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Iran’s Gas Flare Recovery Options Using MCDM

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Abstract**—**In this paper, five options of Iran’s gas flare recovery have been compared via MCDM method. For developing the model, the weighing factor of each indicator an AHP method is used via the Expert-choice software. Several cases were considered in this analysis. They are defined where the priorities were defined always keeping one criterion in first position, while the priorities of the other criteria were defined by ordinal information defining the mutual relations of the criteria and the respective indicators. The results, show that amongst these cases, priority is obtained for CHP usage where availability indicator is highly weighted while the pipeline usage is obtained where environmental indicator highly weighted and the injection priority is obtained where economic indicator is highly weighted and also when the weighing factor of all the criteria are the same the Injection priority is obtained.

Keywords**—**Flare, Gas, Iran.

I. Introduction

It is obviously cleared that by rising the living standards in Iran and also the global population growth, the greenhouse gas emissions will definitely increase during the future years.

Enormous consumption of fossil fuels to supply the demanded energy in the recent decade causes a huge amount production of greenhouse gases which leads to global warming disaster.

Annually, over 140 billion cubic meters of natural gas are being flared and vented which is equivalent to 25% of the United States’ gas demand, 30% of the European Union’s gas demand, or 75% of Russia’s gas exports [1].

Gas flaring in Africa is equivalent to half of that continent’s power consumption. Flaring gas has a global effect on climate change by adding annually about 360 million tons of CO_2.

About 70% of gas flaring in the whole world produces in less than 20 countries whereas more than 70 billion cubic meters of it is generated in just four of the mentioned countries. Iran flared 400 billion cubic feet of gas in 2011. That would meet about a quarter of demand in South Korea. The gas is worth about $7.3 billion on Southeast Asian spot LNG markets [2]. The associated gas in Iran is usually flared for the lack of infrastructure to be processed and transported to demand markets.

The flared natural gas was about 5% of the world’s natural gas production by the end of 2012 [3]. As shown in table I, the top 20 countries accounted for the flaring of 127 billion cubic meters, which is over 86% of the total flaring in the world by the end of 2011. The ratio of CO_2 emissions to natural gas flaring have also shown in the Table I. Russia stands on the first place of gas flaring in the world. The flaring of Nigeria alone amounts 12% of the total flaring and Iran holds the third place of gas flaring.

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TABLE I
Estimated Top 20 Gas Flaring Countries [4]

Rank	Country	Flared Volume, 10^9 cubic			CO_2 from flaring (10^6 tones/year)
		2009	2010	2011	
1	Russia	46.6	35.6	37.4	116.4
2	Nigeria	14.9	15.0	14.6	46
3	Iran	10.9	11.3	11.4	28.9
4	Iraq	8.1	9.0	9.4	17.7
5	USA	3.3	4.6	7.1	14.3
6	Algeria	4.9	5.3	5.0	14.8
7	Kazakhstan	5.0	3.8	4.7	4.5
8	Angola	3.4	4.1	4.1	7.9
9	Saudi Arabia	3.6	3.6	3.7	10.3
10	Venezuela	2.8	2.8	3.5	9.5
11	China	2.4	2.5	2.6	2.9
12	Canada	1.8	2.5	2.4	4.8
13	Libya	3.5	3.8	2.2	7.2
14	Indonesia	2.9	2.2	2.2	6.7
15	Mexico	3.0	2.8	2.1	6.7
16	Qatar	2.2	1.8	1.7	5.2
17	Uzbekistan	1.7	1.9	1.7	-
18	Malaysia	1.9	1.5	1.6	-
19	Oman	1.9	1.6	1.6	6
20	Egypt	1.8	1.6	1.6	6.7
Total for the Top 20 Countries		127	118	121	316.5
Global Flaring Level		154	146	147	365.8

II. Environmental Effects of CO_2

Iran has shown remarkable growth in total fossil-fuel CO_2 emissions since 1954, averaging 6.3% per year. In 2008 total emissions reached an all-time high of 147 million metric tons of carbon. With Iran being the world's fourth largest oil-producing country it is not surprising crude oil and petroleum products account for the largest fraction of the Iranian emissions, 46.4% in 2008. The CO_2 emissions time series for Iran, like other countries in the Middle East, shows sizeable emissions from gas flaring in the late 1960s and 1970s and a decline in these emissions during the 1980s and 1990s. This downturn reflects changes in oil field practices, improvements in oil field facilities, and increasing use of gas fuels. Emissions from gas fuels have grown 390-fold since the first reported natural gas use in 1955 and now account for 42.3% of

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Iran's total fossil-fuel CO_2 emissions. From a per capita standpoint, Islamic Republic of Iran is above the global average at 2.00 metric tons of carbon.

It is generally accepted that carbon dioxide is a greenhouse gas and contributes to global warming. About 75% of the anthropogenic emissions of carbon dioxide come from the combustion of fossil fuels. Flaring produces a great amount of carbon dioxide. Carbon dioxide emissions from flaring have high global warming potential and contribute to climate change. The mounting environmental pressure on the oil and gas production areas to cut CO_2 emissions is directly affecting the practice of flaring [5].

CO_2 emissions from flaring have high global warming potential and contribute to climate change. Flaring also has harmful effects on human health and the ecosystems near flaring sites. The low quality gas that is flared releases many impurities and toxic particles into the atmosphere during the flaring process. Acidic rain, caused by sulfur oxides in the atmosphere, is one of the main environmental hazards which results from this process [6].

According to research performed by the World Bank's Global Gas Flaring Reduction Partnership (GGFR), the equivalent of almost one third of Europe's natural gas consumption is burned in flares each year which is about 400 million tons of carbon dioxide emission to the atmosphere (roughly 1.5% of the global CO2 emission) [7].

Environmental and economic considerations have increased the use of flare gas recovery systems. Flare gas recovery reduces noise and thermal radiation, operating and maintenance costs, air pollution and gas emission and reduces fuel gas and steam consumption.

CO_2 emission in Iran is shown in Fig. 1.

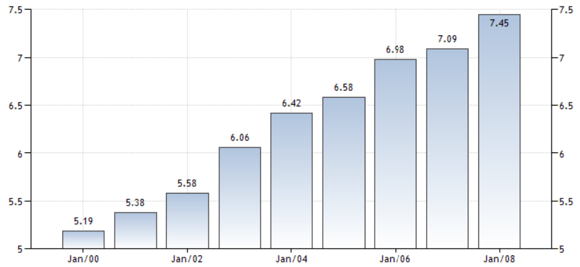

Fig. 1 CO_2 emissions (metric tons per capita) in Iran [8]

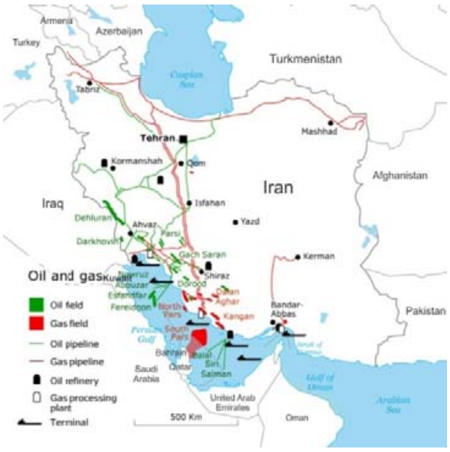

Fig. 2 Schematic of Iran's Gas fields

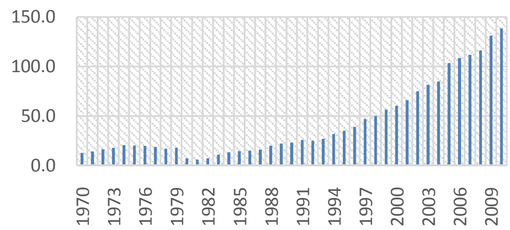

Fig. 3 Iran's natural gas production [10]

III. Iran's Gas Status

The proved natural gas reserves of Iran are about 29.6 tcm or about 15.8% of world's total reserves. Iran has the world's first largest reserves which are estimated up to 18% of the world's share. Iran's gas production by the end of 2012 has been about 160.5 billion cubic meters, which is 4.8 percent of the world's share. Iran's Natural gas fields are shown in Fig. 2

Natural gas consumption in Iran by the end of 2012 was about 156.1 billion cubic meters.

A. Iran's Gas Production

Iran is the largest gas producer in the Middle – East and holds the 3rd place in the world following U.S. and Russia respectively. Global conventional natural gas resources are concentrated geographically, with 70% in three countries: Qatar, Iran and Russia [9]. Iran's gas production by the end of 2012 has been about 160.5 billion cubic meters, which is 4.8 percent of the world's share and shows 5.4% changes over 2011.

Iran's natural gas production has increased by over 550 percent over the past two decades, and the consumption has kept pace. As demand growth rates persist, the potential for shortfalls in natural gas supply grows.

The trend of Iran's natural gas production is shown in Fig. 3.

Iran's gas production share of the Middle East by the end of 2011 is about 30% [10].

B. Iran's Gas Consumption

Iran holds the world's 3rd - largest consumer of natural gas after U.S. and Russia respectively. Natural gas consumption in Iran by the end of 2012 was about 156.1 bcm which is 4.7% of the world's share. Iran's share of natural gas consumption in the Middle East is about 37% which is shown in Fig. 4.

C. Iran's Gas Import / Export

Iran imports natural gas from its northern neighbor Turkmenistan. The import of natural gas from Azerbaijan and Turkmenistan was respectively equal to 0.4 and 9 billion cubic meters in 2012.

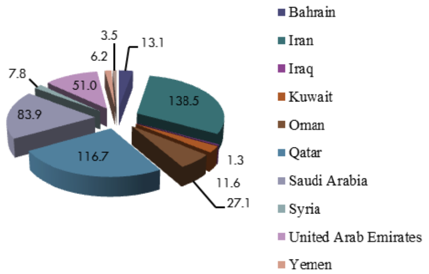

Fig. 4 Iran's share of gas consumption in the Middle East [10]

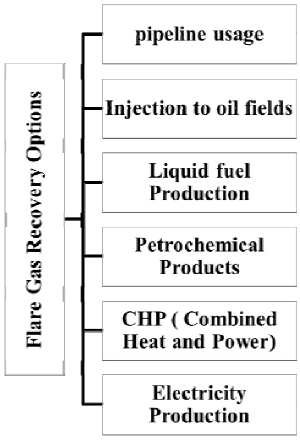

Fig. 5 Possible strategies for flare gas recovery in Iran

Iran exports only a small part of its total natural gas production. Natural gas exports go to Turkey and Armenia via pipeline. Turkey, an importer since 2001, received 8,190 mcm in 2011, while exports to Armenia totaled 250 mcm in 2011. Iran's natural gas exports likely will be limited due to rising domestic demand, even with future expansion and production from the massive South Pars project, and other development projects.

IV. Flaring Gas Statistics in Iran

In this section, Iran's statistics of gas flaring are presented. The status of burned gas in Iran's oil and gas production fields was described in Table II. Iran's flaring gas amount is about 50 million cubic meter natural gas which is equivalent to the 126 million barrel oil equivalent every year. It can be indicated that flared gas from oil and gas production field is about 37 and 13 million cubic meters, respectively in Iran.

Furthermore, statistics indicate that flared gas values about eighteen million dollars a day [11] which is comparable to capital cost of 5MW photovoltaic panels.

TABLE II
Flare Gas in Oil Companies in Iran (Million Cubic Meter per Day) [11]

year	2009	2010	2011
oil production field gas flaring	41.6	37.2	37.5
Natural gas field gas flaring	9.4	11.8	13
total	51	49	50.5
the wasted value($ per day)	18,870,000	18,130,000	18,685,000

V. Flare Gas Recovery Methods

The recovery of flare gas is of importance for many advanced countries around the world due to the saving resources and reducing air pollution. There are various ways to recover flare gas. Fig. 5 represents some possible strategies to recover flare gas in Iran. Statistics shows that the ratio of flare gas to oil and gas production is highly increasing in this country [11].

Moreover, it can be seen that Iran stands in the third place of top flaring countries. Consequently, providing the performance of Kyoto Protocol in Iran, the recovery of flare gas becomes very significant. As a result, in this paper, the feasibility study of the methanol production in small scales from the flare gas is studied. In the first section, for observing the significance of flare gas recovery, the detailed Iran's gas flaring data are presented. Then the simulation of mini methanol plant is described in the second part. In order to present the economic results for the simulated plant, we generate two scenarios, one scenario is with consideration of the environmental taxes of gas flaring and the second one is without considering them. Afterwards, to recognize the feasibility of the simulated plant in Iran, the sensitivity analysis is done on the technical data such as the flow rate of input gas and economic data like flare gas cost and methanol price.

A. GTL Technology

Gas-to-liquid (GTL) technology is a good alternative for reducing gas flaring [12]. Among the various alternatives for combustion of flare gas, there has been an increased interest in GTL technology.

Such technologies play an important role in bringing gas to markets as both fuel and/or petrochemicals [13].

B. Electricity Generation

Electricity generation from flared natural gases via gas turbines Flare gas conversion into electricity is another way for reducing flare gas. Although natural gas has become a key primary source of energy for electricity generation, higher fuel costs of natural gas quickly outweigh the advantages in most applications.

C. Compressed Method

Compression and transmission of gas to practical point of view is another alternative to reduce and reuse flare gas. Initially natural gas was used only in the areas in which it was produced, with excess production being vented to the air or flared. But the large demands for natural gas has developed fairly recently. The increased demand has also greatly increased the price obtained for the gas [14]. This made refineries to use flare gas recovery systems for lowering emissions by recovering flare gases before they are combusted by the flare. A flare gas recovery system compresses the flare gas for reuse in the refinery gas system. A compressor is used to increase the pressure of a compressible fluid. [15].

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D. CHP

Natural gas is the most common fuel for CHP plants and this is a reflection of its price, availability, wide range of applications and the lower environmental impact of its exhaust gases.

The supply of natural gas to a user is by pipeline from the national distribution network, much of which is owned and operated by National Grid Gas.

The installation of a gas-fired CHP plant almost always increases the site's consumption of gas, as the new plant generates both heat and power and usually operates for a large proportion of the year. As well as the increase in total annual gas consumption, the maximum rate of consumption usually increases, and this often requires the uprating of an existing site gas connection. In addition, the gas supply pressure required for operating a gas turbine or a gas engine is often higher than the existing site supply pressure, necessitating the use of pressure-boosting equipment.

E. Petrochemical Products

Low natural gas prices are a magnet for petrochemical producers, who are planning big investments in the province and helping it realize its long-standing priority of adding value to its oil and gas resources.

The large majority of chemical products are produced from petroleum (oil) or natural gas. Several of these base chemicals may be made more readily from natural gas rather than petroleum. Synthesis gas is an obvious candidate, due to the high hydrogen content of natural gas. Moreover, the light alkenes may be made from wet natural gas (NGL) in a process known as steam cracking.

F. Injection

Iran is one of the largest gas rich countries in the world that production capacity exceeds domestic consumption and gas injection requirements. Gas can be utilized as feed stock in petrochemical plants and refineries or exported through pipeline or LNG. Through re-injection of gas to oil reservoirs, while increasing the oil recovery ratios, the produced gases from fields shared with other countries could be stored into domestic gas fields.

VI. Methodology

Multiple criteria decision making (MCDM) refers to making decisions in the presence of multiple, usually conflicting criteria. MCDM problems are common in everyday life. In personal context, a house or a car one buys may be characterized in terms of price, size, style, safety, comfort, etc. In business context, MCDM problems are more complicated and usually of large scale. For example, many companies in Europe are conducting organizational self-assessment using hundreds of criteria and sub-criteria set in the EFQM (European Foundation for Quality Management) business excellence model. Purchasing departments of large companies often need to evaluate their suppliers using a range of criteria in different area, such as after sale service, quality management, financial stability, etc. Although MCDM problems are widespread all the time, MCDM as a discipline only has a relatively short history of about 30 years.

The development of the MCDM discipline is closely related to the advancement of computer technology. In one hand, the rapid development of computer technology in recent years has made it possible to conduct systematic analysis of complex MCDM problems. On the other hand, the widespread use of computers and information technology has generated a huge amount of information, which makes MCDM increasingly important and useful in supporting business decision making. There are many methods available for solving MCDM problems as reviewed by Hwang and Yoon, though some of the methods were criticized as ad hoc and to certain degree unjustified on theoretical and/or empirical grounds. There were calls in early 1990s to develop new methods that could produce consistent and rational results, capable of dealing with uncertainties and providing transparency to the analysis processes.

In this paper, an AHP method is used to identify the priorities of flared gas recovery in different options which are explained as follows. In order to find the priorities, Expert Choice is used as the appropriate software and the result are shown as follows.

A. Options

An individual criterion for evaluation of the potential flare gas recovery options is leading to a limited guidance for the respective decision making process.

In this respect, individual indicators are leading to the priorities of specific options, which will strongly depend on the selected indicator.

The different options of flare gas recovery usage are as follows:

- Liquid Fuels Production
- Electricity Production
- CHP
- Petrochemical Products
- Injection
- Pipeline Usage

B. Indicators

For assessing the priorities of each option different criteria are used. The criteria of the assessment in this paper are as follows which is shown in Table III.

- Environment
- Economics
- Availability

TABLE III
Indicators Measurement

No.	Indicator	Measuring index
1	Environment	CO_2 Content
2	Economics	Cost analysis($)
3	Availability	Delphi Panel Experts

The assumptions of Iran's future gas availability depend on different factors. In order to obtain the most probable ones, the three-round Delphi panel method is used in this paper.

VII. Results

For developing the model, the weighing factor of each indicator is required. In order to define the weight coefficient of each indicator an AHP method is used via the Expert-choice software. Expert Choice is decision-making software that is based on multi-criteria decision making.

Expert Choice implements the Analytic Hierarchy Process (AHP) and has been used in different fields.

VIII. Selection of Cases

For evaluation of any complex system by the MCDM method, appropriate parameters, needed for its application have to be selected. In this paper, all indicators defined by the internal preference amongst the criteria.

These cases are aimed to emphasize the role of the cases when internal priorities amongst them are defined by ordinal information that defines the mutual relations of the criteria and the respective indicators. The cases are formed by ordering the criteria, always keeping another criterion at the first position. In this group, the results are presented as follows.

A. Case 1: Env. > Eco. > Av.

Case 1 is designed with the aim to give the first priority to the Environmental Indicator and the second priority to Economic Indicator. The result of running the program in Fig. 6 shows that the most probable option in this case is the Pipeline usage and Injection, Liquid fuel production, CHP, Petrochemical products, and electricity production stand at the next priorities respectively.

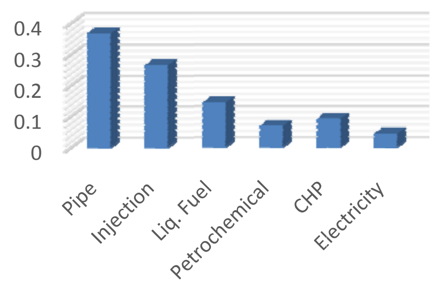

Fig. 6 Weight coefficient for Case 1

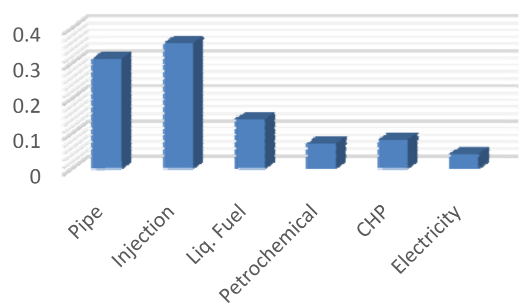

Fig. 7 Weight coefficient for Case 2

B. Case 2: Eco. > Av. > Env.

Case 2 is designed with the aim to give the first priority to the Economical Indicator and the second priority to the Availability Indicator. The result of running the program in Fig. 7 shows that the most probable option in this case is the Injection and Pipeline usage, Liquid fuel production, CHP, Petrochemical products and electricity production stand at the next priorities respectively.

C. Case 3: Av. > Env. > Eco.

Case 3 is designed with the aim to give the first priority to the Availability Indicator and the second priority to Environmental Indicator. The result of running the program in Fig. 8 shows that the most probable option in this case is CHP and the Liquid fuel production, Pipeline usage, Injection, electricity production and Petrochemical products stand at the next priorities respectively.

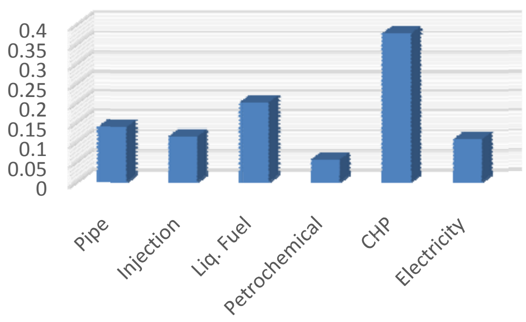

Fig. 8 Weight coefficient for Case 3

D. Case 4: Av. = Env. = Eco.

Case 4 is designed with the same priority to all the indicators. The result of running the program in Fig. 9 shows that the most probable option in this case is Injection and the Pipeline usage, CHP, Liquid fuel production, electricity production and Petrochemical products stand at the next priorities respectively.

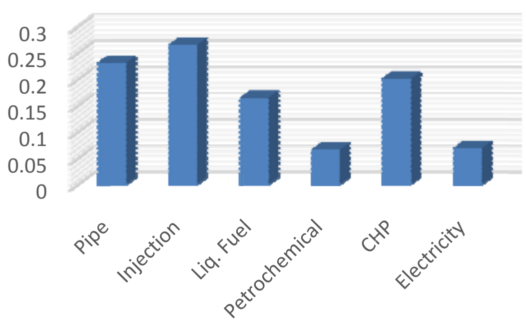

Fig. 9 Weight coefficient for Case 4

IX. Discussion of the Results

Several cases were considered in this analysis. These cases is defined where the priorities were defined always keeping one criterion in first position, while the priorities of the other criteria were defined by ordinal information defining the mutual relations of the criteria and the respective indicators.

When the priorities are the same the results are presented as shown in case 4. The second group comprises cases with hierarchical constraints, with changing priority in constraints in each case. Amongst these cases, priority is obtained for CHP usage in Case 3where Availability indicator is highly weighted while the pipeline usage is obtained in Case 1 (Environmental indicator highly weighted).

The Injection priority is obtained in Case 3 and Case 5 where Economic indicator is highly weighted and also when the weighing factor of all the criteria are the same the Injection priority is obtained.

X.Conclusion

As a result, where availability is the most important criterion, the CHP usage is chosen by the model while the priority goes to injection if the economical criterion has the highest importance.

Even if this type of analysis contains arbitrariness in the evaluation of the priorities among the alternative options, it is noticed that the Injection option and the Pipeline usage and CHP option are the best choices under the constraints used. By increasing the number of cases to be analyzed, a better result for decision making should be obtained.

It should also be noticed that, in this type of evaluation, further improvement of the data might lead to higher quality results.

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