Environ. Eng. Res. 2016; 21(2): 132-139
http://dx.doi.org/10.4491/eer.2015.088

pISSN 1226-1025
eISSN 2005-968X

Environmental awareness and economical profits of replacing gas turbines in gas compressor stations: A case study of Polkalleh station in Iran

Amin Sadrnejad[1†], Younes Noorollahi[2], Tohid Sadrnejad[1]

[1]Mahta Intelligent Development Engineering Analysis Co., Tehran 1911936314, Iran
[2]Department of Renewable Energies Engineering, Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran

ABSTRACT

In early 90s the worldwide awareness about the energy crisis and global warming had been increased and emission reduction (by improving energy efficiency), as well as increasing the capacity of clean and renewable energies, showed themselves as the most important steps towards the sustainable development approach. However, investigations on Iran's environmental situation show huge decline in recent decades and apparently there is no sense of urgency about these issues through the vision of Iranian politicians. In this article the idea of replacing the old gas turbines of Polkalleh natural gas compressor station – as one of the main compressor stations of Iran – with newer and more efficient gas turbines is evaluated, emphatically for reducing greenhouse gases emissions and their environmental costs and decreasing natural gas consumption as well. Clearly such idea is costly, but analyzing its economic impacts, huge declines in annual costs and greenhouse gases emissions can be seen as well. So an investment about $95 million can decrease 40% of Polkalleh compressor station annual costs, 25% of natural consumption and 30% of CO_2 and NO_x emissions. Besides the simple payback period of this investment is about 2.5 years from the cut-expenses of annual costs.

Keywords: Environmental Costs, Gas Turbine, Greenhouse Gases, Polkalleh Compressor Station

1. Introduction

In 2013, US Climate Accountability Organization stated that there are only 90 companies who are responsible for two-third of greenhouse gases (GHGs) which have been emitted since the Industrial Revolution. From 1^{st} to 7^{th}, the list includes American companies of Chevron and Exxon-Mobil, Saudi Aramco, British BP, Gazprom from Russia, Royal Dutch Shell and National Iranian Oil Company. So a skim at the place of the Iranian company in the list shows the importance of improving their approach towards the climate issues [1, 2].

Meanwhile looking at Iran's rank in Environmental Performance Index, there are not any noticeable improvements in this decade [3]. Besides there is no evidence on increasing renewable energies share in energy basket of Iran, and such increase will be unlikely for the years to come. Unfortunately it seems that Iranian politicians look at renewable energies as a luxury stuff more than a necessity.

According to Energy Information Administration and Institute of Energy Economics Japan, the world energy consumption will be increased up to 50% by 2035, which developing economies have the biggest shares of it. Putting it together with the daily decreasing of fossil fuel resources, it can be stated that there would be a huge incline in oil and gas prices in the next decades [4, 5]. Meanwhile, One of the most important issues in the oil and gas section is the transmission system and more than 15% of annual greenhouse gas emissions are related to transportation and distribution of fuels [6, 7] Furthermore, Iran have 17% of the world's natural gas resource and is the second country after Russia from this point of view. So there is a considerable potential for improving Iran's place as a natural gas trans-exporter [8].

In Iran, gas is generally transmitted by the pipelines from the upstream in the south, to the other places of the country and borders. On each main pipeline there are several Gas compressor stations (CS) in certain distances which pressurizes natural gas, in order to recover pressure drop of the line.

Compressors energy demand can be supplied by power from electric grid or the work from the gas turbine (GT) shafts. In Iran nearly all the CSs are being supplied with GTs which burn

Received August 3, 2015 **Accepted** February 13, 2016

† Corresponding author
Email: Amin.i.am.in.Sadrnejad@gmail.com
Tel: +98-21-22922880

a fraction of entering natural gas to the station, while the side effect of this cycle is indeed production of GHGs like CO_2 and NO_x.

This study evaluates the idea of replacing old GTs of Polkalleh CS -as one of the main CSs of Iran- with more efficient GTs, from environmental and economic point of views. The main reason of choosing Polkalleh CS as the case study, is its high rate capacity factor. Hence, if the project has the economic feasibility, not only it can avoid emitting huge amount GHGs per year, but also it saves reasonable amount of wasting natural gas annually.

Given this project is based on replacing an existing energy system with a new one, information of the current system must be gathered and analyzed. On the other hand information of the new system must be calculated and evaluated according to its specifications. At the end, these two systems are compared form different aspects and conclusions are stated.

Polkalleh CS data and information have been gathered from appointments with R&D section of Iranian National Gas Company. This set of data included general information about all the Iran Gas Pipelines and CSs as well as detailed data about Polkalleh CS as the case study and the detailed information contained power and efficiency of turbines, capacity factor, and the molar fraction of fuel. However, there has not been any research on emissions of all of the Iran CSs. So emissions are calculated according to GT efficiency and capacity factor and also molar fraction of fuel with "Emission Calculating Model" of Department of Environment of Iran and Ministry of Energy. The results are verified comparing to "Greenhouse Gas Emission Measurement & Economic Analysis of Iran Natural Gas Fired Power Plants" [9], which gathered emission data of 30 GTs and 20 STs of Iran.

Having the amount of CO_2, NO_x and CH_4, in next step environmental costs of the GHGs of Polkalleh CS are calculated according to "The Marginal Damage Costs of Carbon Dioxide Emissions: an Assessment of The Uncertainties" [10], "The Marginal Damage Costs of Different Greenhouse Gases: an Application of FUND" [11] and "Atmospheric & Geological CO_2 Damage Costs in Energy Scenarios" [12].

Considering that the annual cost of a CS is summation of Operation and Maintenance (O&M) cost, consumed natural gas price and environmental cost, the annual cost of Polkalleh CS was calculated for current condition and the ideal scenario (where a full renovation with new and indeed more efficient GTs is assumed). At the end, these two systems are compared from economical point of view. All these steps have been taken believing that:

- Environmental issues are so important to address and global warming has such dangerous impacts on lives of human beings and other species. Besides greenhouse effect plays a significant role in global warming.
- Because of global warming all GHGs have environmental costs and governments must be committed to invest these environmental cost toward the sustainable development in earth cooling projects.

In this article natural gas price is considered as the average of its global price in 2013 and the first half of 2014, equal to \$4.25/MMBtu or \$0.1916kg [13].

2. Gas Pipelines and Compressor Stations

Nowadays there are two major ways in transporting natural gas:

- Off-shore in liquid state with ships named LNG Carriers
- On-shore in gas state in pipelines which have several CSs on the way in every 50 to 150 km. While that every CS burns 5 to 15% of its entering natural gas, it would not be a logical choice to use this kind of transportation in long distances like 2000 km or more.

Basically when natural gas enters a CS, it passes through scrubbers and dryers and it is pressurized through compressors, then it gets cooled and leave the CS. The compressors are generally from the centrifugal type. As it was mentioned, the energy demand of compressors are supplied either from electrical motors (feed from the electric grid) or shaft work from the GTs which is completely independent from the surrounding conditions.

The first gas pipeline of Iran was constructed in 1965 by USSR for an agreement that sent 10 billion m^3 per year of Iran's natural gas to Russia instead of the pipeline itself and CSs on it, as well as two major companies of Machine Sazi Arak and Isfahan Steel Company. It was a 42 inch, 1100 km long pipeline named IGAT (Iran Gas Trunk Line) 1, which transported natural gas from Bidboland in south of Iran to Astara in north western border. Nowadays Iran have more than ten IGATs with about 33000 km length. Also two-third of Iranian National Gas Company's (INGC) wealth is placed in Iranian Gas Transmission Company. The general information about Iran gas pipelines are shown in Table 1.

Furthermore, Iran has 76 CSs - which will be increased to more than 100 in the next decade - and the energy demand of all of these CSs (except one in Tabriz) are being supplied from GTs inside the CSs. All of these CSs are fully loaded online in about 5 months per year (from November to March). With taking a good estimation, as it is mentioned in Table 2, it can be stated that total power supply of GTs of CSs is about 6000 MW (which two-third of it, is transmitted with shaft to compressors) and the total demand is about 4000 MW. However, the supply and demand in CSs do not obey any rule and it is just the function of the demand[1]. Fig.1 shows the Iranian gas pipelines map.

1) In order to be ready to meet the demand, GTs at the CSs for most of the times are ON and they rotate the natural gas over the CS from the by-pass lines. This cycle goes on till the demand reaches its peak, then the exit valves open and the recycling natural gas goes through the main pipelines and leave the CS. This cycle usually keeps the CS prompt and it makes supplying faster than turning ON and loading an OFF GT, However, takes so much energy.
In this article we neglect the recycling ON mode of GTs and just consider the fully-loaded online working of them per year, although if we opted to consider, the annual costs would have been increased respectively.

Table 1. General Information about Iran Gas Pipelines

Pipeline Name	Path and Destination	Length (km)	Diameter (inches)	Capacity (Mm^3)	Number of CSs on the Line
IGAT 1	From Bidboland refinery to Astara, as a natural gas Reservoir and a feed for other pipelines	1100	40 & 42	40	10
IGAT 2	From Kangan refinery to Qazvin for consumption and export	1040	56	90	9
IGAT 3	From 1st to 5th phases of South Pars and Kangan refinery to Iran Central and Northern provinces for consumption	1195	56	90	10
IGAT 4	From 1st to 5th Phases of South Pars and Parsian Refinery to Saveh and export lines of Qazvin	1145	56	110	10
IGAT 5	From 6th to 8th Phases of South Pars and Fajr refinery to Khouzestan for gas injection to oil wells	540	42 & 56	95	5
IGAT 6	From 9th and 10th phases of South Pars to the Western provinces for consumption and export	610	56	110	5
IGAT 7	From Asalouyeh to the South-Eastern provinces for consumption and export	900	56	50	Under Construction
IGAT 8	From Asalouyeh and Parsian Refinery to the Central Provinces for consumption	1050	56	110	10
IGAT 10 (Loop)	From 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 CSs

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

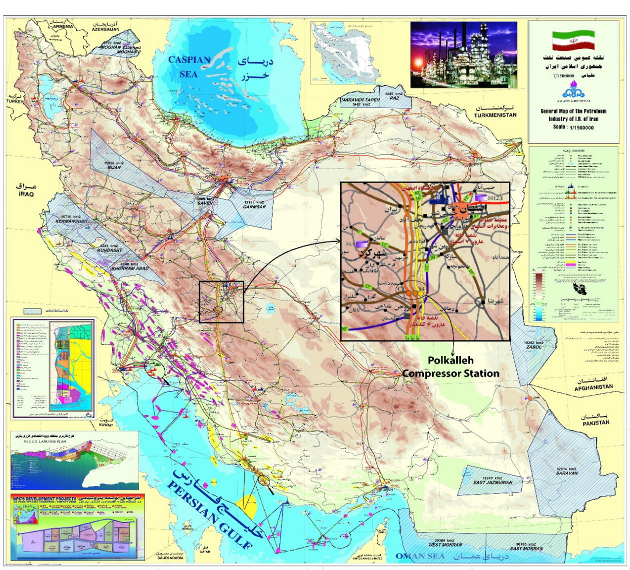

Fig. 1. Polkalleh CS location on the general map of the petroleum industry of Iran (Courtesy of Iran national cartography center).

2.1. Polkalleh Station

Polkalleh CS is in Isfahan province which is one of the main CSs of Iran. It operates loaded about 6 months in a year. The geographical location of this CS is shown on the General Map of the Petroleum Industry of Iran in Fig. 1. Also as it is stated in Table 3, this CS is actually divided to three sub-stations:

1) Polkalleh compressor station number 1 or CS3 on IGAT 1: This CS contains five unites of 10MW GTK-10-3 Nevskiy GTs made in Russia. These GTs alongside IGAT 1 were parts of the mentioned agreement between Iran and USSR in 1965. Practically these GTs are far from being passed their economic life cycles, but they are still coming on the line about 3 months per year. IGAT 1 also has so many technical problems and leakages. Thus, nowadays this pipeline often operates as a natural gas reservoir for other pipelines at the demand peak, more than a natural gas transmission line.

2) Polkalleh compressor station number 2 or S4 on IGAT 2: This CS includes five unites of 16MW UGT 16000 GTs produced by Zorya Mashproekt and installed by Sumi "Frunze" NPO both from Ukraine. These set of GTs are coming into the line about 6 months per year.

3) Polkalleh compressor station number 3 on IGAT 4: This CS is newer than the previous ones, including 4 unites of 25MW SGT-600 Siemens GTs working more than 6 months per year.

As far as there is no transparency and because of the Onion Architecture of INGC, unfortunately even for those who works in that organization, there are too many obstacles on the way

Table 3. Detailed Information of Polkalleh CS

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
GT Efficiency (%)	8~10	23~25	28~30
Ann. Capacity (mon)	2~3	5~6	5~6
CS Capacity (mm^3)	46	90	95
GT Max Speed (rpm)	4400	4800	7700
Compression Ratio	1.18	1.40	1.45

Table 4. Molar Fraction of Polkalleh CS Natural Gas

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 Polkalleh CS Natural Gas

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/m^3)	37.15

of approaching to the exact information about the capital cost and annual costs of different sections. Getting the information - which have been analyzed in this article - also took six months, with awful lot of official processes as well.

For Polkalleh CS in this article, all the costs are calculated based on given data from INGC. In the calculations we also considered that only working GTs are ON, and the stand-by GTs are OFF and out of line.

As it was reported, the annual cost of a CS is summation of O&M cost, price of consumed natural gas and the environmental costs. There is a good estimation between the experts and technical staff of INGC that the operation cost of a main CS -like Polkalleh CS- is about $0.750 million per year and the maintenance cost is about $2 million per 20,000 hours of work.

So looking at the GT annual capacities, the annual maintenance cost of every GTK-10-3 is considered about $0.18 million, every UGT-16000 about $0.40 million and every SGT-600 about $0.43 million. Adding the operation cost to this number, the total annual O&M cost is about $4.4 million. For calculating environmental costs, first and foremost, the amount of emissions must be calculated. However, since the environmental issues are not among INGC concerns, there have not been any research or data on this particular subject. On natural gas also, there is no sensitivity about the consumed amount in GTs; mainly because INGC does not pay any price for the consumed natural gas to Iranian government. However, we did not consider it free. Therefore, in this article it is calculated based on GT efficiency and capacity factor. Table 4 shows the molar fraction of the entering natural

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 (1000 ton)
GTK-10-3	10	8~10	2.11~2.64	15.42
UGT16000	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 (1000 ton)	Annual NO_x Emission (ton)
GTK-10-3	2.29	3.36	41.72	61.22
UGT 16000	0.90	1.31	63.07	91.80
SGT-600		1.04	77.74	113.88

Table 8. The Characteristic and Efficiency of GTs Reported by "Greenhouse Gas Emission Measurement & Economic Analysis of Iran Natural Gas Fired Power Plants" [9]

GT Number	GT Power (MW)	Fuel Consumption (kg/s)	GT Efficiency (%)	Specific CO_2 Emi. (kg/kWh)	Specific NO_x Emi. (g/kWh)
Number 5	9.5	1.06	19	0.87	4.06
Number 8	11	1.08	21	0.77	1.04
Number 2	15	1.62	19	0.85	3.94
Number 1	16	1.65	20	0.81	3.40
Number 29	24	1.89	27	0.70	1.76
Number 32	26.70	2.01	28	0.65	0.89

gas to Polkalleh CS. So the molecular mass, density and heat value of fuel and theoretical air and actual air of combustion based are stated in table 5. Also with looking at the efficiency and capacity factor of turbines, the fuel consumption of each GT are stated in Table 6.

As it was mentioned the amount of Polkalleh CS emissions was calculated by Emission Calculating Model (ECM) which is a software published by Department of Environment of Iran-Ministry of Energy. Inputs of this model are energy system information such as power, efficiency and capacity factor of GT as well as fuel information like heat value. So according to Tables 5 and Table 6 emission results of the model are stated in Table 7.

In order to verify the results, they are compared with "Greenhouse Gas Emission Measurement & Economic Analysis of Iran Natural Gas Fired Power Plants" [9], in which the emissions of 32 GTs of Iran are gathered in 2008, and for this study, 6 out of these 32 are selected, because of their same power production with GTs of Polkalleh CS. Then their efficiency are calculated and numbers are sorted in Table 8, assuming that all these GTs burn the same natural gas with Polkalleh CS GTs.

GTs number 5 and 8 with 9.5 MW and 11 MW are way more efficient than the Nevskiy GTs. However, the efficiency of GTs number 2 and 1 are fairly close to Zorya GTs, as well as GTs number 29 and 32 which are pretty close to Siemens GTs. So looking at the Table 8 and comparing the data with the Table 7, results of model can be considered acceptable.

For safety reasons also, O_2 must be extracted from the line before the GT starts. So this task can be done with filling the line with N_2 or with natural gas itself and then discharging everything into the air before the start. While N_2 is safer, natural gas is cheaper and indeed more available at a CS.

This amount of natural gas can be significant, especially considering that CH_4 has much higher greenhouse effect. If all of the Polkalleh CS starts are assumed 300 per year, then the amount of wasted natural gas (practically CH_4) is about 600,000 m^3. [14]

Since the Siemens GTs are relatively new and efficient, replacing them is not economic. However, the UGT 16000 and SGT-600 GTs are considered replaceable with new GTs having 32% of efficiency which we call it "the ideal condition of Polkalleh CS".

So the amount of total annual emissions and natural gas consumption in going on with the current condition and the ideal condition are stated in Table 9.

In Table 9, there are 25% decrease in natural consumption and 30% decrease in CO_2 and NO_x emissions.

For the environmental costs of GHGs, there is a wide range of numbers from many articles. For example, for CO_2 cost, it was reported from \$4 per tons of CO_2 to \$345 per tons of CO_2. This divergence for sure is because of the wide range of global warming effects and its externalities.

Therefore, mainly based on "The Marginal Damage Costs of Carbon Dioxide Emissions: an Assessment of The Uncertainties" [10], "The Marginal Damage Costs of Different Greenhouse Gases: an Application of FUND" [11], in this article CO_2 costs categorized in five general visions (from extremely conservative to strictly committed) and three of them involved in calculations. Environmental costs of NO_x and CH_4 also comes from "The Marginal Damage Costs of Different Greenhouse Gases: an Application of FUND" [11] and "Atmospheric & Geological CO_2 Damage Costs in Energy Scenarios" [12] again and are shown in Table 10.

So based on the specific environmental costs in Table 10, and emissions from Table 9, Polkalleh CS annual environmental cost are stated in Table 11 and Polkalleh CS total annual costs in current condition with three visions are stated in Table 12.

There are some opportunities and challenges in buying new GTs for Polkalleh CS. The main challenge is indeed the capital cost of new GTs and the need for investing on it. In evaluating the aspects of a full renovation, as it was mentioned, 25MW Siemens GTs are considered as untouchable, because they have acceptable rate of efficiency and replacing them is not economic. However, for the old GTs there is a strong need of replacing. Thus, five 10 MW and 16 MW GTs are needed.

Table 9. Annual Natural Gas Consumption and Emissions of Polkalleh CS at Current Condition and Ideal Condition

Component	Current Condition	Ideal Condition
Total Gas Cons. (1000 ton)	265.71	199.12
CO_2 Emission (1000 ton)	652.42	459.28
NO_x Emission (ton)	953.74	673.65
CH_4 Emission (ton)	468	468

Table 10. Environmental Costs of GHGs in Different Environmental Visions

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

Table 11. Annual Environmental Costs of Polkalleh CS in Different Environmental Visions at Current Condition and Ideal Condition

Polkalleh CS Condition	Annual Environmental Cost (M$)		
	Conservative Vision	Reasonable Vision	Committed Vision
Current Condition	25.85	34.98	50.64
Ideal Condition	18.27	24.70	35.73

For GT prices, in the range of 10 MW to 16 MW, the specific cost are about $500 kW[2]. So considering the need for 130 MW power and neglecting renovation cost of IGAT 1, the capital investment is about $65 million. [15] Adding 25% to this number because of buying new compressors and 15% for transporting, shipment and installing, the total cost for this project would be about $95 million. Therefore, the economic situation after renovation is stated in Table 13.

So looking at the Table 12 and comparing the numbers with the Table 13, first and foremost, remarkable decline in annual net costs of Polkalleh CS in all the three visions can be seen. In the other word there is about 40% decrease in annual costs:

- From $106.04 million per year to $65.61 million per year in committed vision
- From $90.38 million per year to $54.58 million per year in reasonable vision
- From $81.25 million per year to $48.15 million per year in conservative vision

Meanwhile, the simple payback period for the GTs investment from cut-expenses, is between 2 to 3 years.

The 3-year simple economic chart of this project (Fig. 2) also shows the cost-equal points of two scenarios. According to this chart, after 2 and in less than 3 years, the cost of the ideal condition is equal to the cost of the current condition and as it was mentioned, there is about 40% decrease in annual cost in all the three visions.

Table 12. Economic Opportunities and Challenges of Government Sector (INGC) at The Current Condition of Polkalleh CS – The 1st Scenario

Government Sector			
Challenges			Opportunities
O&M Cost (M$/year)		4.4	
Natural Gas Cost (M$/year)		51.00	
Environmental Cost (M$/year)	Cons.	25.85	
	Reas.	34.98	
	Com.	50.64	

Table 13. Economic Opportunities and Challenges of Government Sector (INGC) at The Ideal Condition of Polkalleh CS – The 2nd Scenario

Government Sector				
Challenges			Opportunities	
GT Investment (M$)		95	Natural Gas Saving (M$/year)	2.76
O&M Cost (M$/year)		4.4		
Natural Gas Cost (M$/year)		38.24		
Environmental Cost (M$/year)	Cons.	18.27		
	Reas.	24.70		
	Com.	35.73		

2) The MPNA Group in Iran manufactures GTs -under license of Siemens- with about $0.32 KW, especially because of low labor price in Iran comparing to Europe and US. However, we took more expensive GTs into our calculations.

At the end, looking at 25% decrease in natural gas consumption, 30% emissions reduction and 40% cost reduction with a payback period less than 3 years, the idea of replacing Polkalleh GTs with newer and more efficient GTs can be approved as an exciting and profitable idea for INGC and Iranian government.

2.2. A Macro-Economic Analysis off Replacing All CSs of Iran

In this part with a general estimation, the outcome of implementing this idea on all of Iranian CSs is evaluated. Firstly, it must be mentioned, as far as there is no transparency in INGC, gathering detailed information of all of the numerous Iranian CSs is somehow impossible. So with the help from some of INGC experts, a general but near-reality estimation of all Iranian CSs has been taken. Thus, 20% out of 76 Iran CSs are considered just like Polkalleh CS, 45% with half capacity of Polkalleh CS, and 35% with one-tenth capacity of Polkalleh CS. So things are like Table 14.

Table 14. 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

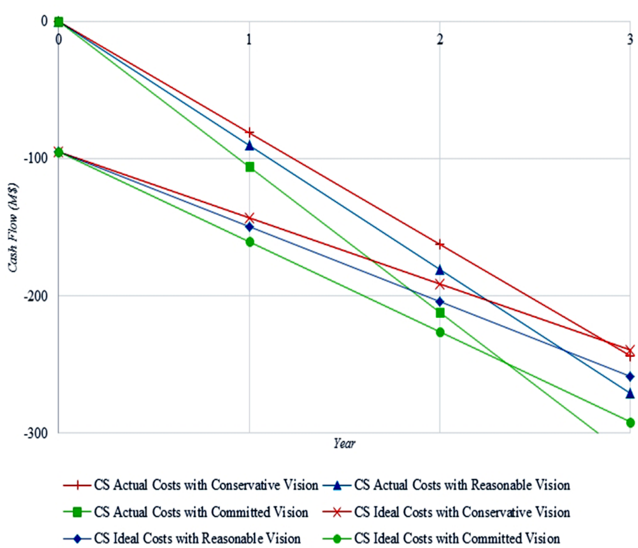

Fig. 2. Simple economic chart of government sector: A comparison between cost of the current condition and ideal condition of Polkalleh CS in next 3 years.

While the total power capacity of Polkalleh CS is 180MW, its specific costs are calculated. Hence as the capital investment of GT renovation is $95 million, and the annual costs of Polkalleh CS are $81.25 million, $90.38 million and $106.04 million in three mentioned visions, then the specific capital investment is $0.52 million per MW, and the specific annual cost at this CS are $0.45 million per MW, $0.50 million per MW and $0.59 million per MW.

So looking at the total power production of all Iran CSs in Table 14, the total annual cost of CSs for INGC and consequently for Iranian government would be equal to Table 15.

So it can roughly be assumed that with $3.3 billion investment there would be more than $1 billion annual saving, including 2.30 million ton natural gas consumption reduction, as well as 6.78 million ton CO_2 and 9,918 tons NO_x emission reduction.

3. Conclusions

There is no doubt that the newer and more efficient energy systems are better than the old ones; however, they are costly indeed.

In this article Polkalleh CS was chosen as the case study and was analyzed as an energy system which currently works on a usual basis. Firstly, the data of this system were gathered, and based on them the current annual cost of the system including O&M costs, the price of consumed natural gas in GTs, and environmental costs of its GHGs were calculated. Then, the idea of replacing this old system with a newer one, is evaluated with calculating its costs in a same manner.

Current situation of Polkalleh CS - as one of important and main CSs of Iran - imposes enormous costs on INGC and Iranian government consequently, because it has two series of old and inefficient GTs, which have huge amounts of annual costs, mostly from environmental point of view.

However, the idea of buying new GTs and replacing the old GTs of Polkalleh CS, can be implemented with $95 million, and new GTs are able to make a huge impact on Polkalleh CS annual costs, with about 40% decrease. Because this idea reduces gas consumption about 25%, along with 30% reduction in GHG emissions per year. The simple payback period of this investment is about 2.5 years from the cutting expenses.

Also with taking a general estimation about the all of Iran CSs, implementing this idea in all over the country can decrease CS costs significantly, as well as natural gas consumption and CO_2 and NO_x emissions. Besides, it can roughly be concluded that $3.3 billion investment can save about $1 billion annually for the government.

Because of the 8-year imposed war on Iran in 80s and sanctions

Table 15. Economic Impact of Implementing the Idea on all of Iran CS

Environmental Vision	Total Annual Cost of Iran CSs		Capital Investment (B$)
	At Ideal Condition (B$/y)	At Current Condition (B$/y)	
Conservative	1.67	2.81	
Reasonable	1.89	3.12	3.29
Committed	2.27	3.68	

and trade difficulties of 90s and 2000s, there are still so many old and inefficient energy systems in Iran, operating on a regular basis. Thus, the same evaluations can be implemented on other energy systems and gas turbines of Iran, and the hidden costs - such as environmental costs or the price of wasted natural gas in old gas turbines- can be calculated as a benchmark for further improvements.

References

1. Goldenberg S. Just 90 Companies caused Two-Third of Man-Made Global Warming Emissions. London: The Guardian, Environment, Carbon Emissions; 2013.
2. Heede R. Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers 1854-2010. *Climate Change* 2014;122:229-241.
3. EPI. EPI ranking of Iran [Internet]. EPI; 2014 [cited 2014 Dec 25]. Avaliable from: http://epi.yale.edu/epi/country-profile/iran
4. Annual Energy Outlook 2009 With Projection to 2030. EIA. Washington; 2009.
5. Matsuo Y, Aoshima M, Kako M. Asia/world energy outlook 2011: Growing uncertainty over international energy trends and the future of Asia. *IEEJ Energ. J.* 2012;7:17-55.
6. Valipour M, Mousavi S M, Valipour R and Rezaei E. Deal with Environmental Challenges in Civil and Energy Engineering Projects Using a New Technology. *Civil & Environmental Engineering*. 2013;3,1:1-6.
7. State and trends of carbon pricing. World Bank Group - Climate Change. Washington DC; 2014.
8. OPEC Annual Statistical Bulletin 2013. Organization of Petroleum Exporting Countries. 2013.
9. Shahsavari H, Kiyoumarsioskouei A, Asheri MH, Naemi S, Shahsavari H, Basirat Tabrizi H. Greenhouse gas emission measurement & economic analysis of iran natural gas fired power plants. *Energ. Policy* 2013;60:200-207.
10. Tol RSJ. The Marginal Damage Costs of Carbon Dioxide Emissions: an Assessment of The Uncertainties. *Energ. Policy* 2005;35:2064-2074.
11. Waldhoff S, Anthoff D, Rose S, Tol RSJ. The Marginal Damage Costs of Different Greenhouse Gases: an Application of FUND. *Economics Discussion Papers* 2011;43.
12. Smekens K, Van der Zwaan B. Atmospheric & Geological CO_2 Damage Costs in Energy Scenarios. *Environmental Science & Policy* 2006;9:217-227.
13. Natural Gas End of Day Price NYMEX [Internet]; c2014 [cited 2014 June 20] Abailbable from: http://www.nasdaq.com/markets/natural-gas.aspx?timeframe=18m.
14. Nikishin A. Energy Saving Technologies During Operation of The Gas Pipeling Systems. Stockholm: KTH School of Industrial Engineering & Management, Division of Energy Technologies, Royal Institute of Technology; 2013.
15. NTC. Gas turbine prices by output [Internet]. NTC; c2014. Available from: http://www.gas-turbines.com/trader/outprice.htm