

Distribution of flare gases in Iran and the potential of using these gases to generate electricity

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ABSTRACT

Every year, billions of cubic meters of flare gas burn in various upstream and downstream sectors of the oil industry. This is a valuable source of energy and is wasted due to the lack of necessary infrastructure. Various solutions have been proposed to recover flare gases and reuse them and electricity production is of particular importance due to its high flexibility and the existence of many technologies. The purpose of this research is to investigate the distribution of associated and flare gases in provinces of Iran based on satellite data provided by the World Bank. Arc GIS software was used to prepare the dispersion map. Then, based on this information, the amount of lost capital, the amount of CO₂ equivalent emissions caused by the burning of these gases, and the potential of electricity generation in each of the provinces of Iran have been calculated separately. According to the obtained results, the total gas flared in Iran raised incredibly from 2020 to 2023 (from 13258.05 to 20421.13 million of cubic meters). It means not only growing in the lost capital from 1521.66 to 2343.48 million dollars and the total equivalent emission of CO₂ from 35.35 to 57.18 million tones but also raising the total potential of power generation from 8181.82 to 12589.19 MW. Furthermore, the dispersion of associated and flare gases in Iran creates a suitable situation for creating dispersed generation power plants, especially in provinces such as Khuzestan, Bushehr, Kohgiluyeh and Boyer-Ahmed, and Ilam.

Keywords: Associated and Flare Gases, Electricity Generation, Flare Gas Recovery and Utilization, Emission Reduction.

1. Introduction

The most significant volume of associated and flare gases burned in the world belongs to the largest oil producers, who produce an average of 1 million oil barrels per day. These countries, which include Russia, Iraq, Iran, the United States, Venezuela, Algeria, Nigeria, Mexico, and Libya, are facing various challenges in solving the problem of burning these gases. For example,

countries such as Iraq, Iran, Venezuela, and Algeria have several large flares in their oil fields, which prevent their utilization due to economic, regulatory, or technical barriers in market development and the infrastructure necessary to use these gases. On the other hand, in some countries, such as the United States, there are thousands of small flares in the oil and gas industry, which can be challenging to connect to the market. The increase in the burning of these gases in Russia is also due to the continuous expansion of oil production in the existing oil fields in Eastern Siberia and their remoteness from the necessary infrastructure to gather and

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transport associated gases. The different and extensive challenges in the recovery and utilization of associated and flare gases indicate that no common and appropriate solution for all countries, fields or regions is conceivable. Therefore, programs and projects to reduce the recovery and use of gases should publish for unique sets of issues and conditions.

Figure 1 illustrates the amount of gases burned in the first 30 countries from 2019 to 2023 [1]. As can be seen, the volume of gases burned in Russia has increased sharply in recent years and has been the largest in the world. After that are Iran, Iraq, and the United States. In Iran, from 2019 to 2020, the amount of burned gases decreased significantly, according to the meaningful decrease in oil production. However, due to the increase in production from 2021 to 2023, the amount of flared gases has increased. In the United States, which experienced a substantial increase in 2019, its level decreased from 2020 to 2022; and then increased in 2023 now it has reached the level of 2016 and 2017.

According to World Bank statistics, in 2020 and 2021, oil production decreased by 8% (from 82.3 million barrels per day (BPD) in 2019 to 76.4 million BPD in 2020 and 76.8 million BPD

in 2021). As a result, the volume of flare gases burned in the world has also decreased by 5% (from 150 billion cubic meters (BCM) in 2019 to 142 BCM in 2020 and 143 BCM in 2021). The World Bank data shows that the United States accounted for 70% of the reduction in the volume of greenhouse gases and flares burned in the world. The 8 percent decrease in oil production and the infrastructure development for the use of associated and flare gases in this country have been the main factors of this significant decrease (32 percent decrease in 2020 compared to 2019).

In 2023, the oil production increased to 81.6 BPD; as a result, the flared gas increased globally. Russia, Iran, the United States and Libya contributed to adding 9 BCM to the global flaring. Russia, Iran, Iraq, the United States, Algeria, Venezuela, Libya, Nigeria, and Mexico are still the first nine countries with the most considerable amount of flare and associated gas burning in the world. These nine countries annually produce 46% of the world's oil but account for almost two-thirds (75%) of the volume of gas burned [1]. The remaining 25% burned in more than 60 other countries.

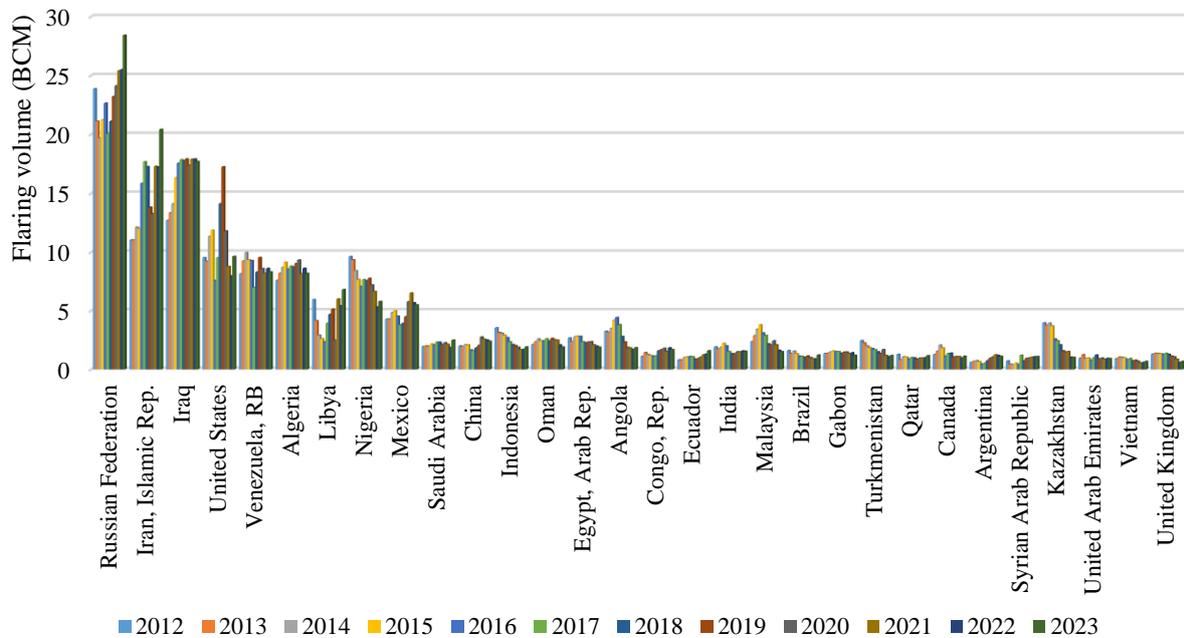
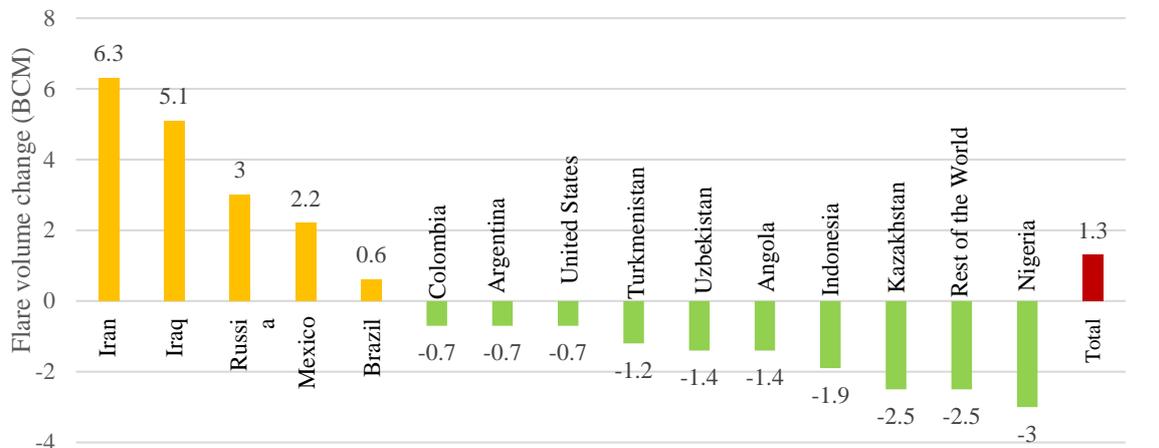


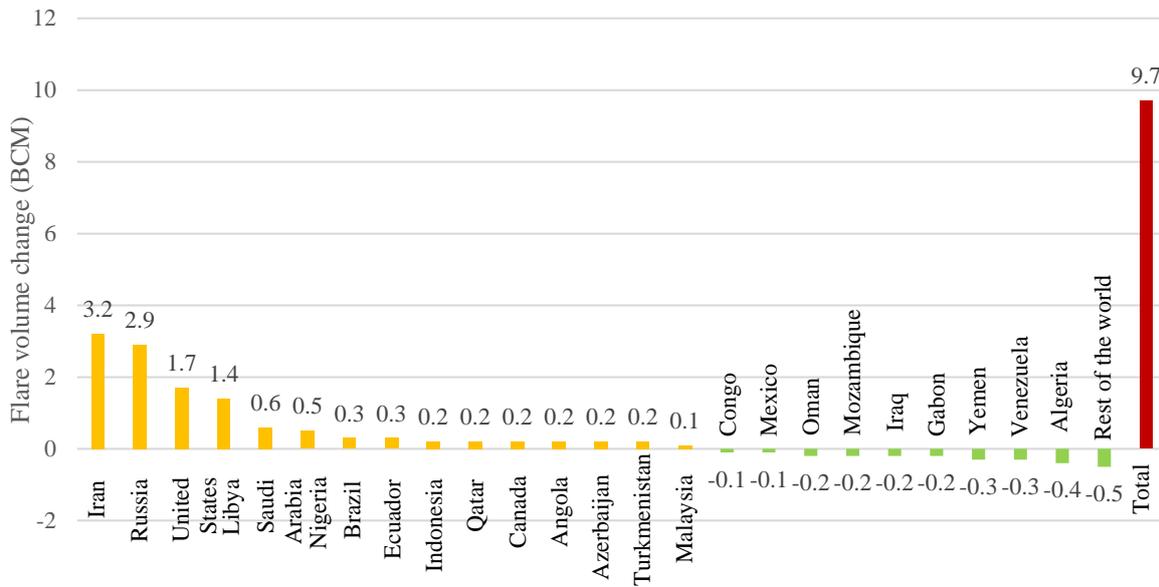
Fig. 1. The amount of associated and flare gases burned in the first 30 countries from 2019 to 2023.

The World Bank-led Global Gas Flaring Reduction (GGFR) is an organization committed to ending conventional flaring at oil and gas production facilities worldwide. The volume of flared gas in the world has largely remained constant in the last 10 years and was almost equal to 145 BCM. During the same period, global oil production levels rose slightly and averaged around 80 million BPD before declining in 2020 due to the effects of the Covid-19 pandemic. However, despite the significant reduction in the burning of these gases by some countries, this reduction is offset

by the increase in burning by other countries. As depicted in Fig. 2a, between 2012 and 2021, Iran has contributed the most, and the countries of Iraq and Russia are following [1]. In the next period (2022-2023), Iran is still in the first place and Russia and the United States are following [1]. As can be seen during 2022-2023, the gas flaring in Iran increased about 3.2 BCM (19%), but the oil production increased by only 10%. As a result, the flaring intensity (the amount of gas flared per barrel of oil produced) reached 15.4 m³/barrel, which is the highest record since 2012.



(a) 2012-2021



(b) 2022-2023

Fig. 2. Change in the volume of flare gases (a) between 2012 and 2021 and (b) between 2022 and 2023 (countries with the most significant change (+ or - 0.6 BCM) and the rest of the world as a whole are shown).

The innovations of this article are:

1. Comprehensive investigation of the distribution of associated and flare gases in Iran
2. Classification of the associated and flare gases based on flow rate
3. Estimating the economic loss and greenhouse gas emissions (the amount of CO₂ equivalent emission) in each of the provinces of Iran
4. Estimating the potential of electricity generation in each of the provinces of Iran

2. Methodology

GGFR is developing the Global Gas Flaring Explorer, an online platform in collaboration with the Oil and Gas Climate Initiative (OGCI) and the Payne Institute (Colorado School of Mines). Through the development of this platform, it is possible to monitor real-time conditions and improve the burning of flare gases globally. This map has visibility of flare gas data in oil and production facilities worldwide. With

this platform, flare gas volumes could be monitored and progress toward the World Bank's Zero Routine Flare by 2030 demonstrated. An overview of the images presented on this platform is presented in Fig. 3.

In order to produce this platform, flare gas data collected by the National Aeronautics and Space Administration/National Oceanic and Atmospheric Administration (NASA/NOAA) Visible Infrared Imaging Radiometer (VIIRS) array is presented. The accuracy of estimating the volume of burned flare gas is $\pm 9.5\%$. In 2012, a total of 7,467 individual flares were identified. The total volume of flare gas is estimated to be 143 (± 13.6) BCM, equivalent to 3.5% of global gas production. While the United States has the largest number of flares, Russia is the leader in flare gas volumes. 90% of flare gas volume was found in upstream production areas, 8% in oil and gas refineries, and 2% in liquefied natural gas (LNG) terminals. The results illustrate that most flare gases occur in the upstream production areas. Figure 4 shows the distribution of flare gases in Iran based on the provided information and satellite images.

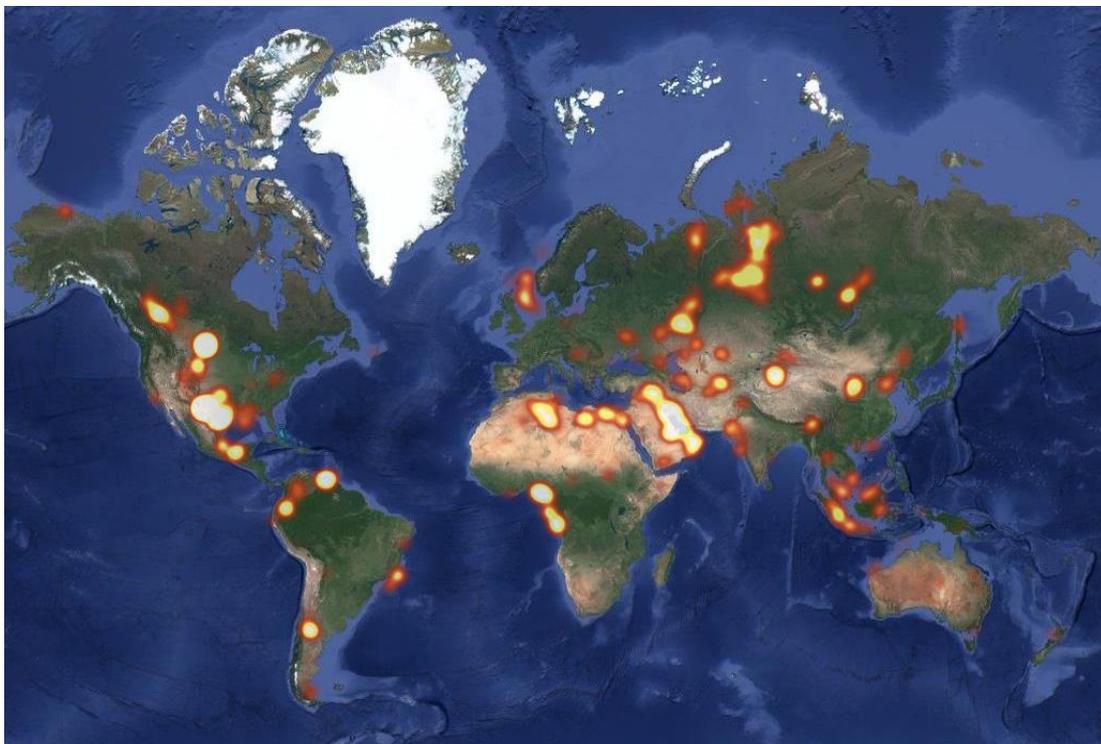


Fig. 3. An overview of the distribution of flares in the world based on satellite images of NOAA

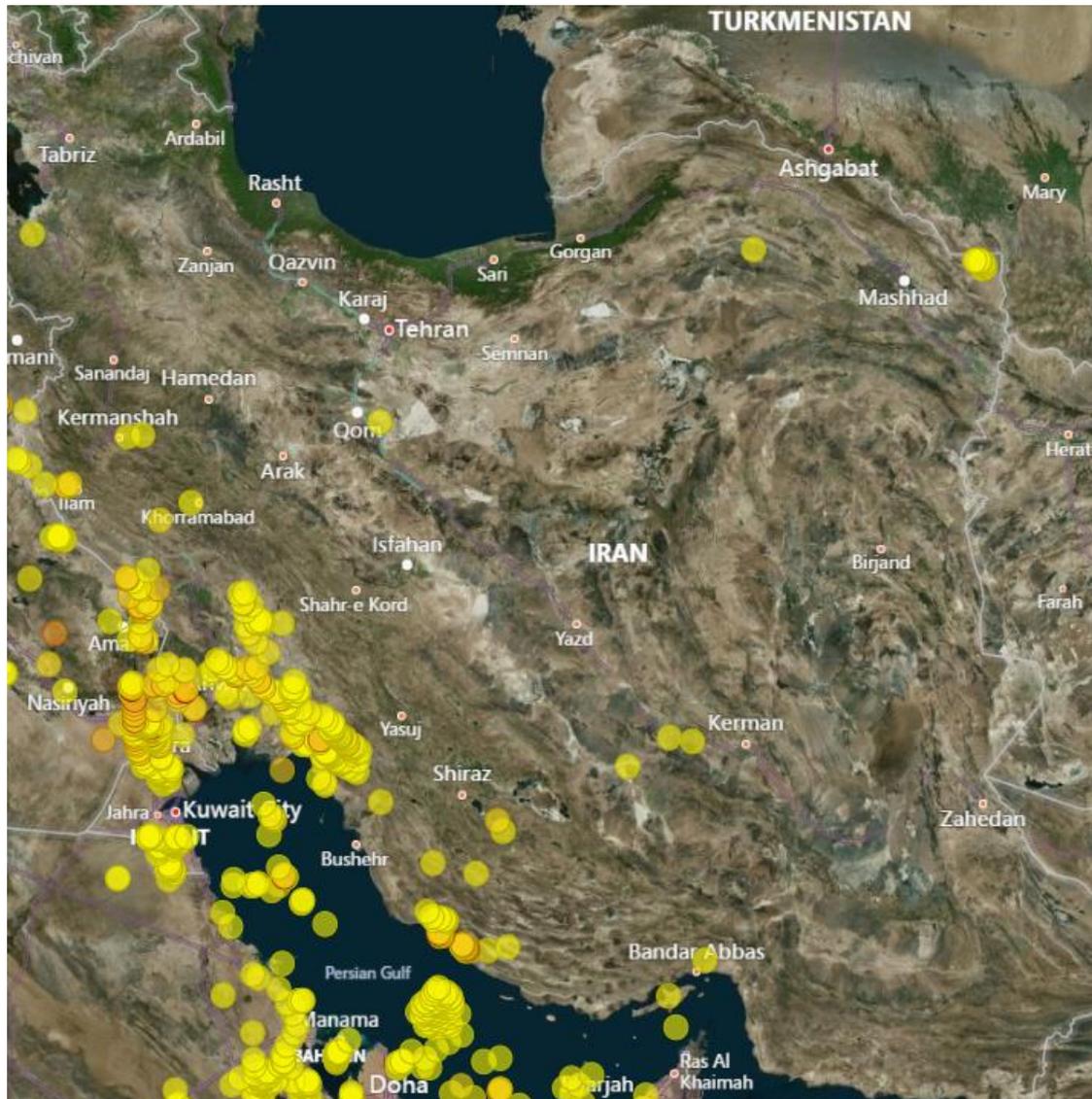


Fig. 4. Distribution map of flare gases in the country based on World Bank information

Due to the ever-increasing improvement of the gas network infrastructure in all regions of Iran, and the concern about the adverse health and environmental effects, the use of associated and flare gases has improved in some areas. Meanwhile, continuous efforts should be made across the country to increase the use of associated and flare gases and to reduce their levels. Studies have shown that there is significant potential for improvement. Effective policies and measures to reduce the burning of these gases should be based on a correct understanding of the conditions of consumption, the amount of emissions and possible costs, and the advantages and disadvantages associated with each solution [2].

The appropriate use and effectiveness of the best economically available technologies to reduce emissions from combustion ultimately depends on several technical and economic variables specific to the operating unit in the oil and gas industry, including current use and frequency of flare gases, available field size and the volume of flare gases, available compounds and usable amount, the remaining life of the field and geographical conditions and other cases [3-4].

There are different ways to recover and use flare gases [2, 5-7]. The first method is the use of pressure boosting, which includes the typical process of using flare gas as fuel gas or returning it to the feed stream in the downstream

section or compression and re-injection of associated gases into oil wells for enhanced oil recovery (EOR) [8-9]. Natural gas liquid (NGL) facility is another method for recycling associated gases, which separates light gases from liquids and is mainly utilized as feed for petrochemical complexes [10]. The methane gas can be used in the production of liquefied natural gas (LNG) or compressed natural gas (CNG). Fuel synthesis through gas-to-liquid process (GTL) or chemical synthesis, such as ammonia, ethylene, methanol, dimethyl ether (DME), etc., is another route by using associated gases [2, 10-12]. The final yet important method considered is power generation or gas-to-wire (GTW) technology. Among these, the GTW is particularly important due to its simplicity and the need for less investment [13-16]. This method can be in the form of electric energy generation in a power plant or using dispersed generators [12]. Comparing electricity generation through dispersed generators with other methods shows the superiority of this method in terms of technical flexibility and short return on investment, which can create hope for the use of private sector investors in Iran [3-5].

In the following, the situation of burning associated and flare gases in Iran will be studied based on the information from the World Bank. First, we will investigate the distribution of associated and flare gases in the provinces of Iran, then we will estimate the lost capital, the amount of CO₂ produced and the power generation potential in this area for different provinces. According to the projects done at

Niroo Research Institute [4] and the World Bank data [1], there could be an average specification assumed for the flare gases for more straightforward estimation and managing decisions. These data are presented in Table 1. It should be noted that the results obtained by this method are just rough estimations of the economic and environmental losses of the flare gases and for more exact calculations, the specification of each flare gases is needed.

3. Studying the distribution of flare gases in Iran

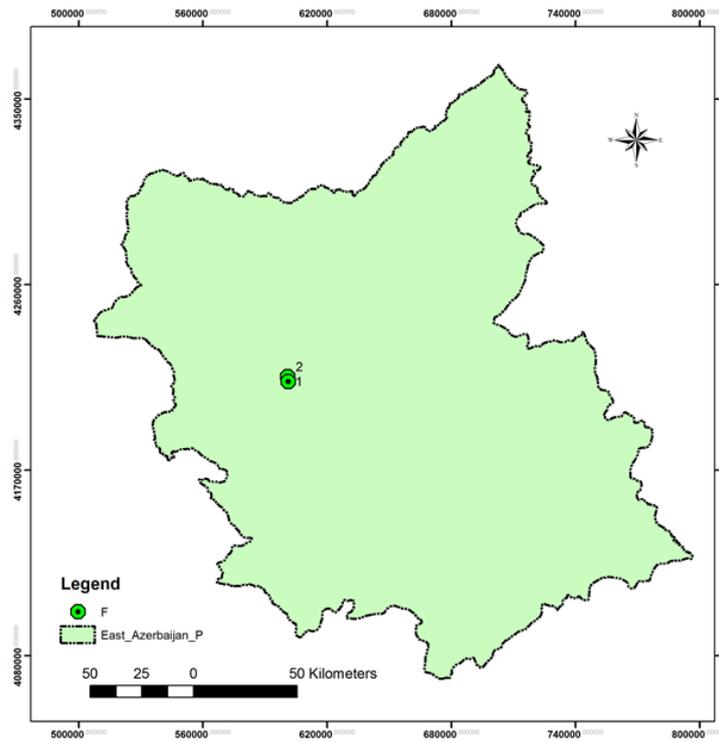
In this section, the existing flares in Iran in both onshore (and coastal) and offshore sections have been studied. The coastal section includes information for 17 provinces (East Azerbaijan, West Azerbaijan, Isfahan, Ilam, Bushehr, Tehran, Khorasan Razavi, Khuzestan, Sistan and Baluchistan, Fars, Qom, Kermanshah, Kohgiluyeh and Boyer-Ahmad, Lorestan, Markazi, Kerman and Hormozgan). The offshore sector includes flares in the exploitation platforms in the Persian Gulf.

3.1. Onshore flares

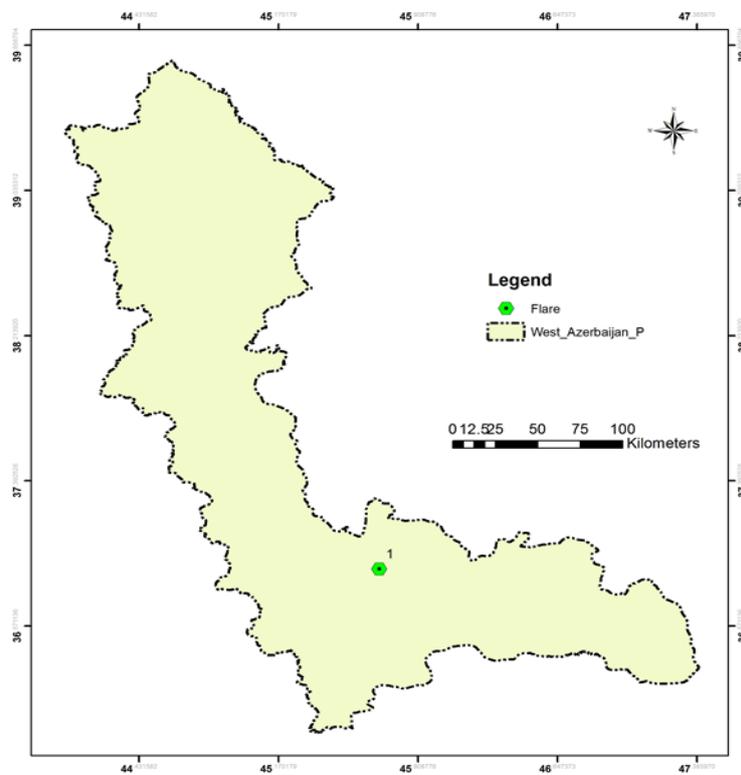
First, based on the images available in the GGFR section on the World Bank website, information on Iran's flares, including geographical coordinates and the number of flares (based on million cubic meters per year) for each flare, was entered into the Arc GIS software, and then a distribution map of the flares was drawn for each province. The result is shown in Fig. 5.

Table 1. Average associated and flare gases specification

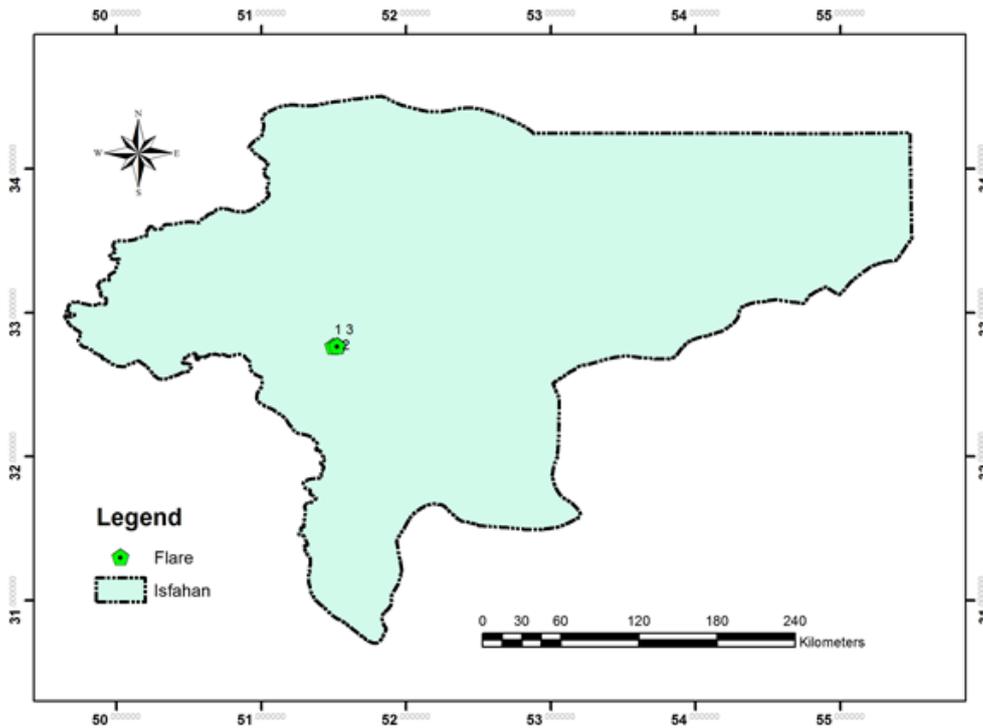
Specification	Unit	Unit	References
Gas sales value	\$/MMBTU	2.5	[1]
Gas heating value	BTU/m ³	45909.1	[4]
CO ₂ equivalent emission	kg/m ³	2.8	[1]
Nominal heat rate for power generated by the gas engine	Btu/kWh	8500	[4]



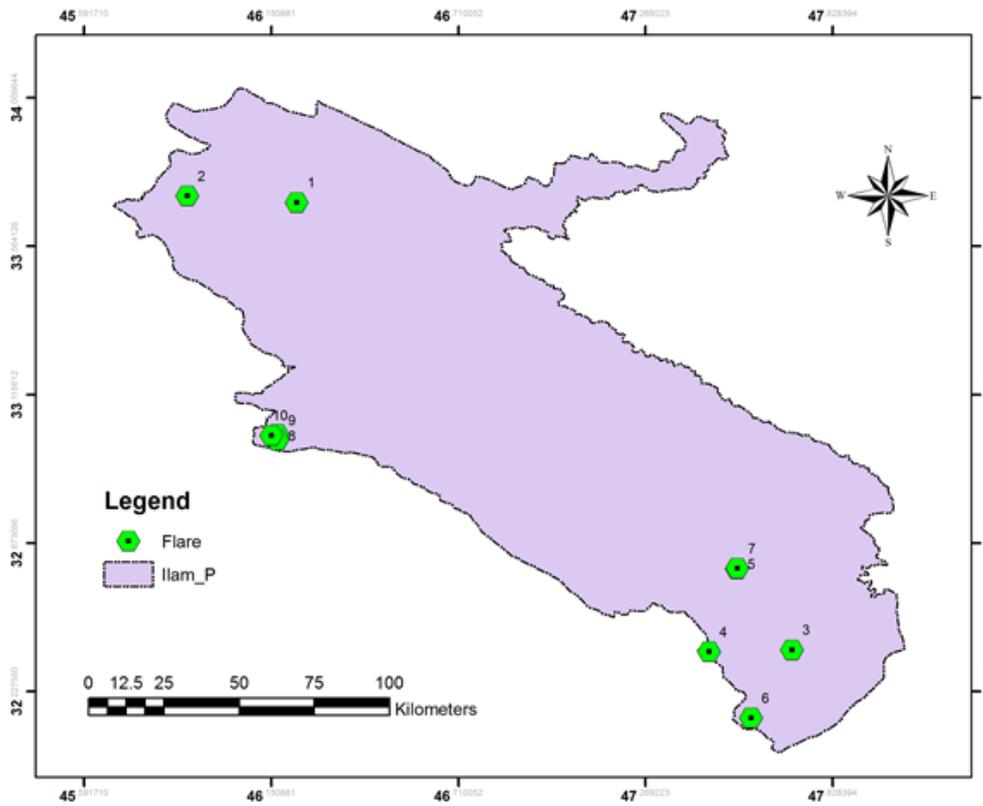
East Azerbaijan



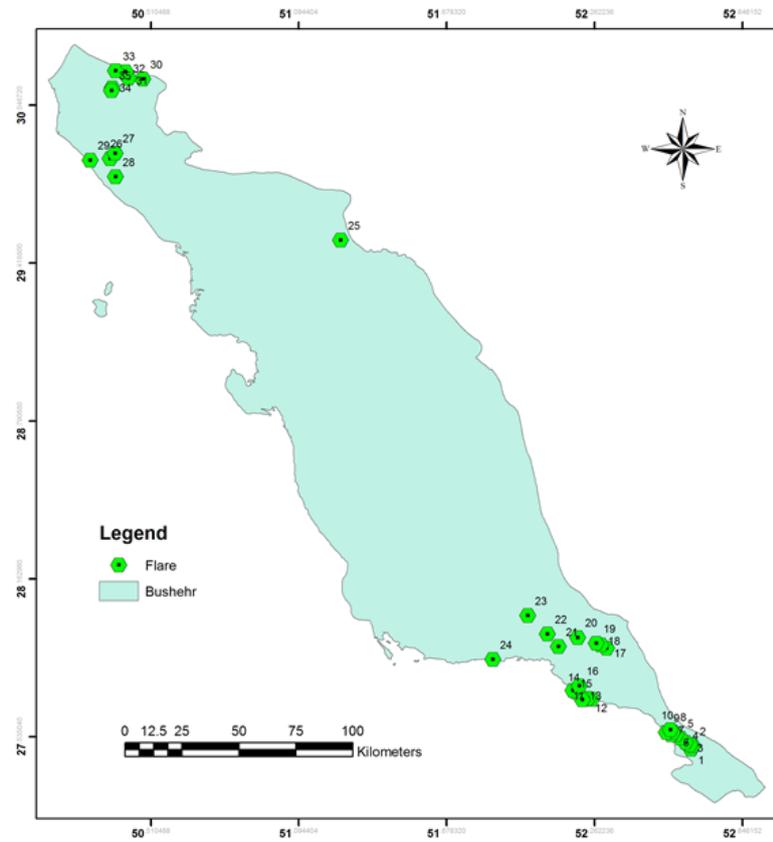
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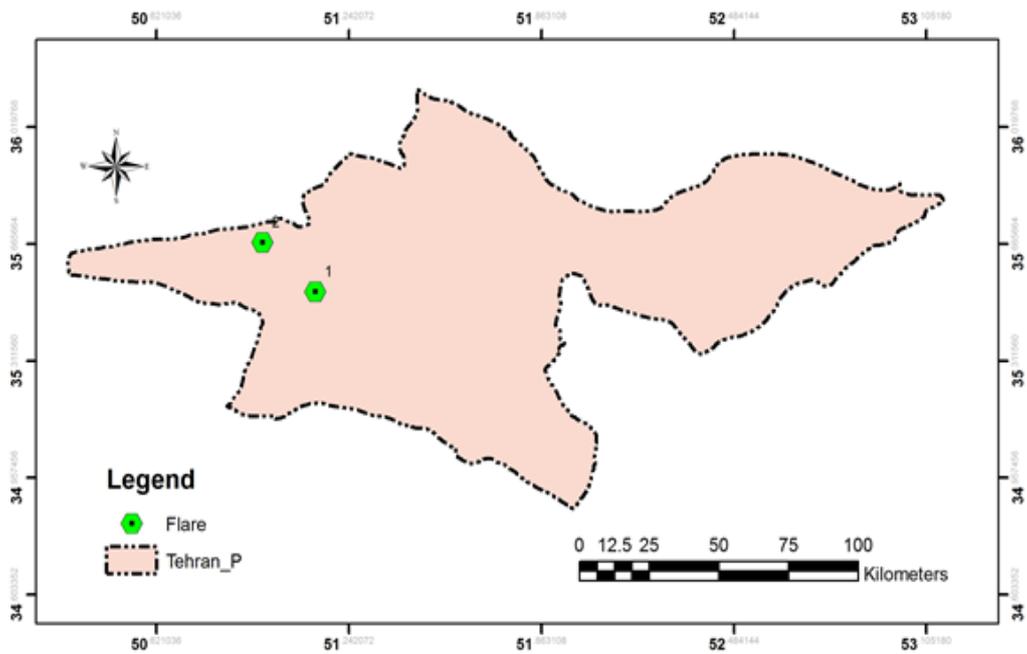
Isfahan



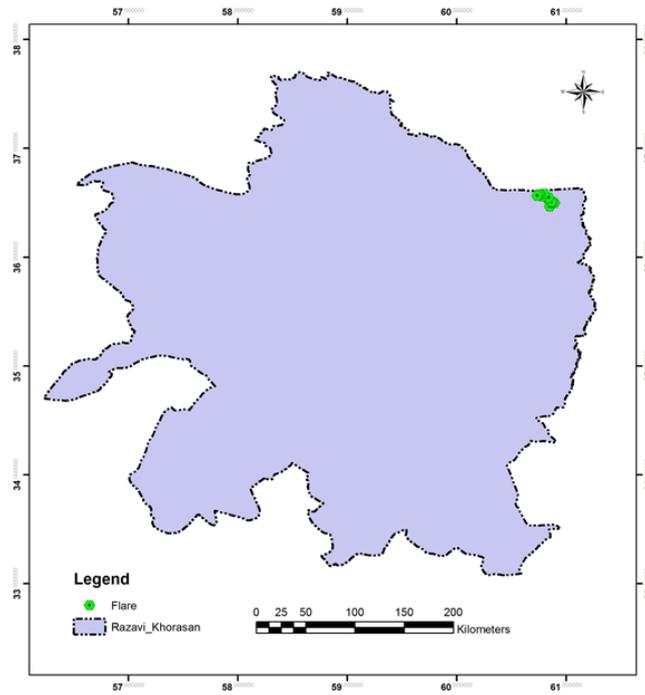
Ilam



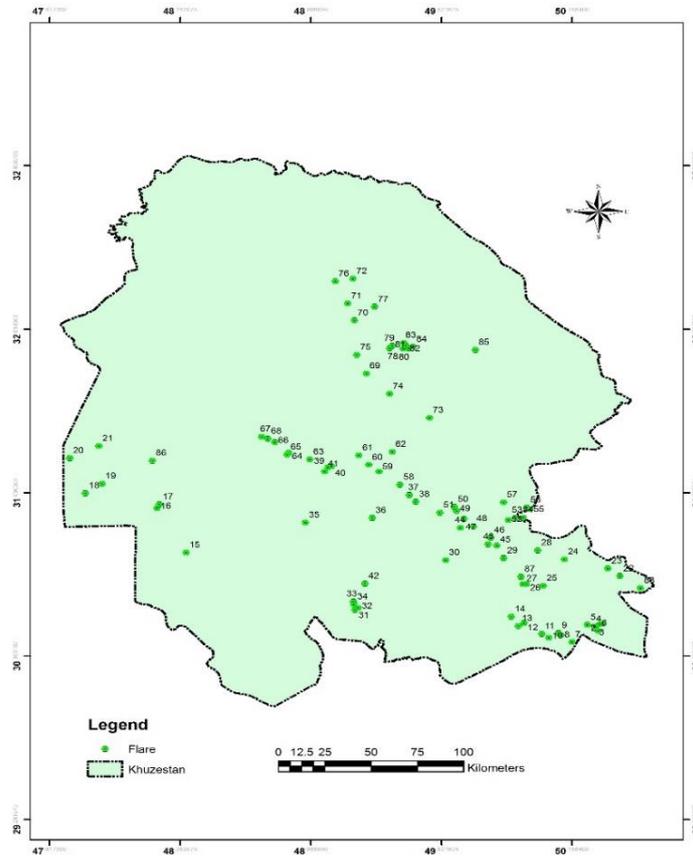
Bushehr



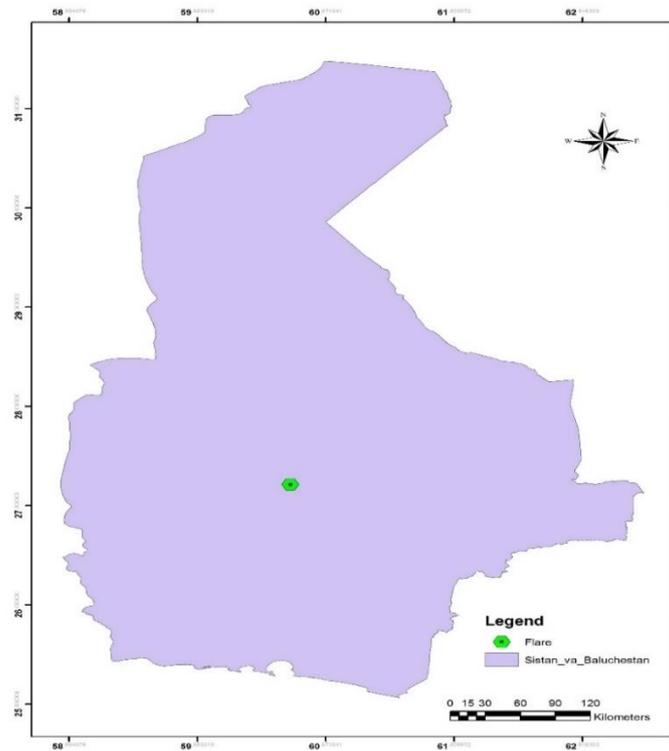
Tehran



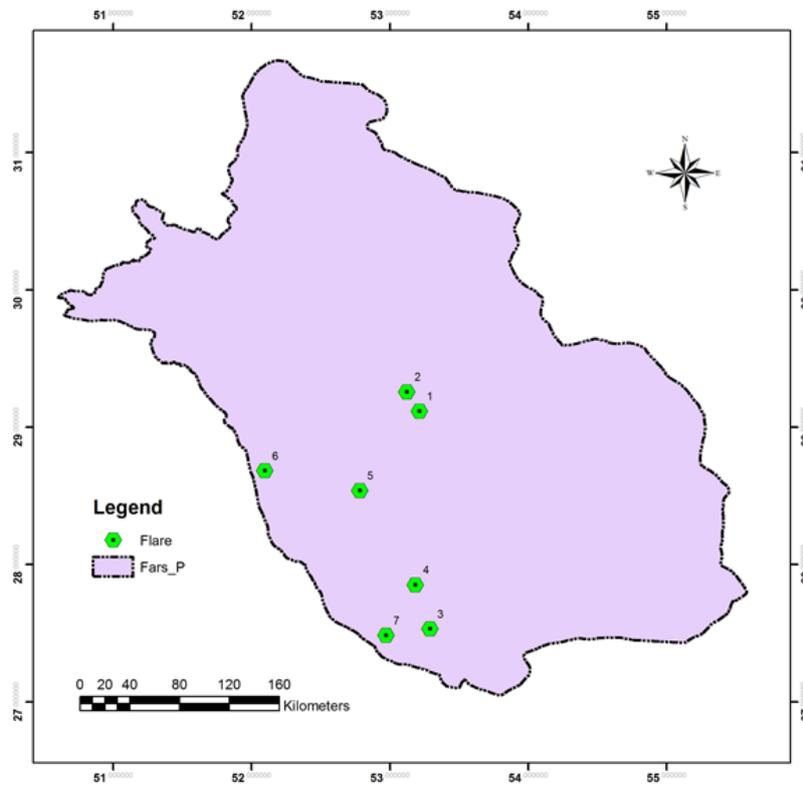
Khorasan Razavi



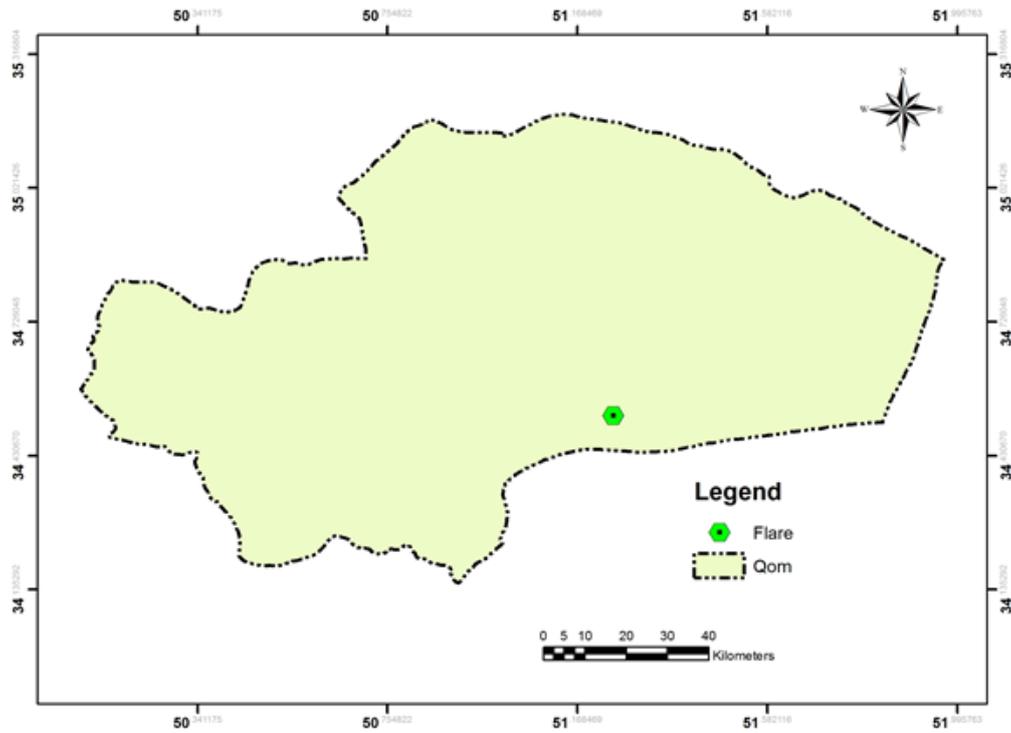
Khuzestan



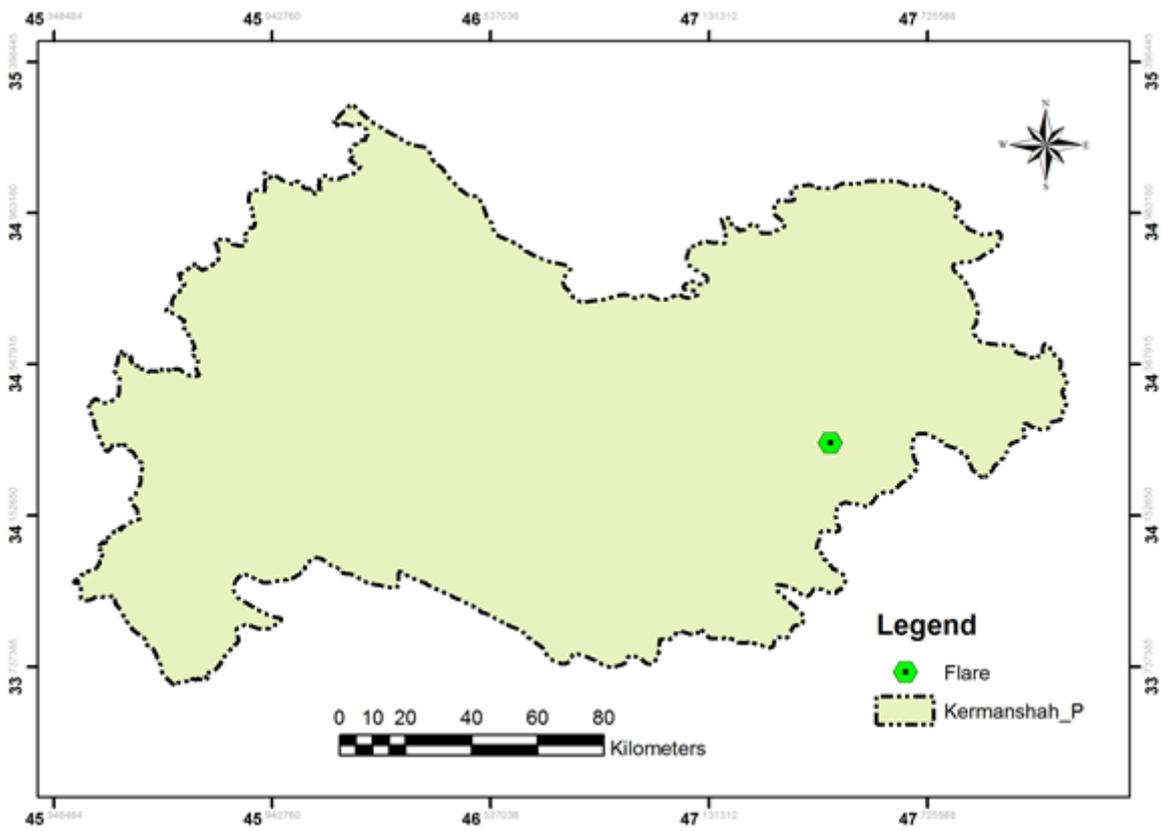
Sistan and Baluchistan



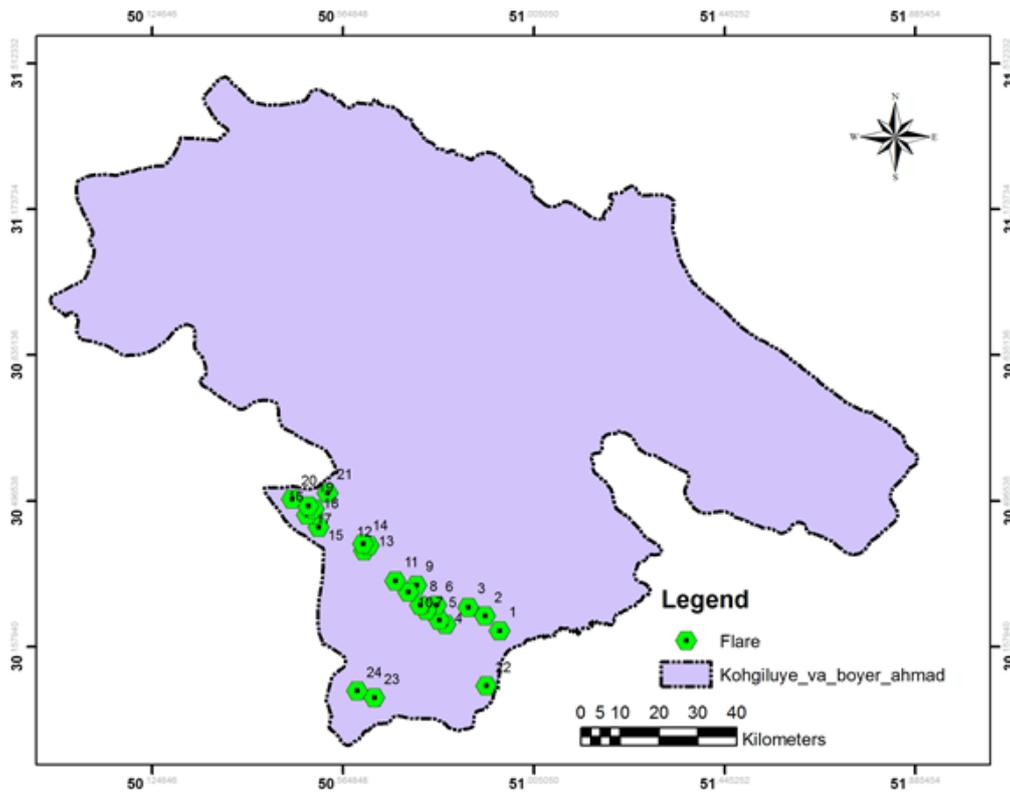
Fars



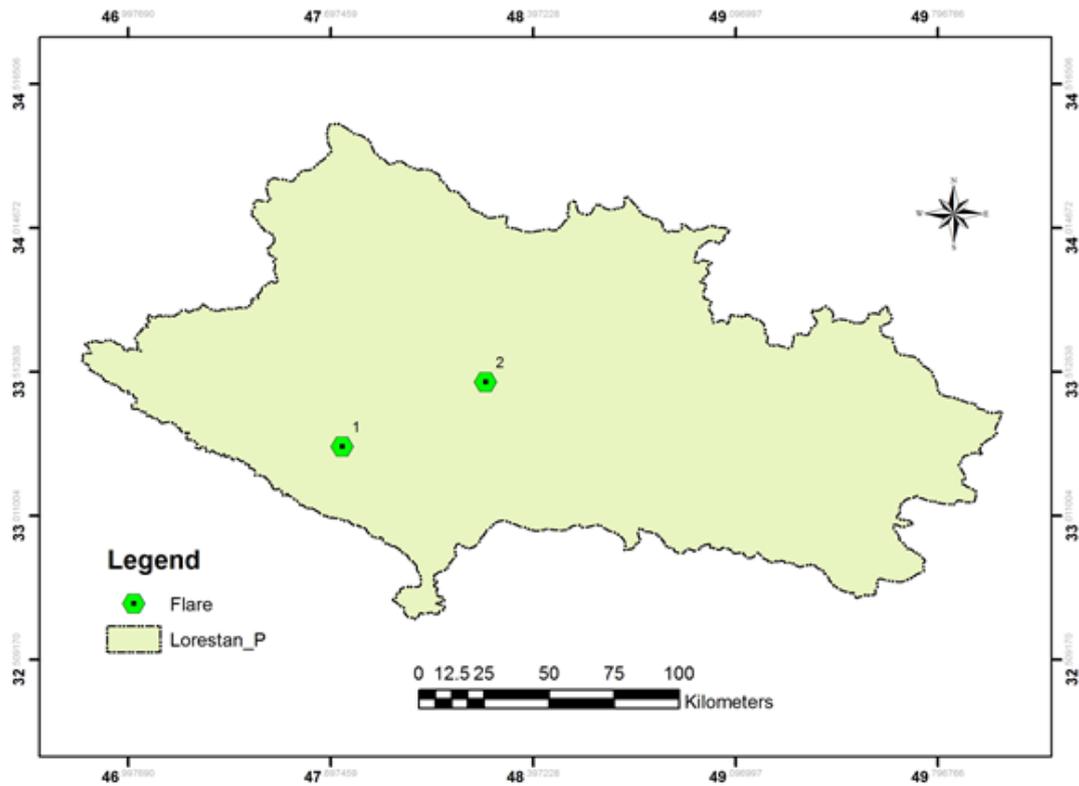
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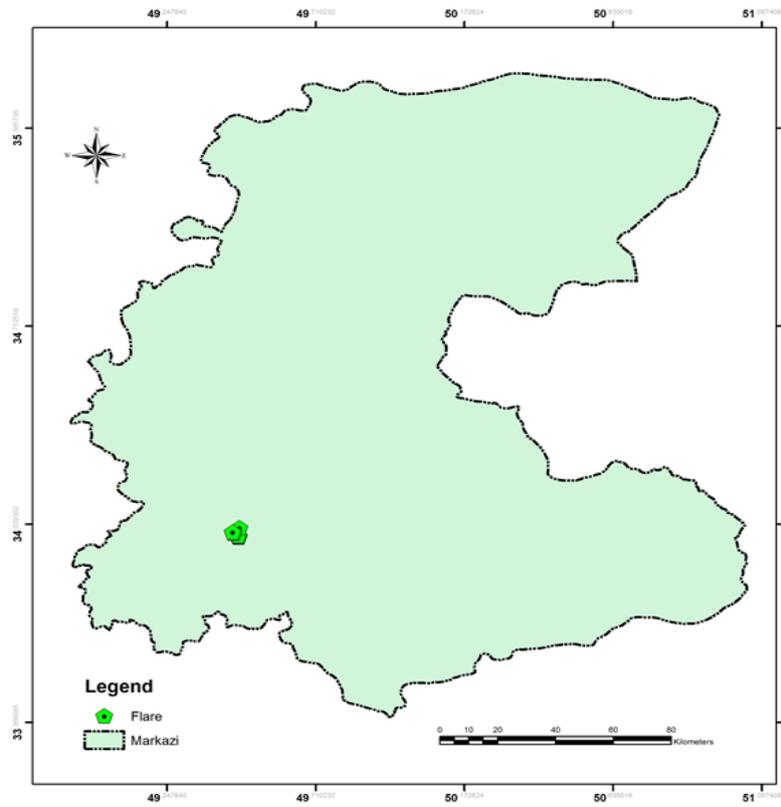
Kermanshah



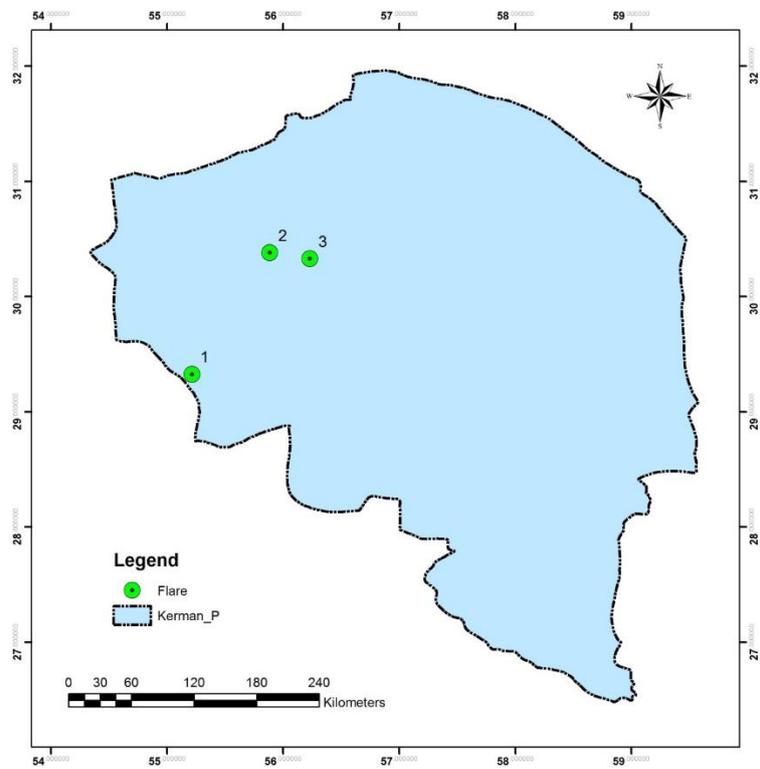
Kohgiloye and Boyer Ahmad



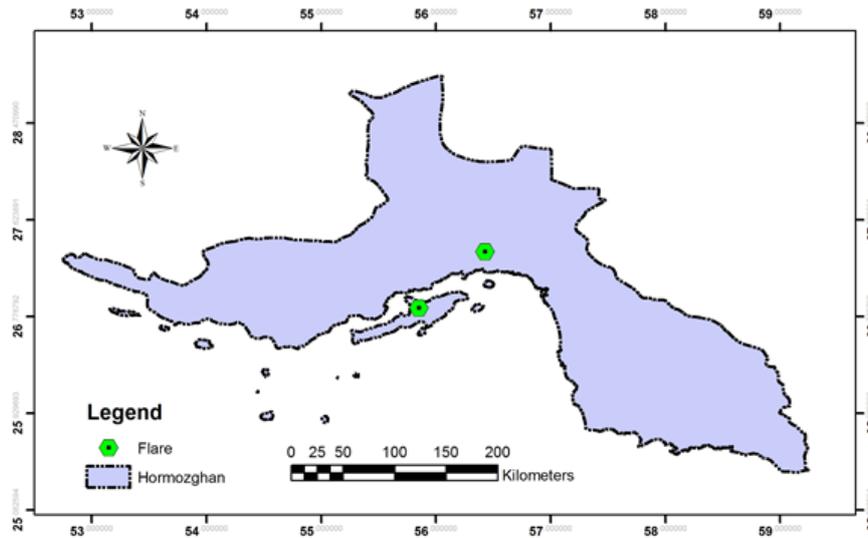
Lorestan



Markazi



Kerman



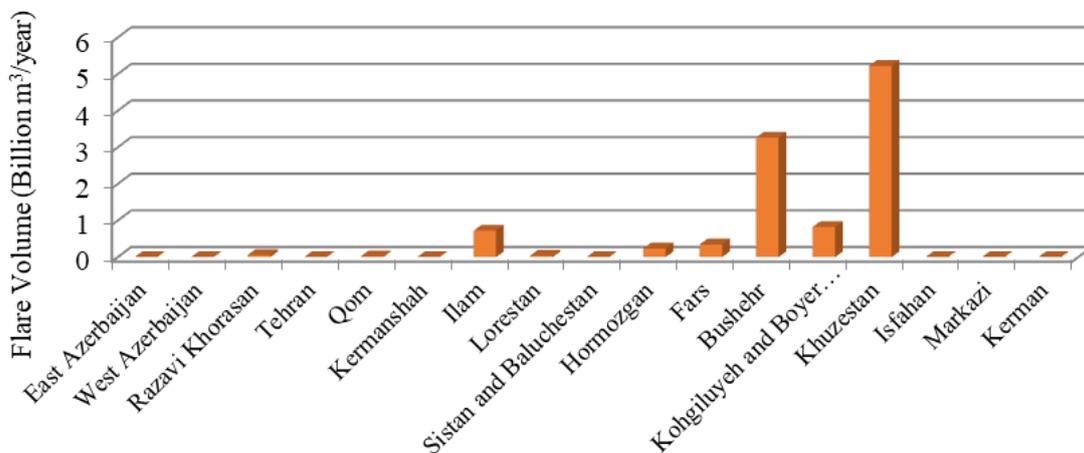
Hormozgan

Fig. 5. The distribution of flares in the provinces of Iran based on the information from the World Bank.

Figure 6 shows the amount of flare burned in the provinces of Iran in 2020 and the contribution of each province in this regard. As can be seen, Khuzestan province accounts for nearly half of the country's flaring, and the provinces of Bushehr (30%), Kohgiluyeh and Boyer Ahmad (8%), Ilam (7%), Hormozgan (2%) and Razavi Khorasan (1%) are in the following ranks.

For a more detailed examination and the possibility of making management decisions about existing flares, a division has been made based on the volume and amount of gas burned. Available flares are divided into six categories:

- Very small (X-Small) with a volume of less than 0.001 BCM per year
- Small with a volume of 0.005-0.001 BCM per year
- Medium with a volume of 0.01-0.005 BCM per year
- Large with a volume of 0.05-0.01 BCM per year
- Very large (X-Large) with a volume of 0.2-0.05 BCM per year
- Very, very large (XX-Large) with a volume of 0.2-1 BCM per year



(a)

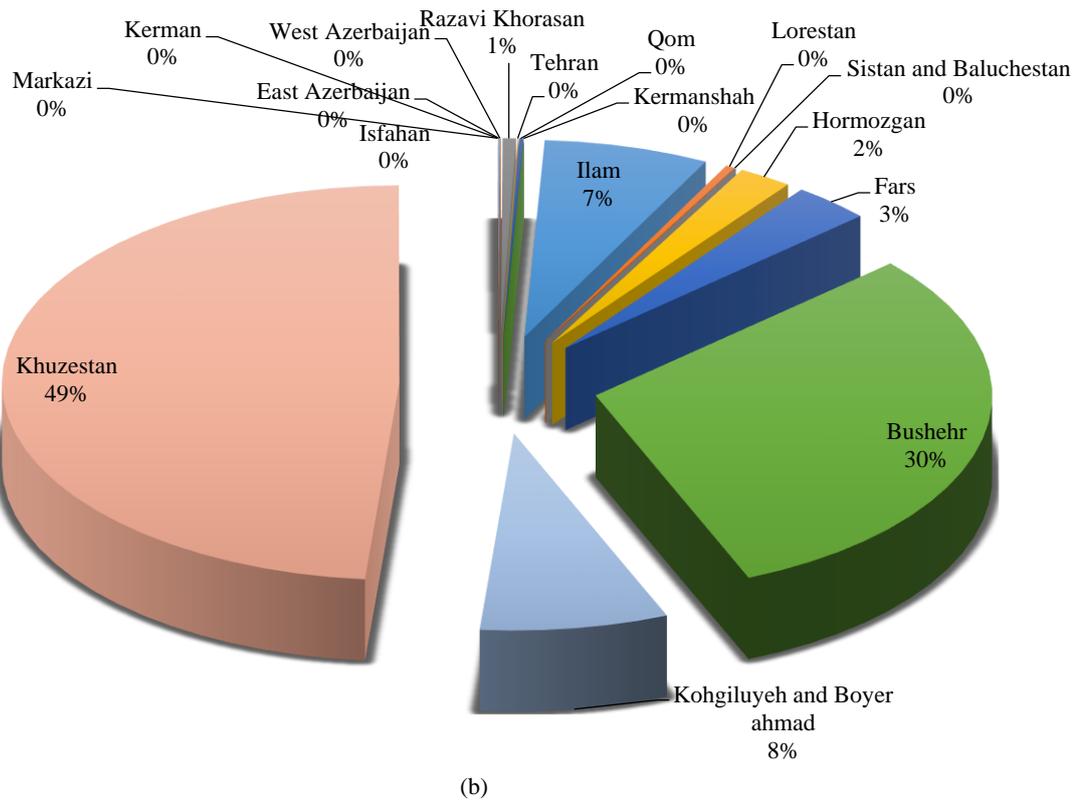


Fig. 6. Flare volume (a) and share percentage of each of Iran's provinces (b) based on NOAA data in 2020

Figure 7 shows the difference in the number and size of flares in different provinces of the country. Based on satellite data, the share of

flares in Iran in terms of small to very large size is shown in Fig. 8.

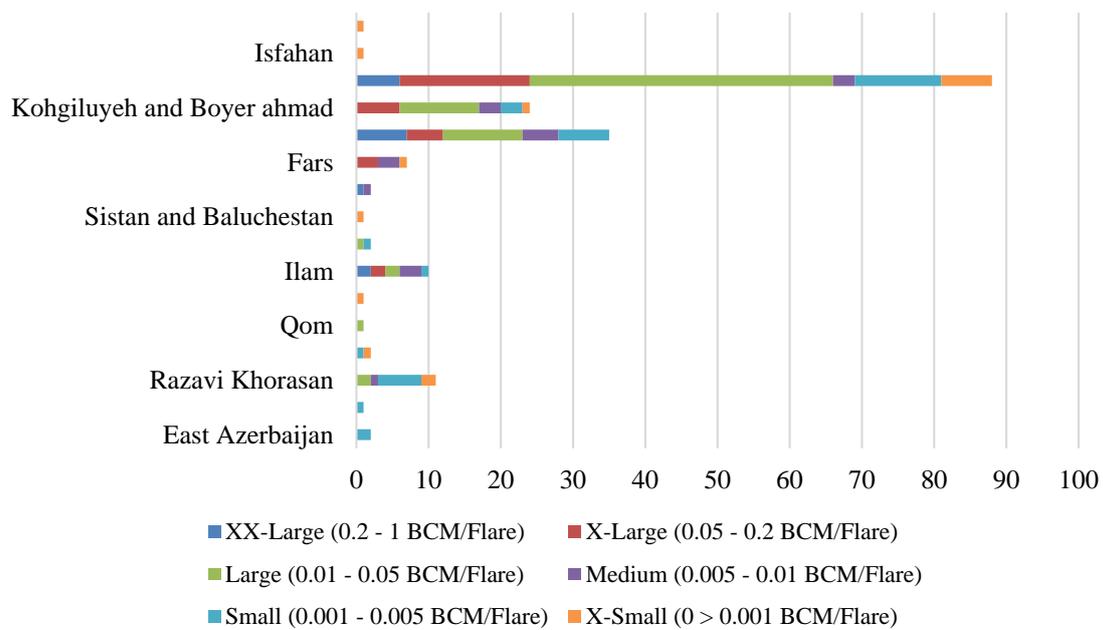


Fig. 7. The number of flares in different provinces according to size

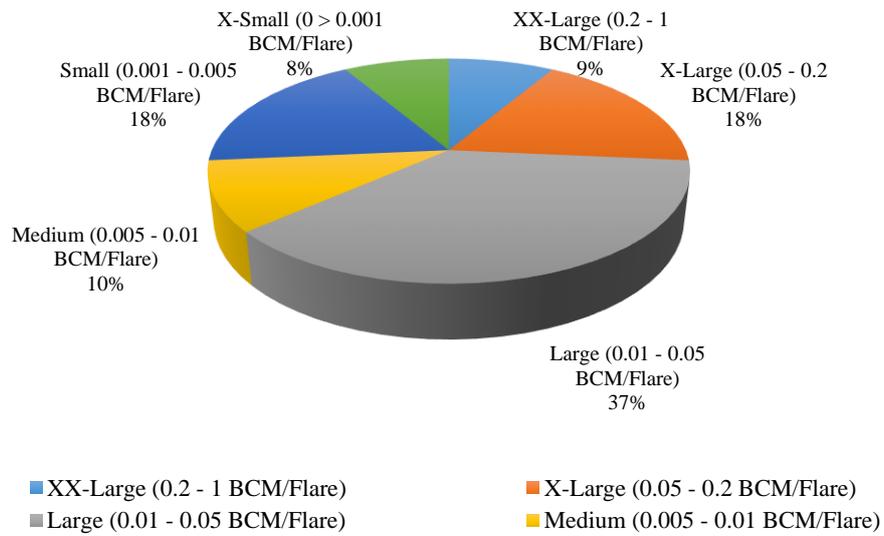


Fig. 8. The contribution of land-based flares based on their size in Iran

3.2. Offshore flares

The distribution of Iran's offshore flares in the Persian Gulf is shown in Fig. 9. According to the results in 2020, the offshore flares comprise 24% of total flaring in Iran with 3232.78 BCM per year. The main challenge regarding offshore flares is

the lack of facilities to transfer these gases to process units or to use these gases in existing exploitation platforms. Figures 10 and 11 show the classification of these flares in terms of size and the contribution of each category to the amount of flare gas burned.

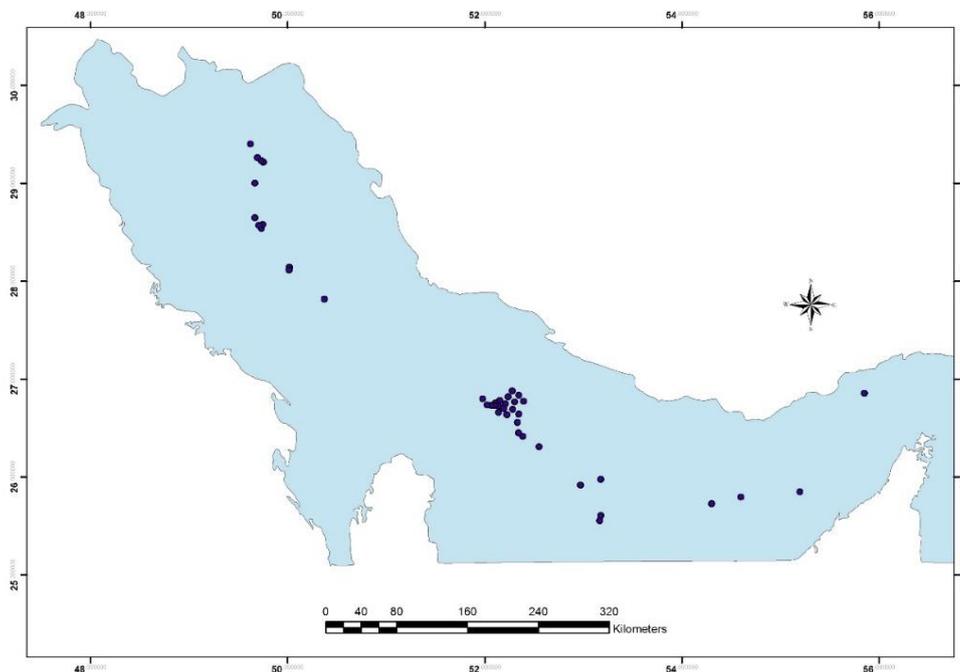


Fig. 9. Distribution of offshore flares in the Persian Gulf

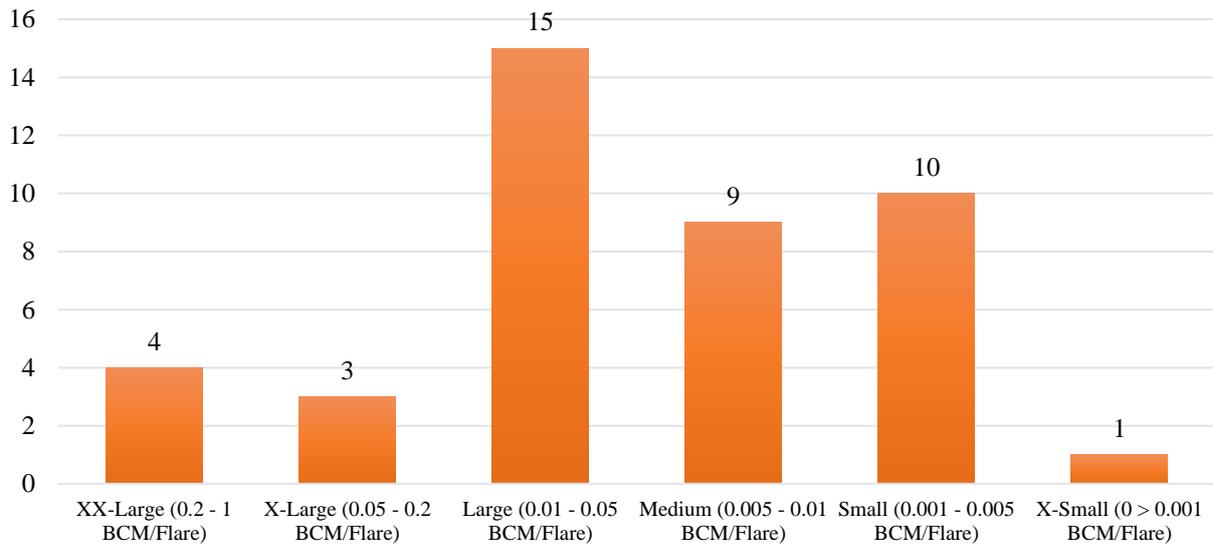


Fig. 10. Number of different existing offshore flares by size

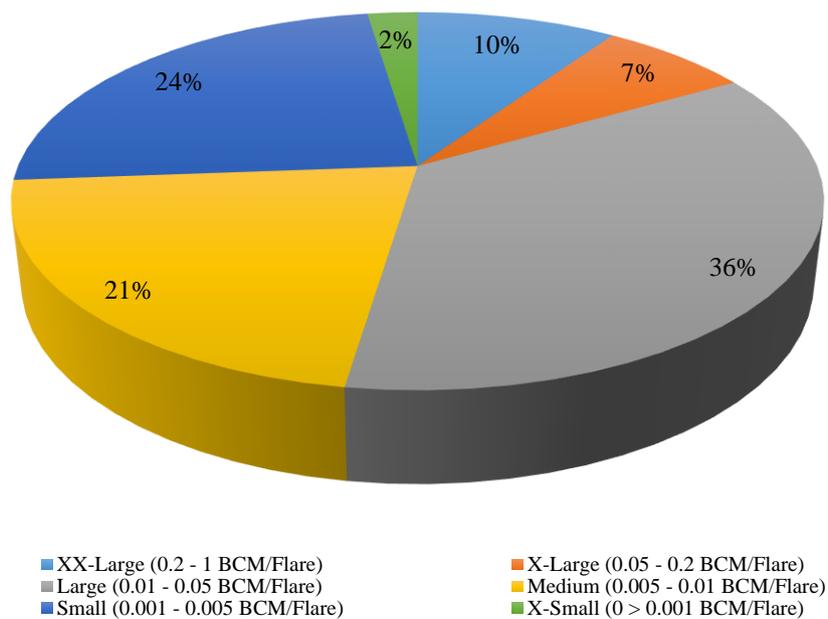


Fig. 11. Contribution share of existing offshore flares based on their size

Figure 12 illustrates the contribution of onshore and offshore flare gases in Iran during 2012-2023. The amount of offshore flare gases is around 3000 million cubic meters per year, and their value fluctuated little during 2012-2023.

4. Discussion

4.1. Technology options

One of the parameters that significantly affects

on choosing utilization process is the flow of the associated and flare gas. Based on the work done by Khalii-Garakani et al. [5] and the classification of the gases presented here, there is a flow domain for choosing each of the utilization methods. Table 2 presents this classification for each process. As can be seen, the gas-to-wire-technology could be applied in all categories.

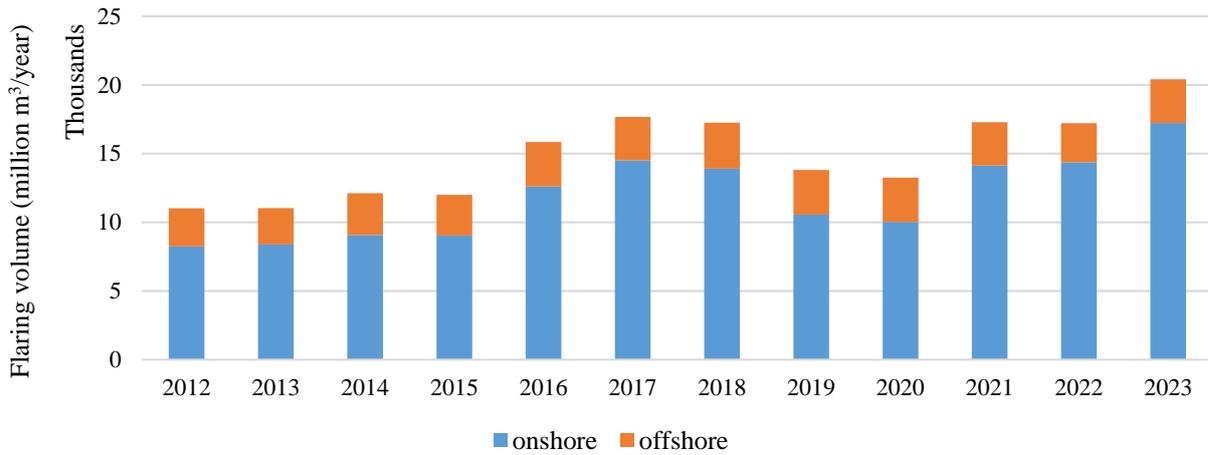


Fig. 12. Contribution share of existing of onshore and offshore flare gases in Iran during 2012-2023

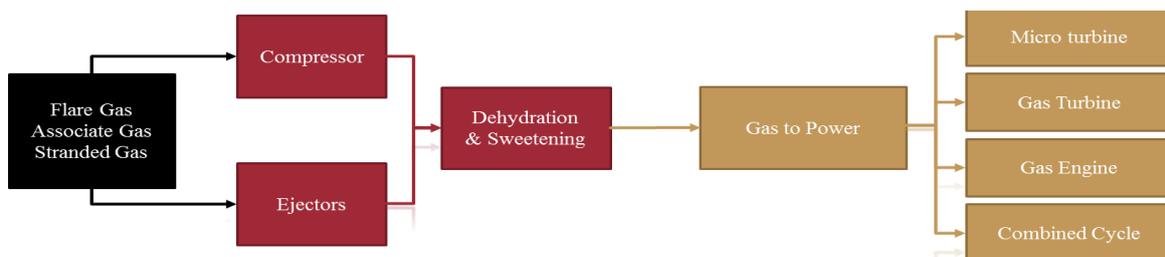
Table 2. The flow classification for choosing each flare gas utilization

Flow classification	Technology
X-Small	Fuel gas, GTW
Small	Fuel gas, GTW
Medium	Fuel gas, GTW
Large	NGL, EOR, LNG, Chemicals, GTW
X-Large	NGL, EOR, LNG, GTL, Chemicals, GTW
XX-Large	NGL, EOR, LNG, GTL, Chemicals, GTW

According to the variety of equipment that can be used for power generation from associated and flare gases, there is no limit in terms of gas quality and its amount, and this equipment can produce electricity in a wide range of parameters according to the discussion of economic justification [4]. In general, different options for electricity generation using associated and flare gases are schematically shown in Fig. 13. Also, in this chart, the amount of suitable production power for each technology is given along with information such as efficiency, the amount of acceptable sulfur in the input feed, the amount of fuel flow required,

and the estimated cost for each of these technologies in terms of USD.

The design and review of the electrical energy production system include the analysis of flare gases, compression and preparation of flare gas, transfer of recycled gas to power generation units, and design and selection of power generation units. Since the characteristics of the gas flow of the main pipe of the flare system, such as flow intensity, temperature, pressure, and percentage composition, etc., are highly variable, a particular flow pattern and its properties will be needed to determine the minimum gas specification required for the system.



(a)

Technology	Unit power (MW)	Efficiency (%)	H ₂ S content (ppm)	Fuel gas flow (m ³ /hour)	Investment (\$/kW)
Micro Turbine	0.015-1	30	70000	25-5000	700
Gas Turbine	1-100+	35	30000	200+	400
Gas Engine	1-18	45	10000	200+	500
Combined Cycle	5+	50	-	-	650

(b)

Fig. 13. a) Schematic of the process of producing electricity from flare gas and types of technologies that can be used and b) Comparison of the conditions and investment costs required for each of them

Determination of the dispersed generation through internal combustion engines is of particular importance due to their greater flexibility against associated and flare gases. Also, using microturbines increases productivity and reduces pollution, and since they are light and portable, they are very suitable for use in drilling areas and platforms. Microturbines can work with different fuels, including sour gas. The generation of electricity for sale to the national grid and the construction of combined cycle power plants are also justified only for using flare gases in large volumes.

5.2. Enviro-economic analysis

Using the obtained information and the volume of associated gases, opportunities and conditions were analyzed in each of the provinces of Iran. As mentioned, 13.3 BCM of flare gases were burned in 2020 in different

provinces of Iran. According to Table 1, if it is assumed that each cubic meter of these gases has a calorific value of 45909 BTU of energy [4], and each million BTU of these gases is worth 2.5 dollar [1], the results show that in 2020 a capital of about 1523 million dollars has been lost due to the burning of associated and flare gasses (Fig. 14); most of which is related to onshore flares (81%). Khuzestan has the most lost capital with nearly 600 million dollars per year, followed by Bushehr with 375, Kahgiloyeh and Boyer Ahmad with 94, and Ilam with 83 million dollars per year. Based on the studies, burning each cubic meter of these gases emits 2.8 kg of CO₂ on average [1]. Therefore, a total of 1.30 million tons of CO₂ is released due to the burning of these gases, the distribution of which is shown in Fig. 15 for different provinces of Iran. Here, too, the ranking of the provinces is according to the amount of gas produced.

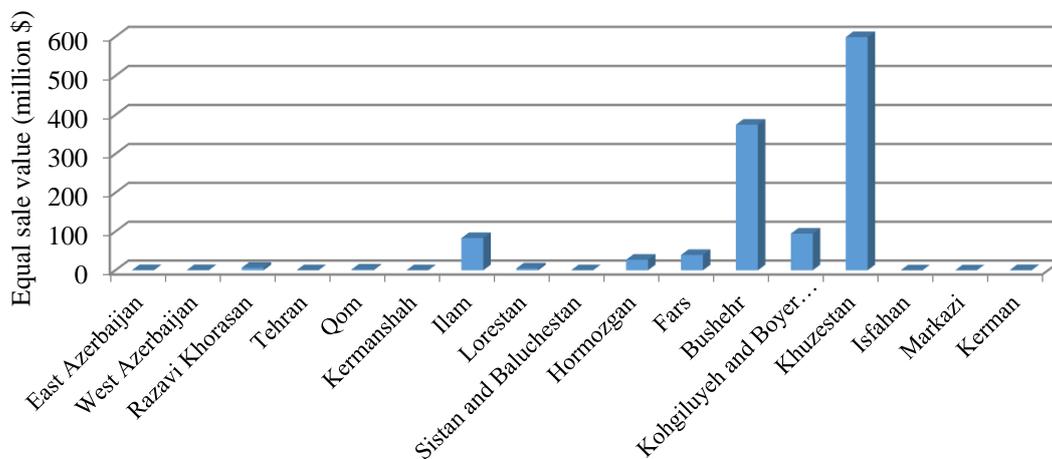


Fig. 14. The amount of capital lost in each of Iran's provinces based on NOAA data in 2020

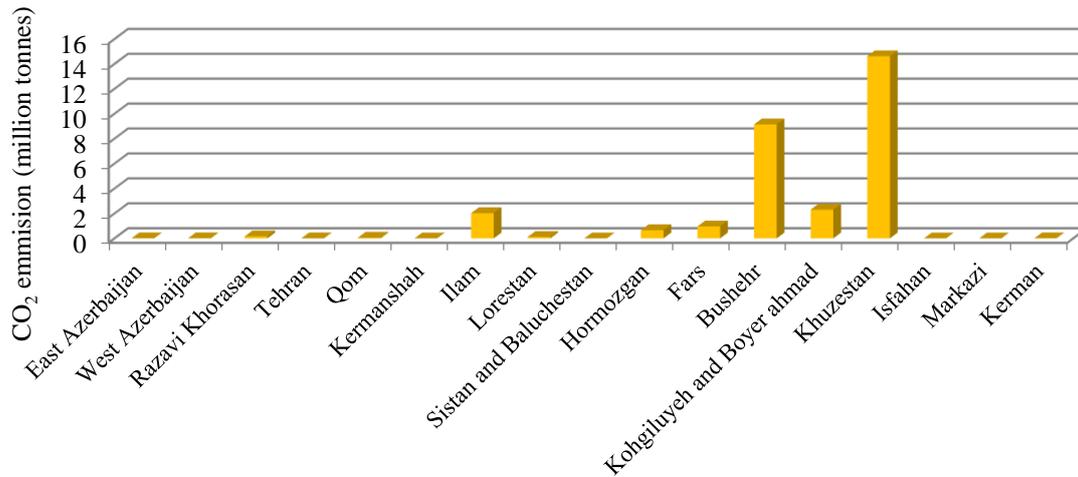


Fig. 15. The amount of CO₂ emissions due to the burning of associated and flare gases in each of Iran's provinces based on NOAA data in 2020

According to studies, about 8500 BTU of power is needed to produce each kilowatt hour of electricity [4], and therefore, according to the results, the potential of electricity generation in each of the provinces can be calculated, which is shown in Fig. 16. In total, the potential of electricity generation from associated and flare gases in 2020 was about 8182 MW. Figure 17 shows the distribution of power generation potential in Iran. Of this amount, 6621 megawatts are in the onshore sector and there is about 1561 MW of potential for electricity generation in the offshore sector. As can be seen, Khuzestan has a significant potential for electricity production with 3218 MW, and Bushehr provinces with

2013, Kohgiluyeh and Boyer Ahmad with 507, and Ilam with 446 MW are in the next ranks. In the following three years (2021, 2022 and 2023), the amount of flared gas in Iran increased from 13285.05 to 17285.12, 17220.78 and 20421.13 million cubic meters, respectively. This significant increase in total flare gas raised the lost capital to 1983.86, 1976.21 and 2343.48 million dollars, the total emission of CO₂ to 48.40, 48.22 and 57.18 million tons and the total potential of power generation of 10655.91, 10616.24 and 12589.19 MW, respectively. The summary of the changes of the estimated parameters is illustrated in Fig. 18.

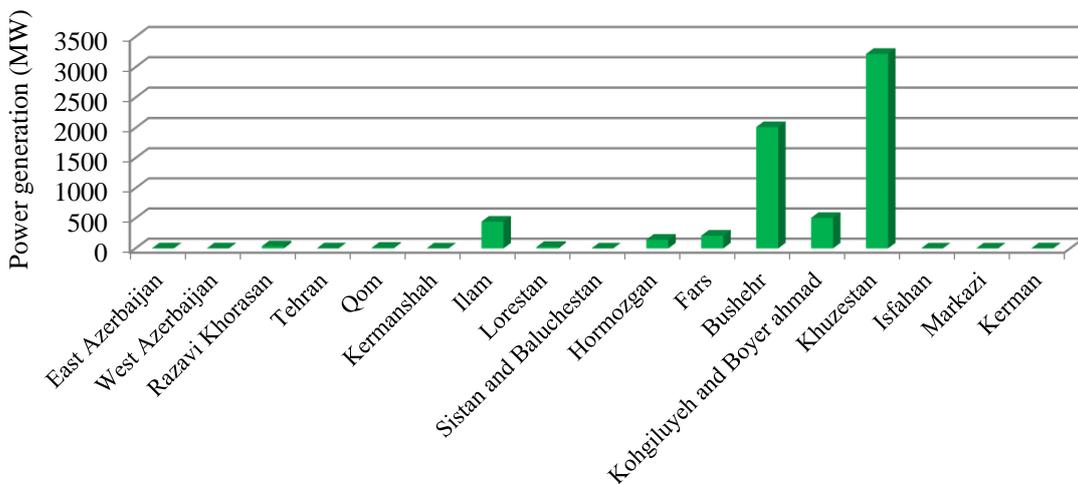


Fig. 16. The potential of electricity that can be produced in each of Iran's provinces based on NOAA data in 2020

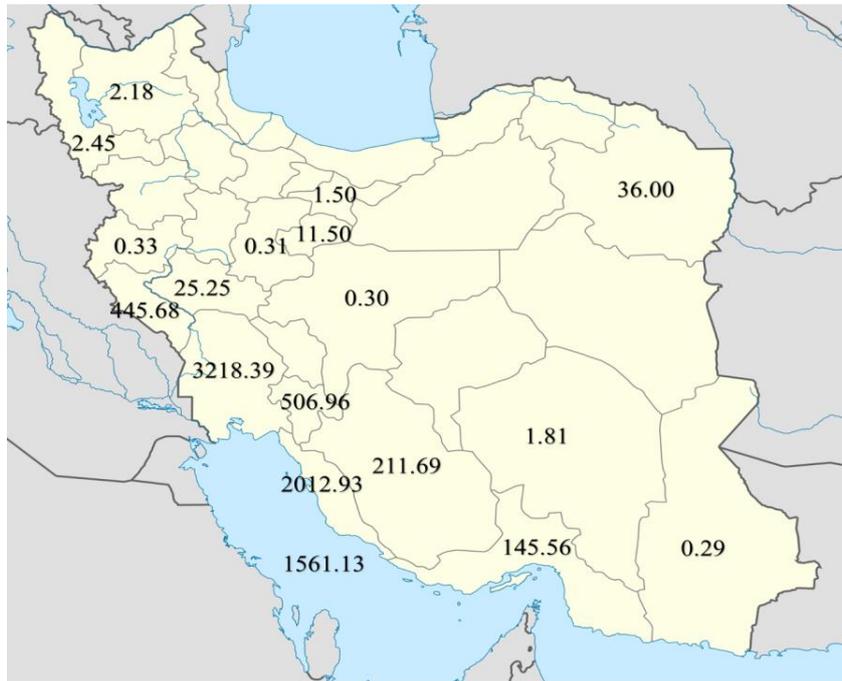


Fig. 17. Power generation potential in different provinces of Iran and the offshore sector in terms of MW

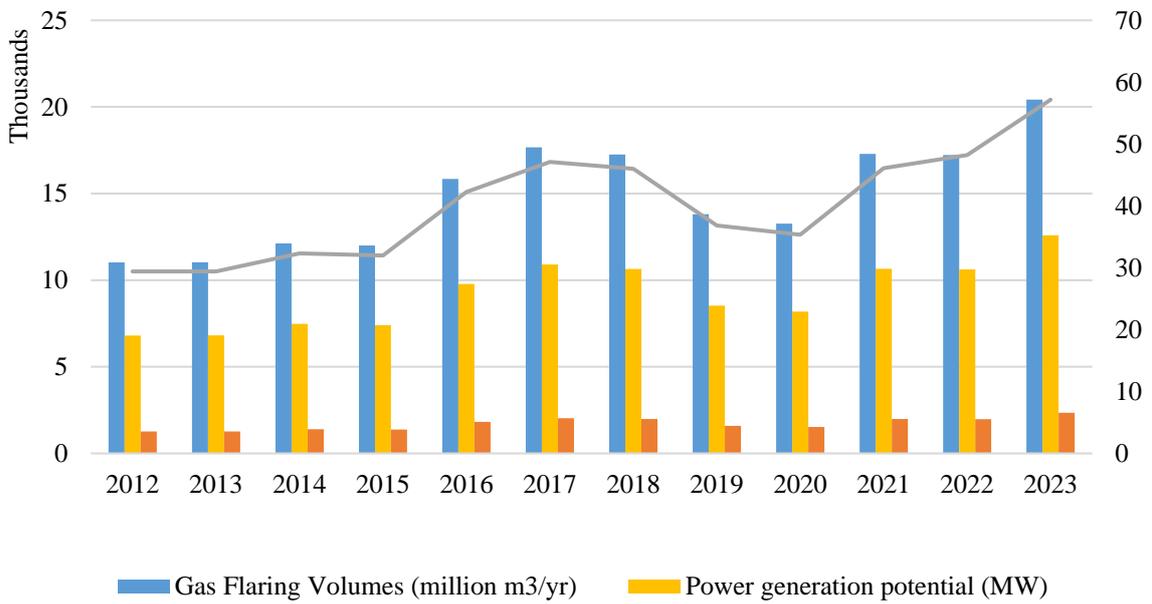


Fig. 18. The summary of the flare parameters for Iran during 2012-2023

6. Conclusion

Today, with the expansion of the oil and gas refining and petrochemical industry in Iran, compiling a comprehensive program and conducting research in line with it is necessary to reduce the problem of flare gases. Studies show that the generation of electricity using associated and flare gases, for local use, has acceptable justification and economic attractiveness.

Based on the results of this research, the total gas flaring in Iran, in 2023, is around 20421.13 million of cubic meters; the lost capital is around 2343.48 million dollars, the total equivalent emission of CO₂ is 57.18 million tons, and the total potential of power generation is 12589.19 MW. Moreover, the distribution of associated and flare gases in the provinces of Iran creates a suitable situation for creating dispersed generation power plants, especially in provinces such as Khuzestan, Bushehr, Kohgiluyeh and Boyer Ahmed, and Ilam. This method is applicable as the best option in smaller flares, because mostly these flares are not part of the recovery program of the Ministry of Oil, and also as an opportunity to develop and increase the scale of technology in the future, in dealing with larger flares. Such studies can help private sector managers and investors in identifying areas that have a high potential for electricity generation (using different technologies) and available opportunities for connecting to the grid or exporting.

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