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An assessment of Iran's natural gas potential for transition toward low-carbon economy

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ABSTRACT

To mitigate climate change, low-carbon economy is introduced as a sustainable development strategy. Natural gas, as an alternative to pollutant fuels such as coal, which is now widely used, could facilitate global transition to the age of renewable energy. Iran is one of the major emitters of CO_2 in the world, and it is thus, crucial to move toward low-carbon economy in order to accomplish its commitment in reducing GHG emissions. This study evaluates Iran's natural gas industry development by reviewing reserves, production and consumption, infrastructures as well as natural gas agreements. The total proven natural gas reserves of Iran is estimated 33500 bcm by the end of 2015, where more than 60% of them are offshore. There exists 23 active fields in Iran and the largest of which is South Pars gas reservoirs in the Persian Gulf. The gross production of natural gas was 257623 million cubic meters in 2015 of which 80% was marketed. The current state of Iran's natural gas industry is assessed as an acceptable level due to massive reserves, high production capacity, wide transmission and distribution network and high penetration of natural gas in cities and villages. That is why natural gas has the highest contribution in the national energy mix, resulting in replacing petroleum fuels with natural gas to decrease CO_2 emissions. However, in recent years, delays in implementing development projects of the natural gas industry made supplying domestic demand difficult during cold seasons. Furthermore, it negatively influenced the nation's gas export potential. Iran's natural gas industry faces some challenges including growing domestic demand, high energy loses in residential and commercial sectors and low efficiency of energy systems in industrial and power generation sectors. If challenges are solved, natural gas could serve as a bridge for transition toward the low-carbon future of Iran.

1. Introduction

Industrialization in a country has significant effects on production and labor patterns, urbanization, lifestyle and family structure. Social-economic development because of industrialization is linked to growth in primary energy supply. Therefore, exploitation of sustainable and reliable energy resources is essential to maintain the growing economy and social development.

According to statistical data from the International Energy Agency (IEA), the total primary energy supply of the world rose from 10,359 Million tons of oil equivalent (Mtoe) in 2002 to 13,699 Mtoe in 2014. The share of various energy sources in the world primary energy supply in 2014 was oil, 31.3%; coal (including peat and oil shale), 28.6%; natural gas, 21.2%; bio fuels, 10.3%; nuclear, 4.8%; hydro, 2.4% and other sources (including solar, wind, geothermal), 1.4% [1].

However, increase in global energy consumption is generally associated with enhanced social welfare. Nevertheless, countries still lack sustainable development. Destruction of vegetation, depletion of the ozone layer, melted glaciers and raised sea levels are consequences of global warming. Increasing social awareness about perilous consequences of climate change led to international treaties promoting reduction of greenhouse gas emissions. In order to respect countries' sovereignty in climate change agreements, selection of approaches to achieve GHG emission reduction targets are assigned to governments. This option led governments to different accomplishments in reducing GHG emissions, among them adopting various energy policies [2,3].

Since the early 90s, by the end of the Iran-Iraq war and beginning of the reconstruction of damaged areas and infrastructures, economic and industrial development efforts were accelerated. The growing energy demand resulting from development was obtained through increased exploitation of oil and gas fields.

In 1990, Iran's total final energy consumption was 402.2 Million barrels of oil equivalent (Mboe), which increased up to 687.8 Mboe in 2000, showing 71% energy growth within one decade [4]. The increasing social concerns about environmental degradation and emissions of hazardous pollutants resulting from consumption of oil

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products as energy carrier in power plants, industries, households and commercial sectors on the one hand, and discovery and utilization of South Pars gas-condensate field (the largest natural gas field in the world), on the other hand, convinced the Iranian government to accelerate implementing the oil products substitution policy with natural gas since early 2000 s. This political decision is included in sustainable energy development policies. As long as natural gas emits fewer greenhouse gasses, comparing other fossil fuels, substituting natural gas for coal and oil may be a more sustainable solution [5].

In Section 2, this research briefly studies Iran's energy policy (i.e. substituting natural gas for petroleum fuels). Then, it reviews the current state of Iran's gas industry development including reserves, production, consumption, infrastructures, as well as distribution networks and trade (Section 3). Carbon dioxide emissions in Iran and the role of power generation and reduction strategies are presented in Section 4. Finally, Section 5 presents the conclusion to our study.

2. Iran's energy transition toward low-carbon economy

Energy is a key factor in efforts for achieving sustainable development [6]. Global efforts in reducing greenhouse gas emissions and protecting the environment led governments to revise their energy policies and to consider deploying renewable and sustainable energies. Among sustainable energy development strategies, substituting fossil fuels with alternative renewable energy sources is of great significance [7]. However, there are many financial, technical, political, legal, social and environmental obstacles in the way of developing renewable energy [8]. According to the BP Energy Outlook report, it is predicted that by 2035, fossil fuels still provide the majority of the world's energy demand; though, it predicts reduction in oil and coal consumption. Generally, in the next twenty years, the energy mix shifts toward low-carbon fuels due to increased ratio of renewables and natural gas. It is expected that approximately one-third of increased energy demand be met by oil and coal, one-third by natural gas, and the remaining one-third by non-fossil fuels [9].

Given the obstacles to renewables development, transition from the fossil fuels age to renewable energies signals a long path ahead. The question raised here is what shall be done to energy supply in the transition age. Natural gas, as the cleanest fuel among all known fossil fuels so far, is assigned a unique place for supplying major global energy demands in the upcoming decades. It is considered a bridge for transition from fossil fuels to renewable energy. Economic, technical, and environmental advantages of natural gas comparing to other fuels led to its emphasized significance as a critical energy source. World natural gas consumption in 1984 and 2014 was 1588.5 Billion cubic meters (bcm) and 3393 bcm, respectively, indicating that world consumption has almost doubled over the past two decades [10].

Energy transition in a country is referred to a phase in which one energy carrier that is dominant in one period gradually decreases its share in the national energy mix due to development of a new energy source and finally is replaced by the new energy source [11–14]. Transition occurred because of the shift toward energy sources that are technically, economically and socially more efficient and high quality. Energy density, efficiency and conversion cost, GHG emissions, storage, financial risks, transportation convenience and human health risks are the determinant indicators of energy carrier desirability [13,15]. The socio-psychological factors may have a considerable effect on the acceptance of an energy source during energy transition in a country [16–18]. Gralla et al. (2017) examined energy transition in countries using nuclear energy. They investigated the development indicators including socio-economic, technological and environmental factors to determine that whether nuclear energy is a technological answer to global challenges like climate change [19].

Natural gas plays a critical role in Iran's energy transition toward low-carbon economy due to petroleum and petroleum products replacement policy with natural gas, which started two decades ago.

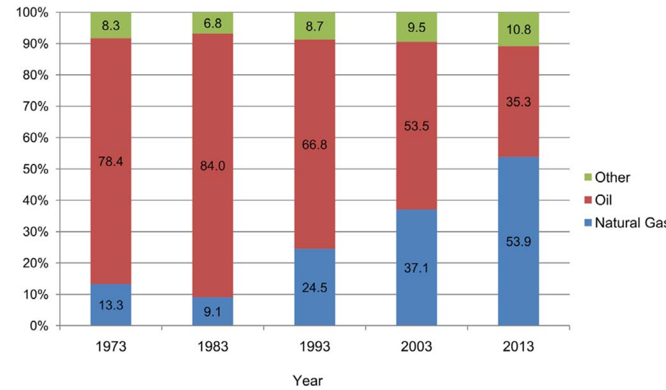

Fig. 1. Percentages of oil and natural gas in Iran's total final energy consumption. (source of data: [4,23]).

Considering economic, environmental and technical advantages such as massive gas reserves in Iranian territory, fewer CO_2 emissions and air pollution, higher efficiency of power generation technologies from natural gas, added revenues through exporting petroleum products compared to domestic usage has resulted in the preference of natural gas for domestic consumption over other primary energy sources.

Understanding the national energy transition requires analyzing energy consumption's long-term data [11]. The percentages of oil and natural gas in total final energy consumption (TFEC) for Iran from 1973 to 2013 are illustrated in Fig. 1. The share of natural gas has been constantly increasing since beginning of the 90s up to the present. In 2013, natural gas, constituting over 50% of national energy mix, turned into the main energy carrier demonstrating the Iranian government's achievement in implementing sustainable energy development policies.

3. Development of the natural gas industry

Since 1908 when the first oil well was discovered in the city of Masjed Soleyman, large volumes of associated gas was flared and lost due to the long distance between production and consumption sites as well as high investment costs and low natural gas consumption that was limited to southern areas of Iran. However, subsequent to increase in the number of exploited oil wells, utilizing natural gas was considered for supplying organizational households' energy demand in areas such as Masjed Soleyman, Aghajari and Abadan. Therefore, besides the main operations of production, transportation and refining of petroleum in southern areas, limited activities were performed for supplying and processing natural gas by agent firms.

A first, in Iran, only extracted petroleum was used; however, large volumes of associated gas were also produced. The produced gas was mainly flared from 1910 to 1960s. In early 1960s, the extracted gas was exported to the Soviet Union in exchange for constructing a steel manufacturing plant contract in Iran. At the same time, associated petroleum gas was commercialized for the first time, through transfer to the cement factory in Shiraz. Then, gas delivery to other cities gradually started. National Iranian Oil Company (NIOC) was responsible for the natural gas industry until independent gas fields were discovered. By discovering independent gas fields like Kangan and Pars, it was essential to establish a firm with differentiated responsibilities from NIOC. National Iranian Gas Company (NIGC) was founded in March 1966. Now, NIGC is one of the four large subsidiary companies of Iran's Ministry of Petroleum [21]. The President of Iran is the president of the General Assembly and the responsible Minister chairs the board.

Substituting natural gas for oil products requires development of the gas industry and its associated infrastructures. Therefore, as the share of domestic natural gas consumption increases and according to the national development outlook, the natural gas industry has always benefited from relevant growth in production, processing and dehy-

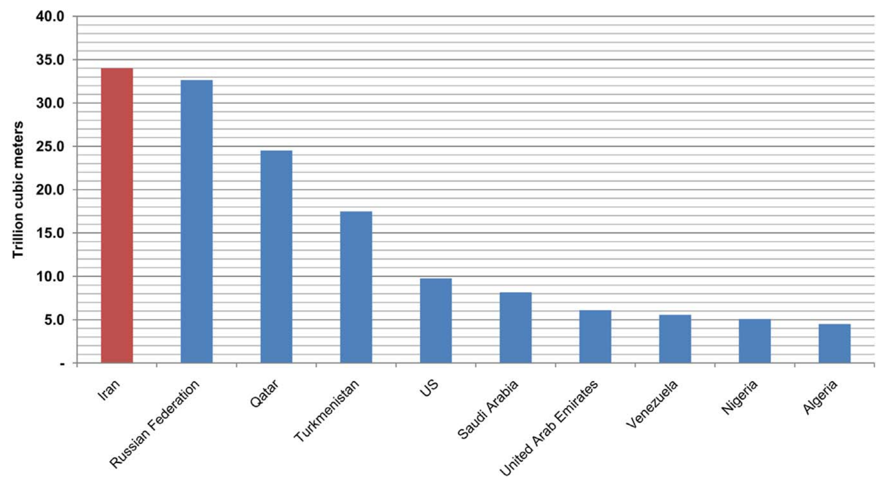

Fig. 2. The largest natural gas proven reserve holders in 2014.
(source of data: [10]).

dration sectors. Regarding development plans, it is expected that this trend will continue. NIGC, with over 50 years of experience is now in charge of supplying over 65% of the nation's fuel demand [21]. In this regard, NIGC has an important place at the national and international levels. This section examines the status of the Iranian gas industry including reserves, production, consumption and trade.

3.1. Iran's natural gas reserves

Iran has the world's second-largest proven reserves of natural gas after Russia. However, according to BP (British Petroleum) statistical reviews published in 2016, Iran was introduced as the largest holder of natural gas reserves in the world. This report estimated Iran and Russia's share of the total natural gas proved reserves of the world 18.2% and 17.3%, respectively (Fig. 2) [10]. The different estimation of Russia's natural gas reserves is the reason behind the contradiction in ranking. Based on OPEC reports, Russia's proved reserves are 49541 bcm, which had reduced to 32300 bcm in the BP report [10,22].

Iran's natural gas proved reserves is estimated 33500 bcm by the end of 2015 [22], where 61% are offshore and 39% are onshore [23]. Developing gas fields and increasing natural gas production are more prioritized than discovering new reservoirs in Iran, as most NG reserves are not developed in Iran.

3.1.1. South Pars gas-condensate field

There were 23 active (offshore and onshore) gas fields in Iran by 2014, the largest of which is South Pars, which is a non-associated gas reservoir in the Persian Gulf (Fig. 3). South Pars is some part of a larger gas deposit located in Iran and Qatar territorial waters. The deposit that is the world's largest natural gas reservoirs covers an area of 9700 km^2 such that 3700 km^2 is located in Iranian border and 6000 km^2 is on the Qatar side [24,25]. It is called North Field in Qatar. Iran's share of this gas field contains around 14 trillion cubic meters of natural gas and 18 billion barrels of gas condensate in place that is approximately 40% of Iran's total NG reserves [24]. This gas field located 100 km off the coast of Iran was discovered by National Iranian Oil Company (NIOC) in 1990. Developing South Pars gas field commenced from 1998 to meet increasing domestic demand of natural gas, injection of oil fields, LNG production as well as utilizing condensates as feedstock of petrochemical units and natural gas export. The development of South Pars was planned in 24 phases. In late 2002, the Iranian section of the field was exploited by daily production of 28 Million cubic meters (mcm) of natural gas from Phase 2 [24]. South Pars gas field development is of high importance to Iran's government because it is shared by Iran and Qatar; as a result, both parties compete for intensive exploitation of the underlying hydrocarbon resources.

Fig. 3. Geographical location of natural gas fields in south of Iran.

South Pars gas field is Iran's most significant energy development project over the last decade, where it has been invested up to 60 billion dollars [26]. The 24-phase development plan of this gas field is managed by Pars Oil and Gas Company (POGC is a subsidiary of NIOC). Each phase holds a natural gas production program with gas condensate and/or NGPL (Natural Gas Plant Liquids). According to the South Pars development plan, production from phases 1–10 is dedicated to domestic consumption and reinjection of oil wells. The produced natural gas from Phase 11 to Phase 24 is planned to be exported through pipelines and/or as liquefied natural gas (LNG) and/or it is applied for gas-to-liquids (GTL) projects.

At present, phases 1–10 and Phase 12 are fully implemented and phases 15–18 are progressing through their final steps. In the case of implementing all 24 phases, national production of South Pars gas field approaches 850 Million cubic meters per day (mcm/d) of natural gas and approximately one Million barrels of condensate per day (bbl/d) [28].

3.1.2. Kish gas field

It is Iran's second largest non-associated gas reserve located under Kish Island 60 km away from east of Lavan Island in the Persian Gulf. This gas field was discovered in 2006 by the NIOC. The development project of Kish gas field was planned in three phases and the implementation was granted to Petroleum Engineering and

Development Company (PEDEC), which is a subsidiary of NIOC.

Kish as the world's fifth largest offshore gas field will produce 28 mcm of natural gas and 11300 barrels of condensates per day in its first development phase. It is expected that completing the field's remaining phases may increase sour gas production capacity up to 85 mcm. The produced sour gas will be transferred daily to the processing unit in order to produce 76 mcm sweet gas and 45000 bbl condensate [27]. Natural gas would be injected to Iran's seventh gas trunk line (IGAT-7) and gas condensates are also transported to a Single Buoy Mooring (SBM) in the Persian Gulf for export. It is estimated that Kish gas field contains 1869 bcm of natural gas and 514 Million barrels of condensate in place [28].

3.1.3. North Pars gas field

Discovered in 1967, North Pars gas field is considered as one of Iran's largest independent gas fields. It is situated 120 km southeast of Bushehr, 10–15 km away from the coast. The estimated reserve is about 1.7 Trillion cubic meters (Tcm) in which the recoverable sour gas volume is almost 1.3 Tcm [24].

The significance of production from South Pars field resulted in pending of the field's development and production plan. The current development plan of North Pars gas field consists of four phases, which ultimately leads to 100 mcm/d. The total recovered sour gas is used for supplying LNG plants in producing 20 Mtpa/year.

3.1.4. Golshan and Ferdowsi gas fields

Golshan is an offshore gas field located 180 km off Bushehr and 65 km from the Persian Gulf coast. It was planned to produce 56 mcm/day gas for the feedstock of two operational units in an LNG production project [24].

Ferdowsi gas field is around 30 km west of Golshan gas field in the Persian Gulf. The development objectives of Ferdowsi gas field are production of 14 mcm/day for domestic consumption and supply of power plant fuel [24].

3.1.5. Kangan and Nar gas fields

Kangan gas field, which is one of the largest gas fields in the Middle East, is positioned 160 km southeast of Bushehr near Kangan City. Kangan gas field was discovered in 1972 followed by drilling up to 48 wells, 44 of which are currently producing. The field's gas and condensate daily production potential is 58 mcm and 18000 barrels, respectively [29].

Nar gas field is located near Kangan field near Jam city in Bushehr province. Thirty-two wells were drilled in this field, 29 of which are production wells. Natural gas and condensate daily production is 32 mcm and 4400 barrels, respectively [29]. The production capacity of some of the largest gas fields is provided in Table 1.

Nar and Kangan, Aghar and Dalan as well as Sarkhun and South Gashu fields are regarded as important gas fields of South Zagros Oil and Gas Production Co. (SZOGPC). This company could meet almost 50% of the nation's total natural gas demand through nine operational gas fields [28,29].

Table 1
Production capacity of some Iranian gas fields in the final operational phase (estimated).

Gas field	Production capacity (in the final phase)	
	Gas (mcm/day)	Condensate (1000 bbl/day)
South Pars	850	1000
North Pars	100	n/a
Kish	76	45
Golshan	56	n/a
Ferdowsi	14	n/a
Kangan	58	18
Nar	32	4.4

Tabnak, Gavarzin, Khangiran, Homa and Shanul are among other critical natural gas fields in Iran. Sardar Jangal (offshore in the Caspian Sea), Forouz B (offshore in the Persian Gulf) and Khayam (onshore) are newly discovered gas fields [30].

3.2. Iran's natural gas production

Iran, holding 5% share of global production, is ranked the third largest natural gas producer in the world following the USA, and Russia [10]. Iran's natural gas gross production was 257623 Million cubic meters (mcm) in 2015, with a 5.3% increase comparing to its previous year [22]. Most of the produced gas (80%) was marketed, 7% vented and flared and the remaining was reinjected for enhanced oil recovery [30]. Average rich gas production within March 2014 to March 2015 was 681.8 Million cubic meters, of which 350.3 mcm and 331.5 mcm were produced by onshore and offshore fields, respectively. Almost 84.3% of the total national rich gas production is assigned to independent gas fields, which is annually increasing [20]. A considerable part of Iran's gross production gas is flared [30]. Gas flaring mainly occurs in southern oil fields such that the environment often suffers from air pollution. The proper solution to this problem is to create necessary infrastructures for collecting and processing of the associated gas so that it may be used for combined heat and power (CHP) units.

After the USA and Russia, the third place of the world's largest dry natural gas producer is attributed to Iran. In recent years, more than 80% of Iran's marketed gas consists of dry natural gas. The annual production of dry natural gas, in the last five years, has grown up to 19.4% [10]. Iran's natural gas production is mainly devoted to meeting domestic demand. Final consumption of natural gas in 2010 and 2014 was 88.8 and 110.6 bcm, indicating a 24.5% increase even larger than dry NG production growth in this time span [20]. Iran, following the USA, Russia and China, is the fourth largest natural gas consumer around the world. However, Iran's reserve to production ratio (R/P), given continued production rate of 2014, is predicted over 100 years [10].

Gas and water injection into oil reservoirs is regarded as enhanced oil recovery (EOR) technique [31]. Iran's Ministry of Petroleum prioritized improving recovery of oil wells. Though, during the year, sweet and sour gases are both injected to oil reservoirs, the major injected gas is sour gas. In cold months, gas injection into oil reservoirs is reduced to meet high natural gas demand; whereas, in warm months, reduced household and commercial NG consumption provides gas reinjection. Water and gas injection in 2013 showed 5.5% increase and 3.6% decrease, respectively compared to the earlier year [23].

3.3. Natural gas consumption in Iran

Iran, with a total population of 79.9 million people [32], is known as the second largest economy in the Middle East and North Africa with Gross Domestic Product (GDP) of 406.3 billion USD in 2014 [33]. Considering Iran is a developing country; therefore, its energy demand is constantly increasing. Total primary energy supply in 2005 and 2014 was 165.9 and 246 Mtoe, respectively, demonstrating an annual growth of 4.8% [20,34]. Iran's primary energy sources consist of petroleum, natural gas, coal, nuclear, hydropower and other non-hydro renewables. Fig. 4 illustrates the share of various sources in Iran's total primary energy supply in 2013. Natural gas has the largest share in the domestic energy basket. Table 2 represents the typical natural gas composition in Iran [35]. The share of natural gas in total final consumption has been doubled over the last two decades. According to statistical data by the Iranian Ministry of Energy, during 1993–2013, the percentage of natural gas in total final consumption increased from 24.5% to 53.9%; whereas, the share of oil decreased from 66.8% to 35.3% [4,23]. The current state results from the substitution policy of conventional energy carriers for natural gas

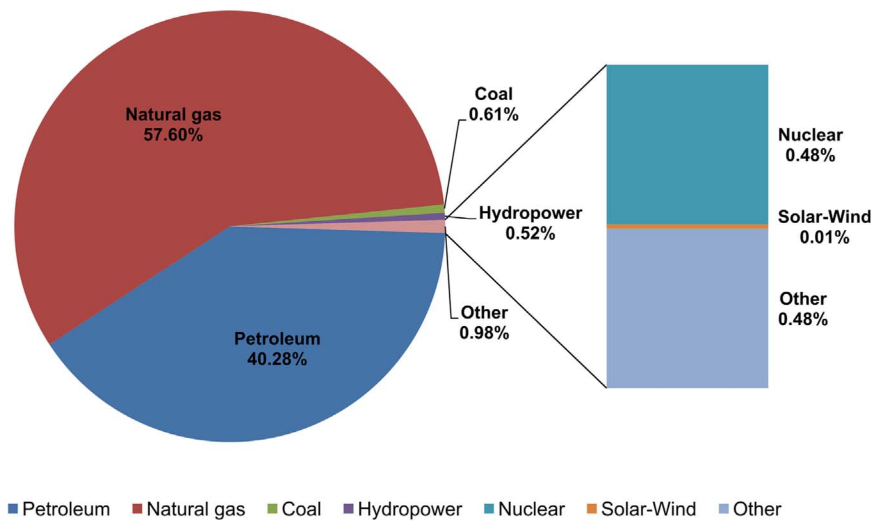

Fig. 4. Share of various sources in Iran's primary energy supply, 2013.
(source of data: [23]).

practiced in the last two decades by the Iranian government. To compare the current status of Iran's natural gas industry with other countries, the natural gas data for some countries is given in Table 3.

Reducing emissions of greenhouse gases, low price, proper replacement capability with oil products, and existence of the world's largest gas field in the Persian Gulf and Iran's fame as the first holder of natural gas reserves are of the factors convincing policy makers to select natural gas as the transition fuel toward low carbon economy. In this regard, NIGC, in charge of treatment, transmission and delivery of natural gas to power plants and domestic industrial, residential and commercial sectors, initiated developing natural gas transfer pipelines and extending distribution networks throughout the country. Iran's high pressure natural gas pipelines in 2003 was 17583 km, in terms of length, which increased up to 36248.5 km by the end of 2014, suggesting that NIGC, by average, annually built 1697 km of gas transmission pipelines [4,20].

At present, there exists 12 natural gas processing units in Bushehr, Khuzestan, Hormozgan, Khorasan Razavi, Fars, Ilam and Qom provinces. The total capacity of Iran's natural gas processing units was 579.2 mcm/day in 2014 [20]. In order to convert natural gas into the first domestic energy source, it is substantially necessary to expand Iran's natural gas distribution network. The installation of natural gas distribution pipelines started in large cities in the early 90s. However, the exploitation of South Pars gas field accelerated the NG distribution network development. It is expected that the gas delivery program to all national provinces will be completed in early 2017 by linking Sistan and Baluchestan province to the national gas network. Fig. 5 shows the total length of Iran's natural gas distribution network pipelines.

Now, 96% of the urban population and 61% of the rural population of Iran have access to natural gas [21], indicating that natural gas is effectively substituted for other fuel and petroleum products; this finding is consistent with Iran's energy policies. Total natural gas consumption in Iran in 2014 was 183.7 bcm, which is classified into four categories of total final consumption including non-energy use, own use of the energy industry, export and storage [20]. Fig. 6 represents NG demands of different sectors in 2014. Total natural gas consumption of the household and commercial sectors was 51.9 bcm in this year [20], revealing 1.4% growth compared to the previous year. Commercial and household sector has the highest share of NG consumption among energy end-use sectors.

Pollutants emitted from transportation are known as the main source of air pollution in Iran's metropolitan areas [36]. Replacing gasoline and diesel with a cleaner fuel is a strategy for environmental protection. Of alternative fuels, natural gas due to its distinctive features is the desired option properly satisfying these requirements [38]. Using CNG (compressed natural gas) as transport fuel in Iran was initiated in 1975 through the conversion project of 1200 taxies and vehicles in Shiraz city [39]. In 2001, the Iranian Fuel Conversion Organization (IFCO) established in the Ministry of Petroleum focused on developing CNG and creating necessary infrastructures. In the last decade, natural gas consumption in the transportation sector has increased up to twenty times due to fewer pollutants, government subsidies and lower price of CNG compared to other fuels as well as an extensive distribution network. In 2013, there existed 3.1 million NG-powered vehicles and 2227 CNG filling stations in Iran [23]. In the same year, CNG consumption was 6.7 bcm, which reduced to 3.4% compared to the previous year [23]. This reduction in CNG consumption was attributed to increasing CNG prices.

Low cost of natural gas, easy access in areas connected to the national NG network as well as lower emissions of GHG led to increasing demands for this energy carrier in the industry. Within 2009–2014, natural gas consumption has grown up to 61.1% in the industrial sector [20]. In 2014, 11.8 bcm of natural gas was consumed as petrochemical feedstock and for producing sulfur, which is considered a non-energy consumption. Energy industry own use including power plants, oil refineries, and NG processing units in addition to compressor stations constituted 33.7% of Iran's total consumption of natural gas [20].

Data of provincial demand is provided in Table 4. From March 2013 to March 2014, the highest consumption was attributed to Tehran province (including Alborz) with 20459 Million cubic meters (mcm) of natural gas. Khuzestan, Isfahan and, Bushehr are ranked next by 14357.5, 14003 and 11643 mcm, respectively. High population, energy intensive industries such as steel, cement as well as refineries and

Table 2
Typical composition of Iran's natural gas [35].

Compound	Methane	Ethane	Propane	Butane	Pentane	Carbon Dioxide	Nitrogen
Volume (%)	88.1	4.2	1.36	0.3	0.06	0.78	5.2

Table 3
Natural gas statistical data for some countries at end 2015.
(source of data: [10,62]).

Country	Proved reserves (bcm)	Production (bcm)	Consumption (bcm)	Population (thousand)	Per capita NG consumption (cm)
Iran	34000	192.5	191.2	79,109	2416.9
USA	10400	767.3	778	321,419	2420.5
Canada	2000	163.5	102.5	35,852	2859.0
Russia	32300	573.3	391.5	144,097	2716.9
Qatar	24500	181.4	45.2	2235	20223.7
Saudi Arabia	8300	106.4	106.4	31,540	3373.5
Turkmenistan	17500	72.4	34.3	5373	6383.8
China	3800	138	197.3	1,371,220	143.9

power plants in these provinces resulted in higher gas consumption. The least NG demand referred to Ilam province by 336 mcm; whereas, Sistan and Baluchestan is the only province that is not yet connected to the national gas transmission network. Gas delivery project to the cities of this province started from 2015 by completing Iran's seventh gas trunk line (IGAT-7).

The socio-economic effects of gas supply to Sistan and Baluchistan Province is explained as a case study to examine the economic benefits of extending the gas distribution network in Iran. The gas supply project to this province approved to receive US $ 1800 million is economically justified, so that by considering the economic savings resulting from the replacement of petroleum products and the payments for supplying liquid fuels for household, commercial, transportation, power plants and industrial sectors in Sistan and Baluchistan Province, the payback period of the gas supply project to the province is 3 years [40]. Despite the high economic potential of Sistan and Baluchistan Province, weak infrastructures and lack of access to cheap energy resources have put this province among the disadvantaged provinces; for instance, many industrial units of the province which provide their required energy with high costs will have access to a cheap and efficient energy carrier (natural gas) and this accessibility will lead to economic prosperity and employment growth in the province. Gas delivery to villages in Sistan and Baluchistan, in addition to the development of social justice, will lead to poverty alleviation and migration reduction to the cities. By using cleaner and more efficient fuels, it is easier to continue living and working in rural areas. In general, economic prosperity, industrial development, promoting social justice, and increasing public welfare, and the security of the country are of the favorable impacts of the establishment of national gas network.

The reason why Sistan and Baluchestan province is connected to the national gas network with so much delay was the ambiguity in the execution of Iran's NG export contract to Pakistan and India. According to this contract, Iran's natural gas from South Pars field is transferred to Pakistan and India by the IPI (Peace) pipeline proposed in 1993 [41]. Due to geopolitical tensions between Pakistan and India, the implementation of the peace pipeline project has been completely stopped. India's withdrawal from this gas project in 2009 caused that alternative plans have been proposed to export Iranian gas to these two countries. The Indian government has proposed that Iranian gas pipeline to be connected to this country through Oman by a sub-sea pipeline. In the Pakistan government's plan, first, Iran's natural gas will be converted to the LNG and then it is exported to this country using the LNG terminal of Oman. Negotiations for alternative projects are in progress.

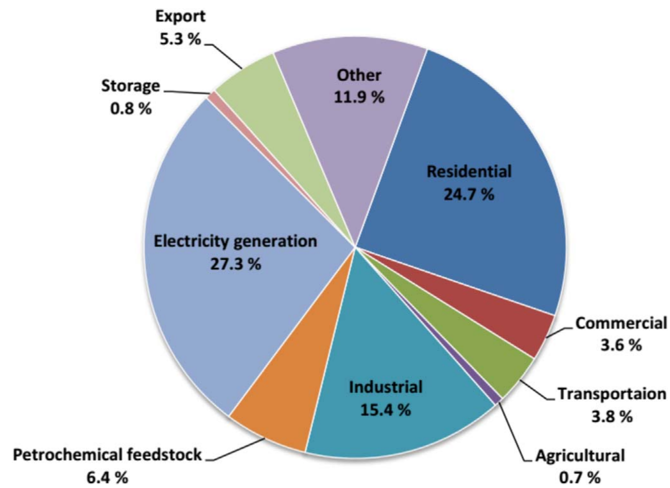

Fig. 6. Iran's natural gas consumption by sector in 2014.
(source of data: [20]).

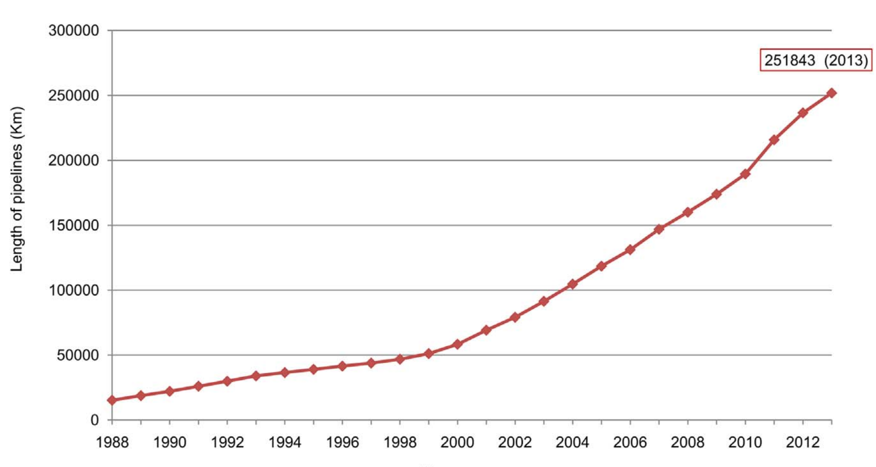

Fig. 5. Total length of pipelines for NG distribution network of Iran, 1988–2013.
(source of data: [37]).

Table 4
Provincial demand of natural gas in 2013 in Iran.
(source of data: [23]).

Province	Residential	Commercial	Industrial	Transportation	Agricultural	Other	Petrochemical feedstock	Energy industry own use	Total (million cubic meters)
East Azerbaijan	2885	458	1209	520	66	154.4	0	351.3	5643.7
West Azerbaijan	1910	261	441	406	6	3.7	0	780.9	3808.7
Ardabil	811	123	179	160	19	0	0	471.8	1763.8
Isfahan	3964	465	6066	449	94	26.2	0	2939	14002.9
Ilam	152	25	124	31	1	0	0	2.7	336
Bushehr	45	12	247	58	0	3238.3	5939.7	2103.4	11643.4
Tehran & Alborz	12350	2035	2748	1004	123	0	0	5136	20459
Ch. Bakhtiari	638	81	169	77	12	0	0	0	977
South Khorasan	226	42	134	32	1	0	0	665.1	1100.1
Razavi Khorasan	3781	618	1967	612	34	0	0	2697.5	9709.5
North Khorasan	455	63	403	87	5	249.3	235.1	852.9	2350.2
Khuzestan	757	97	2202	332	11	3980.2	3927.9	3050.3	14357.5
Zanjan	656	107	347	123	21	0	0	318.1	1572.1
Semnan	433	76	710	110	15	0	0	399.5	1743.5
Sistan & Baluchestan	1	1	0	0	0	0	0	0	2
Fars	1717	254	967	412	24	476	344.1	4242.1	8436.1
Qazvin	828	123	1056	182	18	0	0	978.8	3185.8
Qom	704	97	352	162	14	0	0	609.3	1938.3
Kurdistan	1029	136	117	146	24	0	0	779.6	2231.6
Keman	844	134	749	137	8	0	0	1660.1	3532.5
Kermanshah	1003	125	435	187	4	283	273.9	818.4	3129.3
K. B. Ahmad	271	43	55	73	7	0	0	0	449
Golestan	1014	102	305	203	86	0	0	646.4	2356.4
Gilan	1671	180	358	256	85	0	0	1896.6	4446.6
Lorestan	834	103	219	106	5	0	0	18.4	1285.4
Mazandaran	2763	260	569	367	200	0	0	793.7	4952.7
Markazi	990	130	1019	146	38	364.3	4.8	1647.5	4339.6
Hormozgan	2	0	1038	54	0	0	0	1827.7	2921.7
Hamedan	1400	223	549	137	16	0	0	97.1	2422.1
Yazd	588	97	2019	96	113	0	0	1024.8	3907.8
Total (million cubic meters)	**44692**	**6471**	**26753.5**	**6665**	**1050**	**8775.4**	**10725.3**	**47713.4**	**152845.6**

Although, natural gas has significant environmental and economic benefits compared with petroleum products, in the some countries, the development of gas distribution network has been stopped. Improving consumers' safety and reducing the transmission cost of natural gas are of reasons for this action. The extension of distribution network increases the probability of service interruptions like pipeline explosion. Electricity generation using natural gas in thermal power plants is alternative solution for gas network extension. Generating electrical energy outside the residential areas leads to reduce environmental pollution by direct use of natural gas. Also, the electrical power grid during natural disasters like earthquake is more reliable in comparison with the gas network.

3.4. Iran's natural gas agreements

Natural gas depends on pipeline transportation systems, which comes from physical characteristics of this energy carrier. This dependency led to creating regional markets for natural gas, unlike oil, which has global markets [42]. North America, Europe, East Asia and the Middle East are major regional markets. During 1980–2013, natural gas consumption in the Middle East increased from 37 bcm up to 427 bcm. In other words, the increase in NG consumption is more than 11 times, which is the highest growth rate around the world [43].

Despite the advantages such as high volume of recoverable NG reserves, high production capacity and extensive gas transmission network, proximity to regional markets, strategic geographical location enabling gas transition and swap to Europe and the Persian Gulf countries, Iran still has a low contribution in global natural gas markets. Iran was a net gas importer prior to 2012 (Fig. 7). At present, the share of Iran in global natural gas trade is less than one percent. Due to financial, political and technical constraints of natural gas export projects, it appears that the export of electricity instead of natural gas can be more efficient. Iran has now electricity trade with Iraq, Pakistan, Afghanistan, Turkmenistan, Azerbaijan, Armenia and Turkey. The export of electricity instead of natural gas can be used as an alternative solution to the Iran-Pakistan pipeline. Despite the connection of Iranian electricity grid to neighboring countries, converting natural gas to electricity for export is uneconomic, since the average efficiency of thermal power plants in Iran is 36.3% [20].

Currently, Iran exports natural gas to Turkey, Armenia, Azerbaijan and imports gas from Turkmenistan (Fig. 8). Iran has initiated negotiations with several countries and signed agreements with neighboring countries like Iraq, Oman and Pakistan for NG export via pipelines.

3.4.1. Iran-Turkey NG pipeline

In 1996, Iran signed its first NG export contract during Turkey's former Prime Minister Necmettin Erbakan's visit to Tehran. By this contract, Iran's natural gas export is initiated for 25 years, through a pipeline with a diameter of 40 in. (1.016 m) and 1600 miles (2575 km) length from Tabriz to Ankara. Maximum discharge rate by this pipeline is 14 bcm per year; however, both countries agreed upon annual export of about 10 bcm [45].

It was expected that supplying Turkey's gas through this pipeline would be initiated in late 1999; though, economic downturn in Turkey, Iranian delays in completion of measurement stations and US sanctions led to a delayed inauguration in 2002 [44,45]. Iran is the second largest supplier of Turkey's natural gas after Russia. Iran's share in Turkey's gas market is 16% [46].

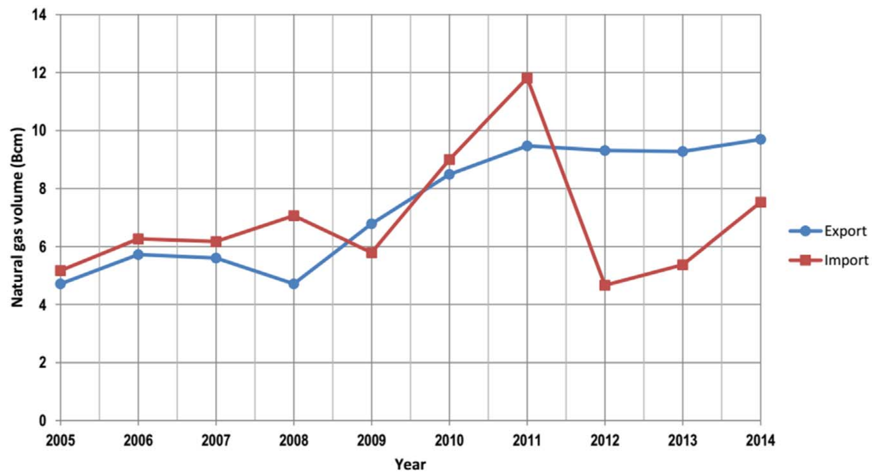

Fig. 7. Iran's natural gas import and export, 2005–2014.
(source of data: [20]).

3.4.2. Iran-Turkmenistan NG pipelines

In 1997, Iran began importing gas from Turkmenistan by inaugurating a 200-Km pipeline transferring natural gas from Korphezhe in Turkmenistan to Kurdkui in Iran. The capacity of this pipeline is around 8 bcm/year [47]. The main objective of signing this contract is to supply the natural gas demands for Northern and Northeastern cities in Iran from Turkmenistan. However, in later years, development and exploitation of South Pars gas field enabled Iran to supply natural gas for northeast regions; due to long distances, mountainous topography as well as high cost of pipelines, gas transfer from south to north of Iran is uneconomical.

The Korphezhe-Kurdkui pipeline is significant to Turkmenistan state as it led this country to export some of its domestic gas, for the first time, independent of Russia's passing pipelines [48]. Iran and Turkmenistan inaugurated the Dauletabad-Sarakhs-Khangiran gas pipeline, in 2010, a pipeline system 120 km in length and 48 in. (1.219 m) in diameter. The daily capacity of this pipeline is 20 mcm in the first phase [28]. Iran is able to import NG from Turkmenistan exceeding its demands. This extra capacity may be used to transit and swap Turkmenistan and other Central Asian countries' gas.

3.4.3. Iran-Azerbaijan NG pipelines

Azerbaijan's natural gas swap contract was signed in 2004. According to the contract, it was agreed that Iran, for 25 years, ships natural gas to the Nakhchivan Autonomous Republic through Salmas pipeline in exchange of Azerbaijan's gas delivered by the Baku- Astara pipeline. Nakhchivan is a landlocked exclave of the Republic of Azerbaijan. Due to some tensions with Armenia, it is impossible to connect Nakhchivan to Azerbaijan's pipeline network. Nakhchivan absolutely relies upon the natural gas imported from Iran.

The volume of swapped gas per day varies from 0.5 to 2.0 mcm. The transit cost received by Iran is 15% [49]. According to National Iranian Gas Export Co. (NIGEC) report, the largest volume of swapped gas by Iran is 347 mcm in 2012. Iran swapped almost 1.752 bcm of natural gas from Azerbaijan to Nakhchivan during 2005–2013 [28].

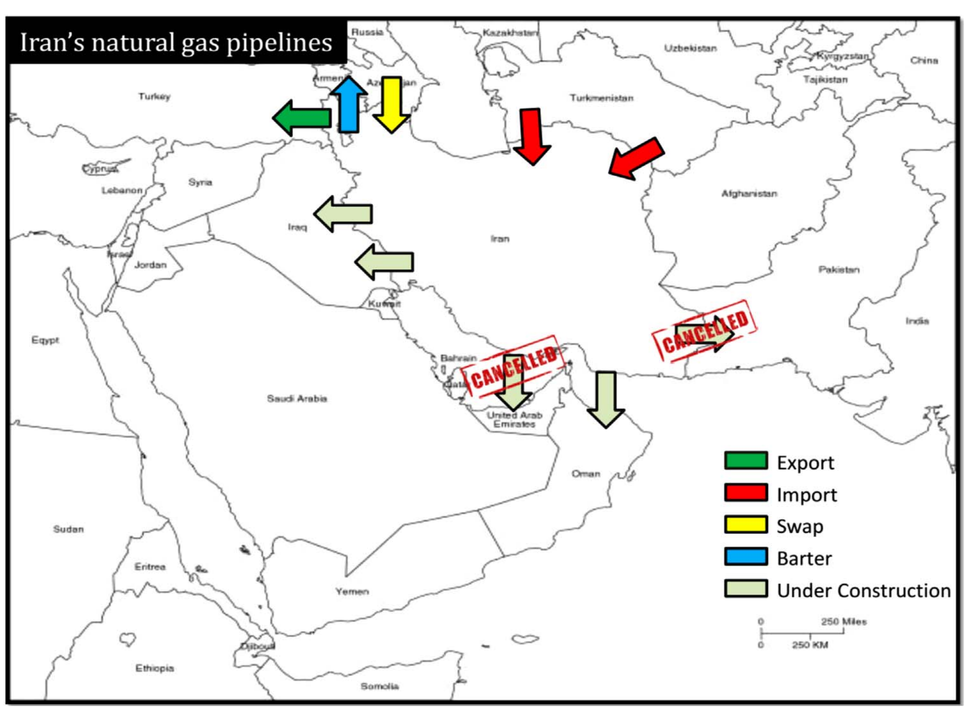

Fig. 8. Iran's natural gas trade (pipelines).

3.4.4. Iran-Armenia NG pipeline

In order to diversify Armenia's gas suppliers, this country contracted with Iran in 2004. They agreed to construct a 140 km pipeline transferring Iran's natural gas to Armenia [28]. The pipeline was inaugurated in 2007. It has the capacity of 1.1 bcm/year. The contract period is 20 years by which Armenia delivers around 3 KWh of electricity to Iran per each cubic meter of exported gas [26].

4. CO_2 emissions in Iran

Climate change and global warming as two critical challenges threatening human life are associated with energy consumption and GHG emissions [50]. The main source of GHG emissions is fossil fuels [51–54]. Iran is a developing country. Increasing energy demands coming from economic and industrial development are supplied by using more fossil energy sources. Adopting this energy policy, as a result of holding huge reserves of oil and natural gas, led carbon-based fuels to constitute over 98% of the national energy basket.

Iran is one of the biggest emitters of carbon dioxide in the world [50]. In 2011 and 2012, total CO_2 emissions from energy consumption in Iran was 594 and 604 million metric tons, which accounts for 2% of global CO_2 emissions [55]. In the last two decades, Iran has experienced three times growth in CO_2 emissions. Fig. 9 shows CO_2 emissions from various energy sources. Considering the country's status, it is essential to implement reduction policies of greenhouse gas emissions by the government. Some recommended strategies for reducing CO_2 emissions in Iran are as follows:

- Improving the efficiency of energy systems by implementing national programs for optimization of energy supply and consumption;
- Reforming pricing of energy carriers and eliminating subsidies;
- Increasing the share of low-carbon fuels in the national energy basket;
- Increasing the share of renewable and sustainable energies in the national energy mix;
- Using educational, technical and financial aids of international organizations;
- Providing financial and legal support for innovation and development of low-carbon technologies, and
- Developing utilization of environmentally friendly technologies.

Iranian government through replacing petroleum fuels with natural gas successfully executes increasing the share of low-carbon fuels in the national energy mix. However, successful implementation of this strategy is insufficient for CO_2 reduction. Improving the efficiency of energy conversion systems, adoption and deployment of renewable and low-carbon technologies are basic strategies that may decrease massive emissions of GHG in Iran.

Energy intensity, illustrating energy efficiency in a nation's economy, is high in Iran and follows an increasing trend for the last twenty years. To compute energy intensity, total primary energy consumption is divided by GDP. By the year 2011, energy intensity in Iran and the world was 11178.6 and 6935.2 kJ per year 2005 U.S. Dollars (Purchasing Power Parities) [55]. In addition to economic and social development, which increased primary energy production and consumption in Iran, the concern is that considerable growth of energy intensity in recent years, contrary to global trends, may decrease efficacy of government measures for reducing GHG emissions. Energy intensity in Iran is almost 60% higher than the world average.

Thermal power plants generating electricity by burning fossil fuels are regarded as the largest source of CO_2 emissions in Iran such that by 2013, power plants merely emitted 179.8 million tons of CO_2 [23]. Among the power generation units in the country, steam power plants are the largest GHG emitters. Iran's power industry in 2013 consumed 36.6 bcm of natural gas, 15.3 Billion liters of furnace oil and 12.2 Billion liters of gasoil. The share of natural gas is 55.9% in power plants' energy supply followed by furnace oil, gasoil and other fuels by 25.2%, 18.3% and 0.7%, respectively [23].

One of the challenges that Iran's NG industry deals with is the inability of the national gas network in supplying peak demands in the winter season. In these periods, gas delivery to power plants and petrochemical complexes is often postponed. Power plants inevitably use alternative fuels (i.e. gasoil for gas turbine and combined cycle power plants and furnace oil for steam power plants) in cold months. Cutting off natural gas, restrictions on transporting and storing liquid fuel influence the performance of power plants such as interfering with schedules of power generation units.

In 2013, consumed furnace oil and gasoil in Iran's power plants increased 5.9% and 57.3% comparing to the previous year; while, natural gas consumption decreased 9.7% [23]. Significant increase in gasoil consumption in power plants results from increased power generation in units within warm months and gasoil substitute for natural gas in cold months. Furnace oil and gasoil combustion generates more pollutants compared to natural gas; thus, CO_2 emissions per capita have relatively intensified in recent years. In 2011, CO_2 emissions in Iran was 7.6 metric tons per person; whereas, emissions per capita in the world and the Middle East were 4.6 and 9 metric tons, respectively [55]. It seems that it is critical to highly prioritize power plants in formulating policies of the petroleum and energy ministries for reducing energy consumption and optimization of fuel consumption in Iran.

At last, one of the questions raised about the policy of replacing

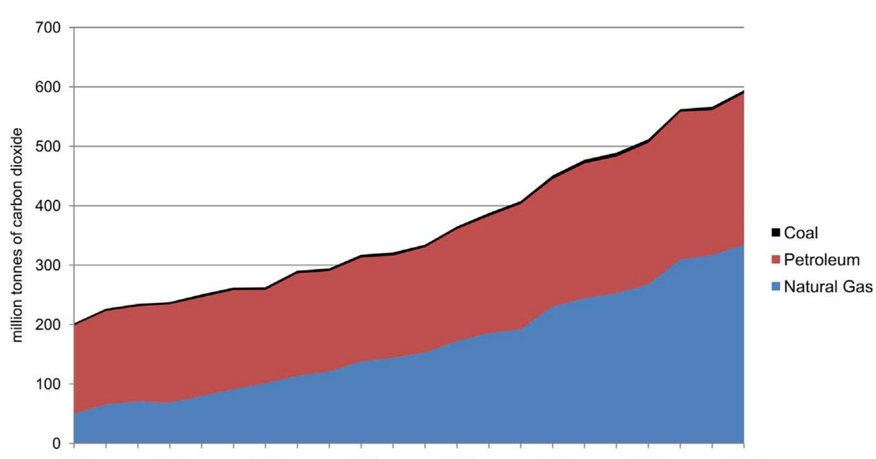

Fig. 9. CO_2 emissions from the consumption of energy in Iran from 1990 to 2011. (source of data: [55]).

petroleum fuels with natural gas, which has been successfully implemented, is that how long this policy will continue? The current share of natural gas in the national energy mix is more than 50% and energy policy makers should determine what percentage of domestic energy basket is supposed to belong to natural gas? Strong reliance on natural gas puts Iran's energy security at risk. In recent years, Iranian gas distribution network has expanded to villages and remote areas. Connecting all parts of the country to national gas network is not economically justified. Electrification is better solution for rural areas. It is important to note that the electrical energy has capability to meet all the needs of consumers (lighting, heating, cooling etc.). For this reason, all regions of the country have need of connecting to the power grid. On the other hand, the development of gas network reduces the share of other energy sources in Iran's total final consumption indicating the vulnerability of the country's energy sector. Diversifying the national energy basket is one way to increase the security and reliability of energy supply. Utilizing renewable energy technologies is a good choice for the implementation of this strategy. Iran has great potential to harness renewable energy resources such as solar, wind and geothermal to meet domestic demands [56–61]. Deploying RE technologies in residential and commercial sectors rather than the extension of the gas distribution network may mitigate the environmental and safety concerns of direct use of natural gas.

5. Conclusions

Global warming and its dangerous consequences for human societies have intensified concerns for greenhouse gas emissions, and thus, has led to creating an international effort to control and decrease GHG emissions. On the other hand, economic growth in developing countries is associated with increased energy consumption and carbon dioxide emissions. One solution toward low-carbon economy is replacing petroleum fuels with natural gas. Natural gas combustion properties have turned it into a suitable fuel to be used in various sectors.

Currently, Iran's most significant energy policy is to reduce shares of oil and oil products' in the national energy basket and to substitute it for natural gas and renewable energies. Many gas fields situated in the north and south of the country have made Iran the second-largest holder of natural gas proved reserves in the world. Iran's estimated proven natural gas reserves is 33500 bcm. It provides a unique opportunity for Iran's transition toward a low-carbon future. Assessment of different aspects of Iran's natural gas industry, conducted in this paper, demonstrates that the gas industry is properly developed in the country. At present, Iran ranks fourth in natural gas production capacity. Iran's natural gas industry produced 257623 million cubic meters from 23 active gas fields in 2015. In the last two decades, required infrastructures were created for natural gas transfer and distribution in various sectors including agriculture, household and commercial, power generation, industrial, petrochemical and transportation. Iran currently possesses 12 natural gas processing units with a daily production capacity of 579.2 mcm, and the total length of installed high-pressure pipelines for NG distribution network increased up to 36248.5 km in 2014. Natural gas penetration in urban and rural areas is 96% and 61%, respectively. However, the higher costs of developing NG distribution network in comparison with electricity grid raises questions about the economic justification of extending the national NG network. In addition, deployment of renewable energies to supply the electrical and thermal demands in remote regions is a powerful alternative to natural gas.

In general, the Iranian government may benefit its high NG potential and facilitate transition toward low-carbon economy. It is worth notifying that the Iranian gas industry is facing principal challenges. Production capacity is not increased in proportion to the rapid growth of domestic demand, which led to cut off gas supplies to power plants and petrochemical complexes in winter. On the other hand, the government-pursuing national interests in the long-term tries to balance domestic consumption and export. Regarding enormous gas reserves by the year 2011, Iran was a net gas importer indicating the significance of implementing energy consumption management and optimization plans. The other challenge is delays in completion of gas industry projects, the most important of which are Iran LNG (also known as NIOC LNG) and development of South Pars phases.

Despite implementation of petroleum and its products replacement policy with natural gas, CO_2 emissions from energy consumption in Iran account for 2% of global CO_2 emissions. This status suggests that several GHG reduction policies should simultaneously be taken into consideration in order to yield significant results. To promote rational use of domestic natural gas, reduce household and commercial losses, and to increase energy efficiency at the national level, the gradual elimination of energy subsidies was initiated since 2010. Implementing this plan decelerates rapid growth of gas demand and provides more export opportunities. It is expected that removal of nuclear sanctions may facilitate foreign investments for developing Iran's gas industry and implementing energy optimization plans and accelerating movement toward a low-carbon economy.

In future studies, conducting relevant cost-benefit analyses for the extension of the national natural gas network could facilitate energy policy making regarding the future of the nation's energy infrastructures. Investigating the effects of the natural gas network in economic prosperity and energy security may specify the significance of establishing such gas networks and may justify the economic benefits of having a national NG network.

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