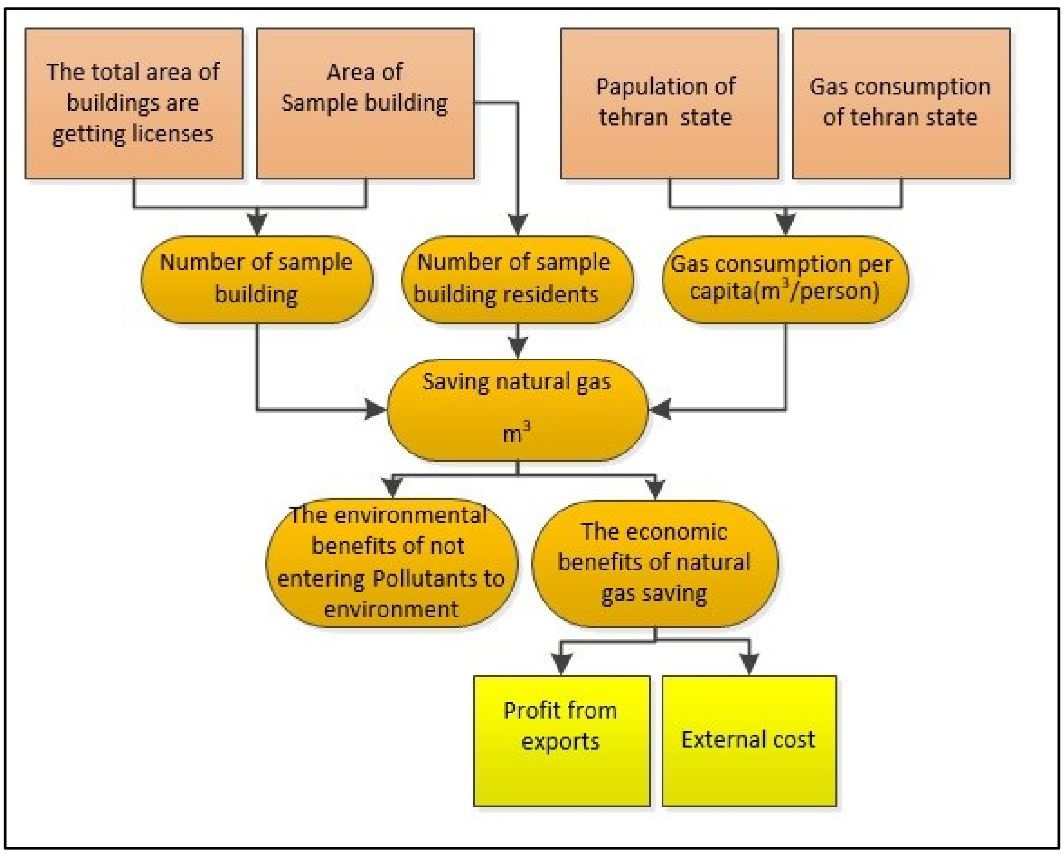


Figure 5: Modeling process

According to Statistical Center of Iran, the area of buildings under construction in 2013 was 260’665 m^2. By knowing the base area of 360 m^2 for sample building, the Number of equivalent buildings is calculated:

$$\frac{260'665\ m^2}{360\ m^2} = 724$$

71% of gas consumption in domestic sector is for heating and cooling. The 2012 per capita consumption of natural gas in the Iran Energy Balance Sheet is 1257.7m^3. Then, the annual savings of natural gas in the sample building is (Yousefi et al., 2015) :

$$2 \times 10 \times 0.71 \times 1'257.7 = 17'860\ \mathrm{m}^2$$

Subsequently, if all buildings under construction in district 11 equipped with GSHPs, the annual natural gas savings would be 12931360 m^3.

$$17'860 \times 724 = 12'931'360\ \mathrm{m}^3$$

Thermal value per cubic meter of Iranian natural gas is 8600 kcal therefore nearly 130 million kilowatt hours of energy will be provided by heat pumps. The price of Iranian gas export to Turkey was 35 cents in 2015, while it was sold 0.1$ per cubic meter to Iranian residential sector. Therefore the amount of annual gas savings by the government sold, there would be 3’232’840 $ profit.

$$12'931'360 \times (0.35 - 0.1) = 3'232'840\ \$$$

3. ENVIRONMENTAL ANALYSIS

With economic growth, environmental damage and waste has always been found. One of the major issues related to the use of fossil fuels is gas emission like NO_2, SO_2 and CO_2. An important goal of alternative energy is reduction of these kind of emissions especially CO_2 and the greenhouse effect (Aydın et al., 2015).

Natural gas is much cleaner compared with other fossil fuels, and has the least amount of pollution, But 50 percent of carbon dioxide emission in Tehran is related to natural gas consumption. It also has a very significant effect in climate change (Yousefi et al., 2015) .According to previous section by reducing $12'931'360\ \mathrm{m}^3$ natural consumption, the reduction of air pollutants will be like table 1.

Table 1. Reduction of emissions through the use of GSHP (Yousefi et al., 2015)

Pollutants	Index of emission production (grams per kWh)	The amount of emission deduction through the use of heat pump (tons)
CO_2	767.48	99’576
SPM	0.154	20
CO	0.694	90
SO_2	3.887	504.32
CH_4	0.02	2.6
NO_x	20.894	375.48
total	793.129	100’568

External costs (benefits of preventing 6 pollutants to be spread into the air) are shown in Table2. Figure 6 is shown the logarithmic tons of annually emission reduction by GSHP in district 11.

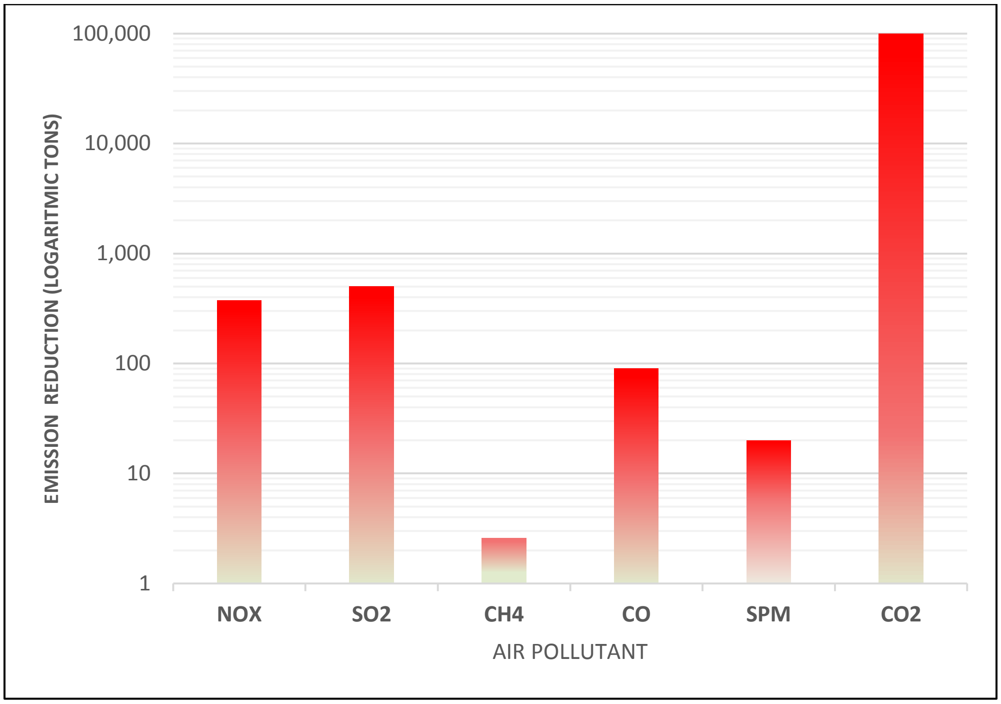


Figure 6: Annually emission reduction by using GSHP in district 11 (logarithmic tons)

Table 2: The amount of emission reduction through the use of GSHP

Pollutants	External costs of pollutants equal to environment demolition ($/tons)	The amount of emission reduction through the use of GSHP (tons)	Amount of external costs reduction
CO_2	2.86	99’576.416	284’505
SPM	1’228.57	19.981	24’548
CO	53.57	90.043	4824
SO_2	521.43	504.317	262’966
CH_4	60.00	2.595	156
NO_x	171.43	375.481	64’368
total	2’037.86	100’568.833	641’265

Thus the annual profit for the government from selling natural gas and preventing pollution spread is equal to:

$$3'232'840 \ + 641'264 = 3'874'104 \ \ \$$$

Now to find out how government should encourage citizens to use GSHP system, 2 strategies are examined.

1. The rate of return calculation if government does not support,
2. The rate of return calculation if government help residents by giving them 5 years of the project’s benefit as subsidization.

3. The rate of return calculation if government help residents by giving them 9 years of the project's benefit as subsidization.

According to what was said earlier, the maximum load of sample building is 18.5 cooling tons. Cost of installing heat pump is 5000 $/ton (Inquiry of Bernoulli company): (Yousefi, et al., 2015)

$$18.5\ ton \times 5000\ \$/ton\ = 92500\ \$$$

By using GSHP, the initial costs of boiler, chiller and condenser is saved.

Table 3: Equipment costs

Equipment	Costs ($)
Boiler	2900
Chiller	18000
Condenser	5500
Total	26400

So, by using GSHP in sample building extra initial cost will be:

$$92'500\ \$ - 26'400\ \$ = 66'100\ \$$$

Iranian natural gas price for domestic consumption was 0.1$ per cubic meters in 2015. In the case of heat pump technology utilization, 17'861 m^3 of gas is saved in the sample building annually. After the first year, 1'786$ is stored by residents.

According to the Iranian central bank reports, inflation rate in 2014 was 33%. The discount rate was assumed 20 % (equal to 2014 minimum benefit in long time deposit).

Economic calculations in the first strategy proved if building under construction in district 11 equipped with GSHPs, rate of return will be 18.5 years though, though it's not economical. Therefore, if government does not support the replacement of GSHP systems, this will not be used by residents.

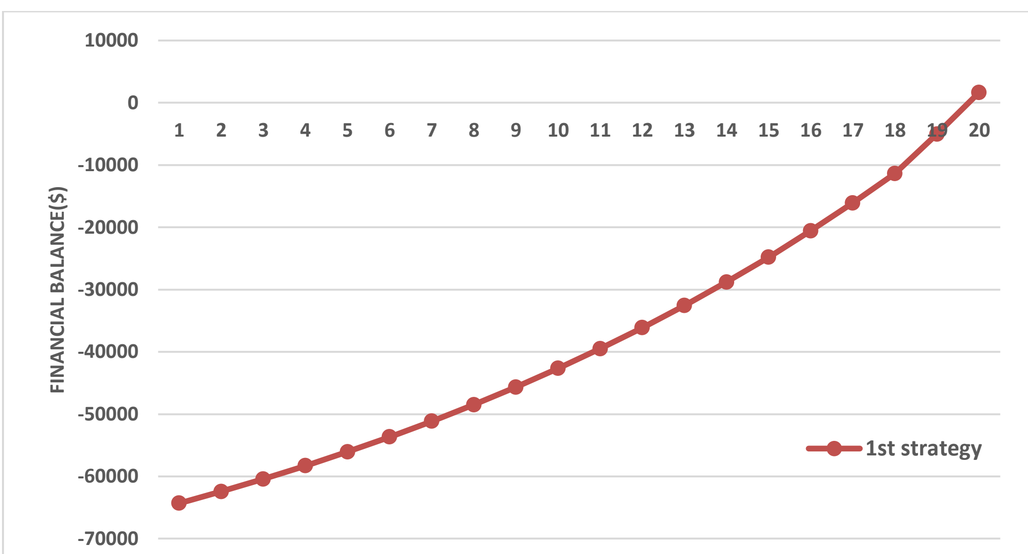


Fig 7: first scenario of financial balance

At present, two governmental supportive strategies are discussed. These supportive systems can be like decreasing in GSHP manufacturer taxes in order to keep it's price low for citizens. Another supportive way is to discount on construction permit. In second strategy, government pay 5 years of project's benefit as support .And in third strategy 9 years of benefit is paid.

By dividing the annual interest of replacement to the number of sample buildings, annual benefit of each building is given.

$$\frac{3'874'104\ \$}{724} \cong 5'351\ \$$$

Table 4: GSHP benefit annual benefits

year	NPV(benefit)$	NPV(total benefit)$
1	5'351	5'351
2	5'667	11'018
3	6'003	17'021
4	6'358	23'379
5	6,733	30'112
6	7'132	37'244
7	7'553	44'797
8	8,'000	52'797
9	8'473	61'270

According to the table above, subsidized by the government for Strategy 2 and 3, are $ 30'112 and $ 61'270, respectively. Consequently, the initial cost of strategy 1 and 2, respectively is:

$$66'100\ \$ - 30'112\$ = 35'988\$$$

$$66'100\ \$ - 61'270\$ = 4'830\$$$

By economic calculation, rate of return for second strategy will be occurred after 12.6 years; On the other hand, rate of return is possible for the third strategy in 1.6 year.

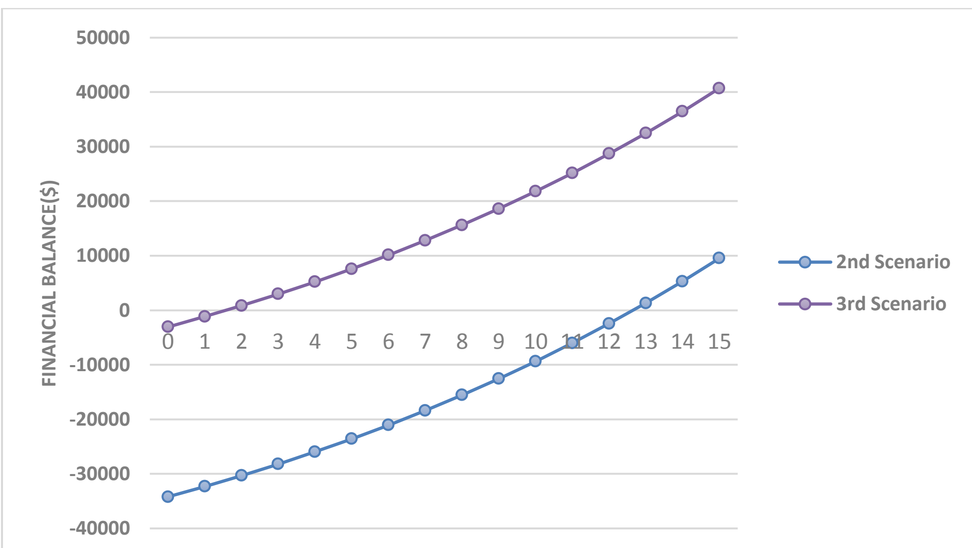


Fig 8: second and third scenarios of financial balance

Large difference in rate of return is because of high natural gas export price per cubic meters (0.35$) while it's price for Iranian residential consumers is too low (0.1$).

4. CONCLUSION

Since Iran is located in an appropriate place for using renewable energies, it can use benefits of these kinds of new energy sources. In this paper it is investigated as if buildings in district 11 of Tehran which are getting construction license in 2014 equip with GSHPs by government, 12'931'360 cubic meters can be saved annually. Nevertheless, Iran exports natural gas to neighbor countries like Turkey and Armenia.

Regarding to gas exportation price per cubic meters in 2014, the amount of cash flow which can enter to the country during one year by supplying buildings with GSHP energy in district 11, will be 3'232'840 $.

The amount of reduced environmental costs due to shorten pollutants is estimated 641'364 $. It is observed if government supports residents for using GSHPs, the rate of return will be changed from 18 years to less than 2 years.

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