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Energy Dependence on Fossil Fuels and the Need for Unconventional Energy in India

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Abstract: India ranks third in coal production in the world, and most of its energy demands are primarily fulfilled by coal. While using these conventional energy sources, various environmental issues need to be addressed. As a result, the future trend for energy supply is heading towards various unconventional energy sources such as shale gas, geothermal energy extraction, underground coal gasification, and coalbed methane. The current work includes a detailed summary of India's energy dependence on fossil fuels and the need for unconventional energy from an Indian point of view. Furthermore, it briefly discusses the concept of various unconventional energy sources. However, the current work has been more inclined towards exploring and exploiting unconventional resources such as shale gas. Considering shale gas development worldwide, a detailed review has been included in the manuscript that provides its status in various developed countries such as the USA, China, the European Union, and Canada and the impact of shale gas on their energy security. Furthermore, the manuscript discusses the status of shale gas in India and its current status of commercial exploitation. The final portion of the manuscript discusses the advantages and disadvantages of shale gas development.

Keywords: Shale gas, coal bed methane, unconventional energy, energy security.

Introduction

In the present scenario, global energy predominantly comes from oil, coal, and natural gas. Out of total electricity production, coal contributes nearly 40 % through thermal power plants. For countries like India, coal is the major energy source due to its abundance and ease of exploration. Burning fossil fuel leads to various environmental issues, such as air pollution, by increasing atmospheric greenhouse gases. Figure 1 illustrates the year-wise atmospheric CO_2 concentration. It suggests a 47 percent rise in its concentration compared to the pre-industrial age of 280 ppm and a 13 percent rise since 2000 of 370 ppm. In such a scenario, unconventional energy resources or alternative energy sources can be proved to be very useful that will minimize such environmental impacts and fulfill the energy demand. Various sources of unconventional energy can be listed as (i) Shale gas, (ii) Coal bed methane, (iii) Geothermal Energy, (iv) Gas Hydrate, and (v) Underground Coal Gasification, etc. However, most of these energy sources need improved technology and a better understanding of the reservoir and source rock characteristics as they are involved with processes such as wellbore stability, water flooding, hydraulic fracturing, enhanced oil recovery (EOR), hot fluid injections, and thermal stimulation where the associated rocks are exposed to different levels of elevated temperatures and pressures.

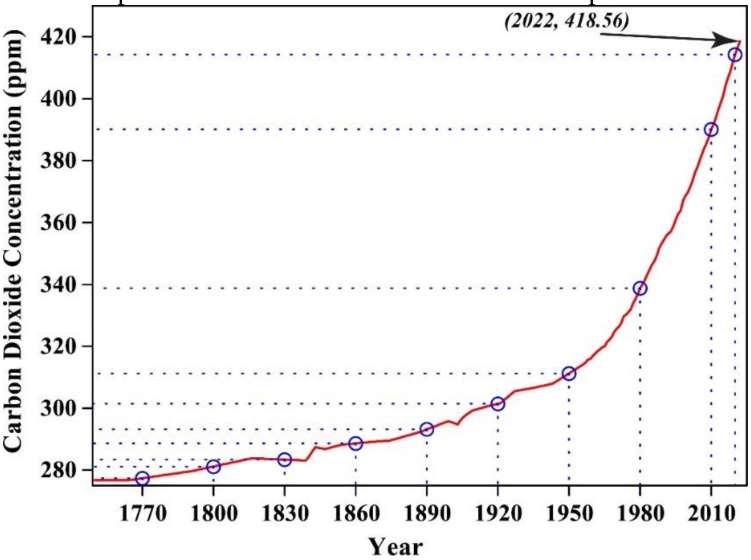

Fig. 1. Year-wise atmospheric CO_2 concentration (Global Monitoring Laboratory, 2023).

Figure 2 illustrates the resource triangle that compares the volume of conventional reservoirs with the other unconventional reservoirs. The larger-volume unconventional reservoirs are of lower grade having a reservoir permeability in the range of milli- Darcy to nano-Darcy, which is far less than conventional reservoirs. These unconventional reservoirs need improved technology and higher costs for successful exploration and exploitation. In countries like India, these energy sources are entirely unexplored and need various research for their development. The successful development of these less understood reservoirs can be achieved by addressing three major concerns: their system integrity, the amount of pore volume present, and the ease of extraction, which can be explained in terms of the strength, pore volume, and permeability of the reservoir rocks, respectively.

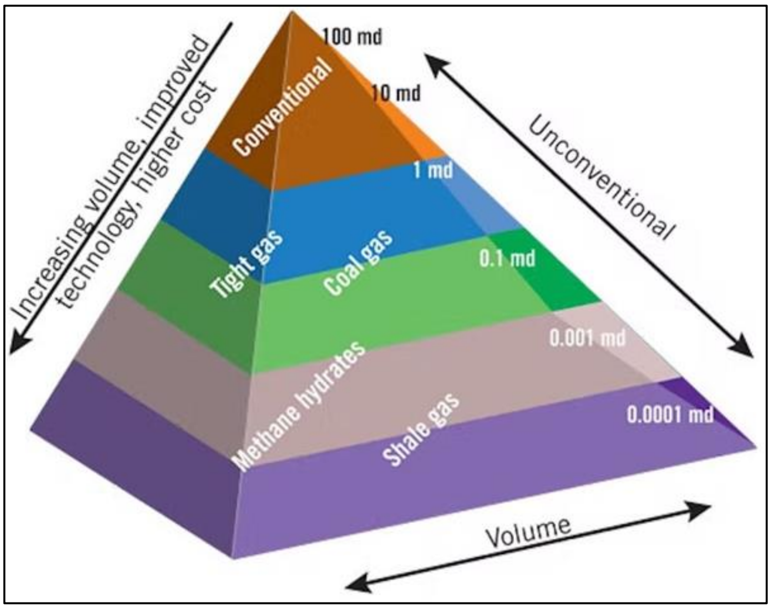

Fig. 2. Resource triangle indicating reservoir properties and reservoir volume (Rahim et al., 2012).

Unconventional energy, such as shale gas and coalbed methane, has been turning out to be major contributors to the energy security of India. Currently, India does possess massive trapped unconventional resources. As per the current estimates, India does have a potential of 96 trillion cubic feet (TCF), technically risked recoverable shale gas, and 3.8 billion barrels of shale oil (Sharma and Sircar, 2018; EIA 2013). However, exploration and exploitation of these unconventional energy sources are still in their preliminary stage, and they need various improved technology, massive research, and development prior to their commercialization in India.

The present study focuses on summarising the position of shale gas development in India, particularly focusing on the current development status, the challenges, and the way-forward research for their successful exploration and commercial exploitation. The authors are envisaged minimizing the existing knowledge gap by providing helpful information.

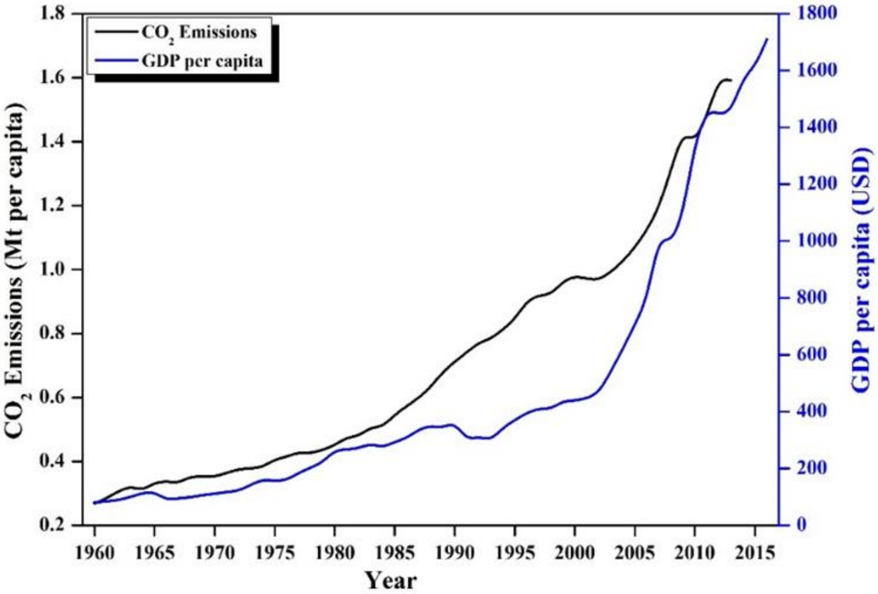

Fig. 3. A comparison between the per capita GDP and the CO_2 emission of India (Mahanta and Vishal, 2020; The World Bank, 2017).

India's energy dependence on fossil fuels

Nearly 80 percent of India's energy demand is being fulfilled by three types of fuels such as coal, oil, and solid biomass, of which coal and oil have served as anchors for its industrial growth and modernization. A rise in per capita energy consumption always goes hand in hand with a nation's growth; being a developing country, India requires massive energy resources to cope with its growth rate. After China and the USA, India is the world's third-largest energy consumer.

The sudden rise in fossil energy consumption has resulted in India's annual CO_2 emissions placing at the third highest position globally. In the current scenario, most of its requirement is being fulfilled by fossil fuels, predominantly coal and oil. Since the early step towards development, coal has been used as the primary energy source due to its abundance and easy exploration. India ranks third in coal production, and most of its energy demands are being fulfilled by coal. Figure 3 illustrates a comparison of the CO_2 emission of India and the growth of domestic product (GDP) in the past 50 years, suggesting that high GDP growth has always been accompanied by a high rate of CO_2 emissions. Out of these fuels, coal has the dominant position as the single largest fuel resource due to its extensive use for electricity generation and industrial usage.

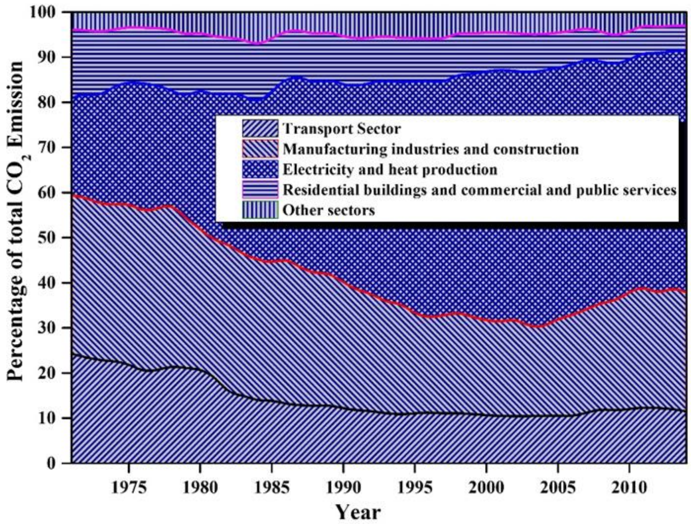

Fig. 4. Year-wise CO_2 emission from various sectors in India (Mahanta and Vishal, 2020; The World Bank, 2017).

Figure 4 illustrates a comparison of CO_2 emissions coming from various sectors such as transportation, manufacturing and construction, electricity and heat production, residential and commercial use, and others. It suggests the electricity and heat production sector contributes a major portion of emitted CO_2 in India, and its percentage has increased in the last three-four decades.

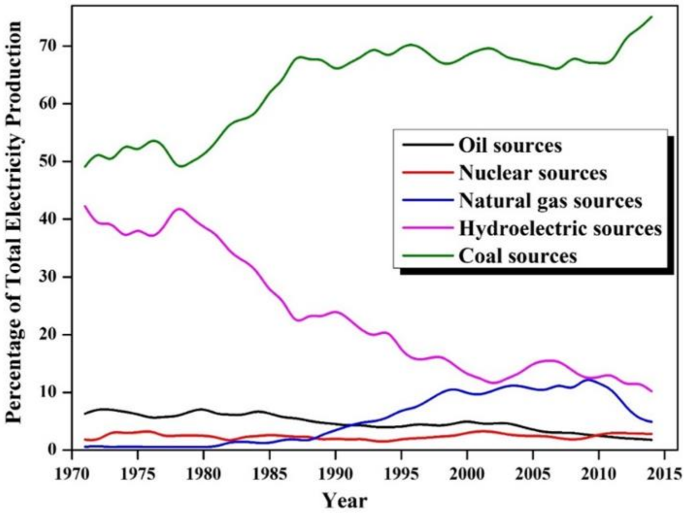

Fig. 5. Year-wise various sources of electricity production in India (Mahanta and Vishal, 2020; The World Bank, 2017).

A close comparison to the different energy sources for electricity production reveals that coal is the major contributor, impacting more than 70 percent in 2015 (Fig. 5).

Need for unconventional energy

Energy resources are the lifeblood of humanity because, without them, the present-day world would cease to function. Most of our energy demands are met by the consumption of fossil fuels. Still, the rapid consumption of these is generating large amounts of greenhouse gases, which in turn are exacerbating the climate change issue by trapping excess solar energy from the sun, thereby increasing the potential of atmospheric temperature change by significant amounts ranging from 1.1 °C - 6.4 °C. We have been actively looking for alternative sources that are less polluting than the conventional energy resources we currently depend on. Currently, some different renewable energy sources have been established, like windmill farms for wind energy generation, solar farms for solar energy generation, and dams for hydroelectric power generation, which can help us with a part of our required energy budget. Recent advances in nuclear research have displayed the potential of energy generation from the nuclear fusion of hydrogen molecules. However, all of these methods of energy generation are not affordable for the majority of the general population, so we have to find an energy source that is affordable for the masses and is less polluting than the present-day resources being used. Unconventional energy sources are seen to satisfy both of the above conditions as they produce lesser greenhouse gas emissions and can be affordably extracted as their extraction processes have reached a certain level of technological maturity by which the cost of extraction has been reduced a lot which in turn has a very prominent effect on the end of the supply chain. The main difference between conventional energy and unconventional energy sources would be that the source rock, or the hydrocarbon-generating rock, and the reservoir rock, or the hydrocarbon-storing rock, are the same in the case of unconventional energy resources; however different in the case of conventional energy reservoirs. Since the source rock and reservoir rock are the same in unconventional reservoirs, they require more work to be made economically feasible for gas extraction than conventional energy reservoirs. Some of the unconventional energy sources being explored right now are given below.

Shale gas

It is a type of natural gas primarily composed of methane that is trapped in shale formations deep underground. Extraction of this gas is done by a process known as hydraulic fracturing or simply fracking. The details of the hydraulic fracturing mechanism can be found in Lee et al. (2016). This process involves pumping large amounts of water, sand/proppants, and chemicals into the rock to promote fracturing and increase its permeability. This increase in permeability directly correlates with improved gas flow. The gas flowing from the formation can then be processed and used as fuel.

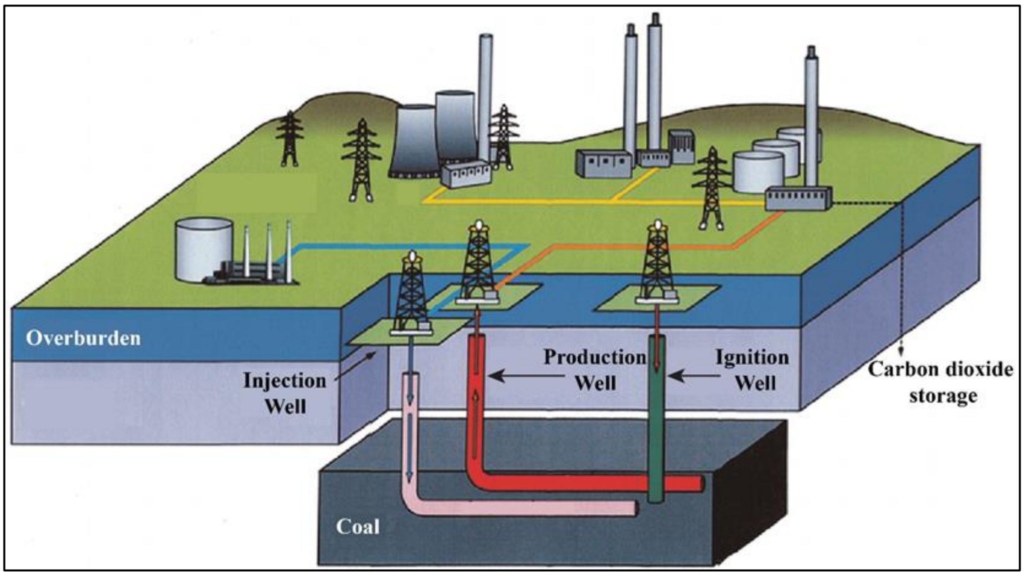

Fig. 6. Simplified diagram of UCG (Modified after Green et al., 2012).

Coalbed methane (CBM)

It is a type of natural gas that can be found in coal seams. Production of this gas occurs when methane gas is released by the pressure of the coal seam, which is then trapped in the coal. CBM can be extracted by drilling into the coal seam and pumping out the water holding the gas. The gas can then be captured and used for fuel. Further details about the concepts of CBM and ECBM can be found in Buckler and Ross (2015), Mahanta and Vishal (2020), and Vishal et al. (2018).

Underground coal gasification (UCG)

It is a process of converting coal in situ into a combustible gas that can be used as fuel. It generally consists of drilling boreholes into unmined coal seams, injecting air or oxygen to ignite the coal, and finally extracting the gas produced as a result (Fig. 6).

Geothermal Energy

It is a type of renewable energy that comes from the natural heat of the Earth's core. Kumari and Ranjith (2019) can be referred for detailed concepts and mechanisms of harnessing geothermal energy. This energy can be harnessed through various technologies that tap into underground reservoirs of hot water and steam to generate electricity or heat buildings.

Gas Hydrates

Gas hydrates are naturally occurring solid compounds consisting of water molecules and gas molecules, such as methane. They are formed under low temperatures, high pressure, and conditions in sediments found in the deep sea and permafrost regions. Gas hydrates are often referred to as "flammable ice" due to their appearance and high energy content. They can potentially be a significant source of natural gas; however, the extraction and transportation of gas hydrates are technically challenging (Fig. 7).

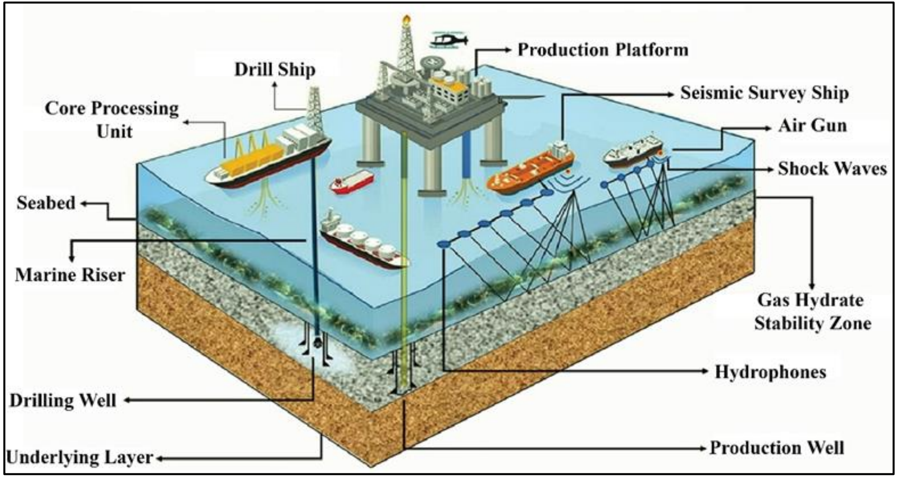

Fig. 7. Exploration and drilling methods for Gas hydrate Extraction (Modified after Sahu et al., 2020).

Significance of Shale Gas in the World

Shales are fine-grained sedimentary rocks, and because of their less porous and impermeable nature, they can trap hydrocarbons and be a rich source of oil and natural gas. Shale gas is regarded as a global fuel energy and is now considered a natural gas which is the most traded commodity in most of the developed and developing countries of the world. Therefore, the countries that hold maximum shale gas reservoirs get the maximum opportunity to generate a massive amount of national revenue through the exports of those gases, improving the country's economic conditions, thereby contributing to that nation's GDP. Moreover, the presence of shale gas in a particular nation helps those nations in various sectors, such as reducing energy dependence on other countries and supporting cleaner energy in comparison to coal (as it produces more CO_2, which is a very harmful greenhouse gas with a long period of residential time in comparison with CH_4) and helps in balancing the oil price. Other benefits include greater national energy security, reduced air pollution, and lesser carbon emission. Nowadays, most countries are in the race to find an alternate energy source to replace oil, petroleum, natural gas, and other energy sources in which the country depends on the other country for its energy needs. Major countries ahead in the shale production race include the USA, China, Canada, Australia, and European Union.

North America (United States)

The USA is best known for its supreme leadership and superpower in this world. Whether in the military, spacecraft, or industry, the USA is known to maintain its legacy in every sector and field. However, its dependence on the Middle East countries for oil and natural gas raises the question about its supremacy, for which the USA was on a mission to search for an alternate source of energy, i.e., shale gas. Due to technological advancement and the excellent partnership between industry and researchers, shale gas production has increased rapidly in the last decade. Such technological advancement includes horizontal drilling and hydraulic fracturing at very high-pressure that induces permeability in the shale formations. Since 2006, an escalated and large-scale drilling operation has been performed in various wells in different basins in the USA. Such an intensified procedure facilitated a large-scale shale gas production that was responsible for the downfall of gas prices from $10 per million British thermal units (BTU) in 2010 to $2.5 per million BTU in 2014. As per the energy information administration (EIA), the U.S. has a reserve of 2552 TCF with an annual consumption of 22.8 TCF; the present natural gas resource in the USA is good for the next 110 years (Dayal and Mani, 2017).

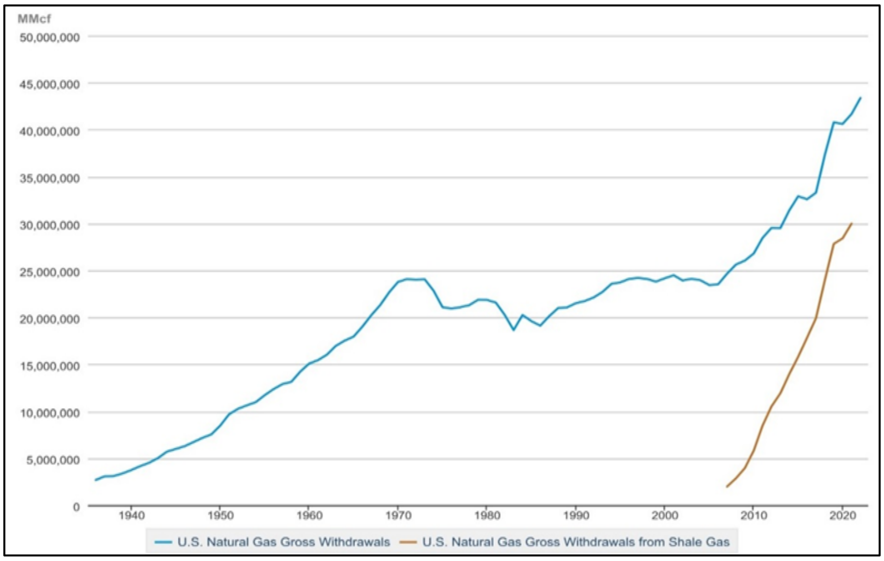

Fig. 8. Natural Gas Gross Withdrawal and Production in the USA (U.S. Energy Information Administration, 2021).

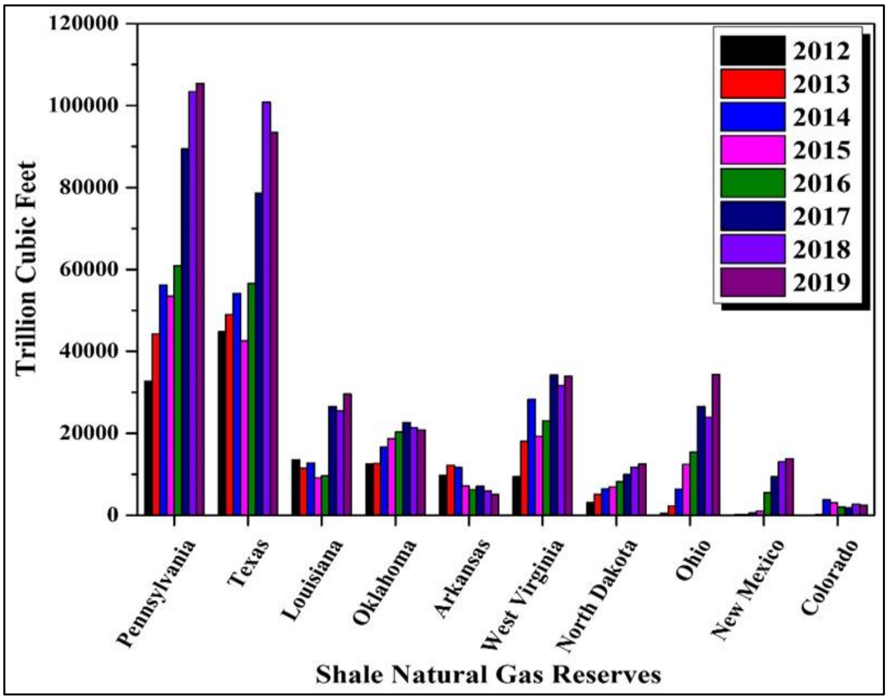

Fig. 9. Proved shale gas reserves of the top U.S. shale gas reserve states (U.S. Energy Information Administration, 2021).

The primary source of increased production of natural gas since 2000 is the shale gas revolution. The revolution is primarily due to massive technological breakthroughs in gas exploration like large-scale hydraulic fracturing, horizontal wells, and advanced subsurface imaging developed by government agencies working alone or with private entrepreneurs and scientists. In 2007, the shale gas extracted from U.S. shale gas plays was 1293 billion cubic feet (BCF) which were around 8 % of the total natural gas extracted in the U.S. This amount has increased rapidly with the last few years, reaching production values of 27985 BCF of shale gas in

2021 which is 72% of the total natural gas produced in the U.S. that illustrates the shale gas has gone from being a minor supplement to the total natural gas produced to be the most significant contributor in the total amount of natural gas produced in the country. The amount of shale gas produced with respect to the total natural gas produced per year is depicted in the graph given in Figure 8.

The proven shale gas reserves based on states are seen to be maximum in the state of Pennsylvania and are present in lower amounts in the state of North Dakota. The representation in a graphical format on the yearly basis of proved shale gas resources is given in Figure 9. The monthly shale gas production is generally seen to be maximum in Texas, and the minimum production is usually seen to occur in Montana. The monthly shale gas production by shale gas plays is generally seen to be maximum in the Marcellus shale gas plays, with the minimum being the Fayetteville shale gas plays (EIA, 2021). Overall, the relatively simple geology of the USA compared to other regions like Europe, governmental subsidies, participation of the general population due to equal enrichment of all parties involved in shale gas exploration, and the moderate environmental laws in the USA have helped it reach these new production heights in shale gas.

China

China, a developing country mostly known as the "manufacturing hub of the world, " relies heavily on fuel to run its industries. Therefore, like the USA, China is also busy finding alternate energy sources to fulfill its basic energy needs and cut its dependency on other fuel sources. China is one of the countries in the world with abundant shale gas resources reaching almost 123.01 × 1012 m^3, with 46.6 percent being concentrated in and around the Sichuan basin (Sun et al., 2021). Economic development has only been accomplished in the Wufeng Formation deposited during the Later or Upper Ordovician period and the Longmaxi Formation deposited during the Earlier or Lower Silurian period, even though shale gas flows have been seen in the shales deposited during the Cambrian, Permian, and Jurassic periods. Fuling in the eastern Sichuan Basin and Weiyuan and Changling in the southern Sichuan Basin are some of the primary commercial gas fields. The area outside the Sichuan basin is still being explored for the economic prospects of shale gas flows. The formation mechanisms and the enrichment process of shale gas in the Wufeng and Longmaxi formations have been understood in greater detail than the surrounding stratigraphy, and accordingly, extraction methods have been formulated for that (Ma and Xie, 2018; Sun et al., 2021). Some wells drilled in the Sichuan basin have failed to be profitable even after showing high test yields because of their insufficient stable production capacity and low estimated ultimate recovery (EUR). Some of the other formations in the Sichuan basin, like the Jurassic, Triassic, and Permian shales, have been explored for shale gas production by drilling test wells, and they have shown good yields. The complex structure of areas near the Sichuan basin is one of the factors that makes the prospect of shale gas resources unclear. Even though many of the wells drilled here have demonstrated gas flows after hydraulic fracturing, EURs are quite low, making the development of shale gas in most of these situations uneconomical. The preservation conditions of these reservoirs have been determined to be normal pressure which means the reservoir energy is not enough to push more gas up to the ground. In other areas like southern North China (Dang et al., 2018; Liu et al., 2018; Sun et al., 2021), western Hubei to eastern Chongqing (Zhang et al., 2019, 2019; Sun et al., 2021), central Hunan (Xiao et al., 2018; Sun et al., 2021), the Erdos Basin (Loucks et al., 2017; Zou et al., 2019; Sun et al., 2021) and the Taibei Sag of the Turpan – Hami Basin (Guo et al., 2018; Chen et al., 2020; Sun et al., 2021) drilling has been carried out; however the low EUR values of these wells hold them back from commercial production. Studies have reported that solid tectonic movements have changed these reservoirs from the original over-pressured state to normal pressure that allows to extraction of a small amount of gas, which is uneconomical (Nie et al., 2019; Sun et al., 2021).

European Union (EU)

The initial estimation of shale gas in Europe was around 510 × 1012 Standard cubic feet (SCF) (Rogner, 1997; Maierean, 2021). Shale gas was thought to be present only in the western part of Europe, and the eastern part of Europe was not assessed during this time. After secondary assessments, the US Department of Energy raised it to 18 TCM or 636 × 1012 SCF (Kuuskraa et al., 2011). The government supported and subsidized preliminary shale gas exploration in the United Kingdom (UK). Still, all forms of shale gas exploration in the UK have come to a halt. The government is conflicted about shale gas exploitation and use because of environmental contamination from spillage of flow back fluid and induced seismicity due to wastewater injection. France has imposed a full-scale ban on fracking, which translates directly to no possible exploration of shale gas in France (Tomasi and Nicolet, 2013). Germany has not yet allowed or given permission for exploratory drilling to confirm whether the geology is suitable for commercial shale gas production. Poland is believed to have four basins from where shale gas can be extracted (Karcz et al., 2013; Jarzyna et al., 2017; Maierean, 2021). It was a part of the pilot group of countries for shale gas exploration and production. Still, all kinds of drilling and exploration for shale gas in Poland have stopped even though the government still favours shale gas exploration. The primary reason for that is the extremely high cost of drilling in Poland compared to that of the USA, with costs reaching up to three times the cost in the USA, making shale gas production extremely expensive and uneconomical. The Czech Republic introduced a moratorium on shale gas exploration in 2012 even though certain companies showed a lot of interest in the potential shale gas-bearing basin present in this country (Kister et al., 2012; Maierean, 2021), which is in sharp contrast to Poland's favorable stance on shale gas exploration. This moratorium was introduced primarily due to environmental concerns like high consumption of water per drill well, a significant risk of groundwater contamination under conditions of technological lack of restraint, degradation of the landscape surrounding the drill site, and air quality deterioration (Kister et al., 2012; Maierean, 2021). There has been no activity in the Czech Republic after the 2012 moratorium, so we can consider shale gas production from the Czech Republic to be highly improbable. Lithuania announced in 2011 that it would start pursuing shale gas development to combat its energy dependence on Russia as it imported nearly 60 percent of its energy, and the main supplier of its energy imports was Russia. Russia had tried to strong-arm Lithuania into buying its energy exports at a higher price than the industry standard, which further led to the alienation of Lithuania from Russian gas. According to rough estimates, it has been determined that nearly 100 BCM of natural gas reserves can be recovered from the shale gas basins present in Lithuania. In March 2012, Chevron, an America-based oil company, started exploratory drilling in Silute and Taurage areas after bidding and winning the rights for shale gas exploration in those areas in Lithuania. During the period of drilling rights acquisition by Chevron, many Lithuanians protested strongly against shale gas exploration, with the primary focus being the contamination resulting from fracking, especially in the areas close to the Baltic Sea. Chevron pulled out of Lithuanian shale gas development projects in 2013, citing the restrictive laws and regulations present in the country as the primary reasons for its departure. The Lithuanian government has also postponed discussions about opening another tender for shale gas exploration due to immense pressure from the general population. Bulgaria also depends heavily on Russian energy imports, which is why it had considered the idea of self-sustainability from shale gas production present in the different reservoirs in the country. In 2011, after it was announced that Chevron would start shale gas production in the country, it triggered large-scale protests against fracking in the country. Environmental concerns like groundwater contamination, habitat destruction, and earthquake induction due to wastewater injection eventually led the government to retract the shale gas exploration permit it had granted to Chevron. The government of Bulgaria eventually completely banned fracking in 2012, and there has been no activity on this front since then. The case of Romania differs from the other countries we have mentioned until now. It ranks second in natural gas production in the European Union, just after the Netherlands. So, it has less pressure to adopt alternative energy sources like shale gas within a short period. Romania has provided lucrative offers to foreign shale investors; however, the actual shale gas development has been limited by public opposition. Its poor decisions and chronic lack of public consultation regarding natural resource exploitation have led to the complete distrust of the general population against the policies formulated by the government. In 2013, Chevron obtained the extraction rights of shale gas from an area of around 2 million acres in eastern Romania; however, the company decided to suspend all its activities after large-scale protests against fracking started to form in different areas of the country starting from the villages impacted by the exploration to the largest cities and the capital. Shale gas exploration has not been carried out in any part of Romania after these incidents. Overall, the countries in the European Union where shale gas exploration can be carried out have much more complex geology than their American counterparts, strict environmental laws compared to America, complicated legislation, and mistrust of the general population against fracking which has led to an overall standstill in the production of shale gas in Europe.

Canada

According to the Canadian Association of Petroleum Producers (CAPP), over 215,671 natural gas wells have been drilled in Canada to date, with a large portion of it, i.e., 174,049 wells being drilled in Alberta alone (CAPP, 2022a, 2022b). The first instance of petroleum development in Canada was in 1858, in the eastern part of Canada, where an oil well measuring 15.5 m was dug in Oil Springs present in Ontario (Rivard et al., 2014). This is believed to be the first commercial oil well in North America. Ontario was also the first region where natural gas was discovered in 1859; however, commercial production was not initiated until 1889. In the late 1800s, natural gas production for local industrial purposes from unconsolidated Quaternary sands took place for a very short time in the Trois - Rivières area. The reason for the very short duration of gas production from this area was that the gas reservoir was very small and was depleted rapidly. During that period, conventional hydrocarbons at shallow depths were targeted, mainly in overburden regions (often at the region of bedrock/overburden contact). While drilling for water in western Canada, near Medicine Hat, Alberta, in 1883, the first discovery of gas was accidentally made. The following year saw the drilling of another well that generated enough gas to heat and light several buildings.

The excellent Leducoil field, which was discovered in 1947 by Imperial Oil, placed the Western Canada Sedimentary Basin at the centre of Canada's petroleum exploration and production. To start the development of domestic and international markets, the industry began to create a vast network of pipelines in the 1950s. Canada is the world's 6th largest producer of natural gas, with 194.619 BCM or 6907.752 BCF of raw natural gas production in 2021 (CAPP, 2022a, 2022b). As per the report of the Canada energy regulator (CER), Canada has a very well-developed export market, and the USA is the only customer of the natural gas produced in Canada, with Canada having exported around 79.56 BCM of natural gas to the USA. The energy consumption of Canada in 2021 was a total of 11,274.06 petajoules (PJ). Fossil fuels accounted for the largest share of this energy consumption, with oil products representing 37.77 percent, natural gas at 37.1 percent, thermal electricity production at 3.4 percent, and coal at 1.26 percent. The rest of the energy consumption is supplied by other sources (nuclear, hydro, wind, and solar) representing 15.03 percent, and biofuels and other emerging energy sources at 6.72 percent. To offset declining conventional production, shale, and tight resource production is growing. In 2014, tight gas accounted for almost 47 percent of total Canadian natural gas production, and shale gas 4 percent. CER expects that by 2035, 80 percent of Canada's natural gas production will be made up of tight and shale gas. In 2014, around 10 percent of total Canadian crude oil production consisted of tight oil. The first area where commercial modern shale gas production started was in Horn River Basin in 2006 found in British Columbia. Shale gas plays in Alberta and New Brunswick is also being commercially used for shale gas production in Canada. There are 20,945 producing CBM and shale gas wells in Alberta, Canada (CAPP 2022a, b). Although the development of shale gas in Canada is progressing the state of the industry is still in its infancy compared to its neighbour the USA.

Importance of Shale Gas in India

Rising shale gas production in the USA makes it the largest producer of oil and gas in the world. India is the 4th largest energy consumer in the world. The total natural gas consumption was 226.7 million Standard Cubic Meters of Gas per day (MMSCMD) (January 2013), with power and fertilizer sectors consuming 86.17 and 59.86 MMSCMD of gas, respectively. While power sector consumption accounted for 38 percent of the total natural gas consumption in India, the fertilizer sector consumption accounted for 26 percent of the total consumption (Ariketi et al., 2015). In India, several shale formations in the basin, like the Cambay Basin, Krishna-Godavari (KG) Basin, Gondwana Basin, and Cauvery Basin, etc., have good potential for shale gas production. According to the EIA, India has 96 TCF of recoverable shale gas across above mentioned basins. To date, India has not made significant progress toward shale gas production. As shale gas is cleaner and causes less environmental pollution, most countries are heading toward shale gas. The shale gas reserve can help India to meet its increasing high energy demand and to boost the economy of the country, and become less dependent on the oil import. As we know that shale gas is obtained by the unconventional method. There are two main mechanisms behind the exploration, i.e., horizontal drilling and hydraulic fracturing (due to the compactness of reservoirs). Massive shale deposits are present all across India in the Gangetic Plains, Assam, Rajasthan, Gujarat, and many areas near the coast. Still, its extraction has been deemed potentially unfeasible due to the high economic cost of extraction. Several shale basins in India have high organic content, mainly including Cambay, KG, Cauvery, Assam – Arakin Basin, and Damodar Valley Basins. The other potential shale gas basins in India either had shales that were too thermally immature to produce shale gas, or there was no data available regarding those shales. The geology of the shale gas-bearing basins in India is highly complex.

Although the shale deposits in these basins are thick, there is considerable doubt about the depth at which thermally mature shales are present, which is an essential prerequisite for shale gas generation. Schlumberger and American Research Institute (ARI) have surveyed different areas in India and estimated there are around 600 TCF – 200 TCF of shale gas reserves in India, with the technically recoverable shale gas being around 63 TCF with possibilities of it being extended to 114 TCF. Indian scientists and academicians have done extensive work to increase the recoverability of shale gas present in India. Although extensive theoretical work has been done in India concerning shale gas extraction, drilling for exploration and production in potential shale gas sites in India is very minimal. As of March 2017, five exclusive shale gas wells have been drilled in the Cambay basin, and seventeen dual objective wells have been drilled in the rest of India. These wells are being evaluated for shale gas and/or shale oil production feasibility. Oil and Natural Gas Corporation (ONGC) has received permission from the government to drill five wells for shale gas and oil exploration in the KG Basin, and further investigation after the drilling of the five wells is under consideration by the government of India. The drilling has been promised to be carried out using water – base mud only, with land usage being around 5 – 6 acres per well and drilling time per well being 90 – 120 days. Overall the remarkably complex geology of Indian shale gas-bearing basins, the offering of no significant subsidies for the companies willing to invest in shale gas exploration and production, the huge initial costs of shale gas production setups, the unpredictability of production of shale gas from shale gas wells, the need of extraction of large amounts of water from an already water-stressed India, the environmental contamination concerns are the main reasons behind the poor exploration and production of shale gas from potential sites.

Advantages and disadvantages of shale gas development

Advantages

Abundance of supply

One of the main advantages of shale gas is the large reserves of shale gas found around the world. In the report by the U.S. EIA on global shale gas availability, which focused mainly on 32 countries, almost 48 shale gas basins containing around 70 shale formations have been found and evaluated for their economic profitability (Fig. 10). It has been seen that the reserves of shale gas that have been proven are almost on the same level as that of the conventional reservoirs present around the world (Kuuskraa et al., 2011).

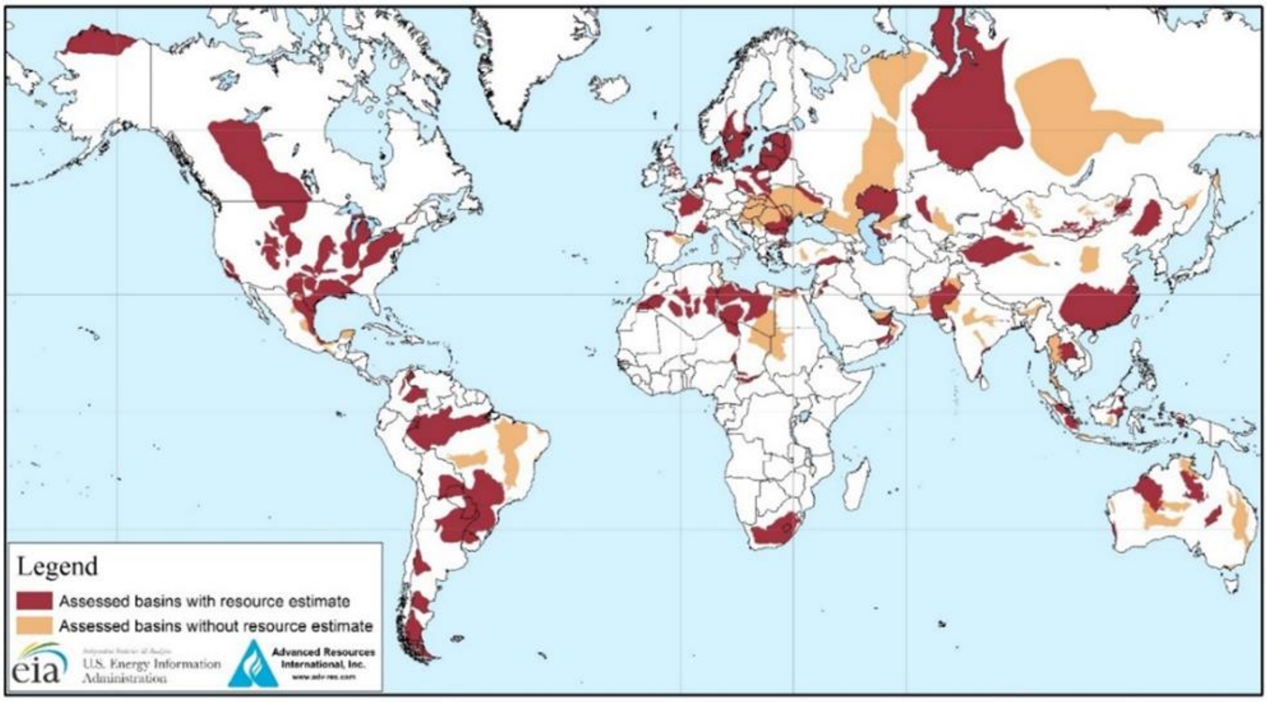

Fig. 10. Map of major shale gas basins in 32 countries (EIA, 2012).

Revitalisation of the Chemical Industry

It has been suggested that ample amounts of natural gas can help renew the chemical production industry. An extensive range of products, such as pharmaceuticals, agrochemicals, and plastics, use natural gas as an essential component in manufacturing. The supply of fertilizer also has an extreme dependence on natural gas which is why the availability of cheap natural gas on a large scale can help us to maintain the reserves of food required for comfortable sustenance and lower the conversion of forests to agricultural farms for increased yield of food (Sovacool, 2014).

Economical natural gas prices

Even though, on average, the cost of production of shale gas varies according to the conditions at each site, it is on a cumulative basis around 50 to 66 percent cheaper than the production of resources from new conventional reservoirs, and the cost of production could be reduced further if the technology for extraction continues to advance at a fast rate (Deutch, 2011; Sovacool, 2014). It has also been seen that greater shale gas production will help Europe reduce its dependence on Russian oil and gas, thereby decreasing Russia's strategic hold on Europe (Deutch, 2011; Sovacool, 2014). Accelerated production of shale gas globally might reduce gas prices in Asia as monopolies run by the state would reduce their prices to compare with the prices offered globally to keep up business (Medlock, 2012; Sovacool, 2014).

Cleaner environmental footprint
Shale gas production has some polluting tendencies associated with it, as discussed in the later portion of the article; however, it has an environmental footprint that is cleaner than fossil fuels like coal and oil. Coal and oil production have much higher nitrogen oxides, sulfur oxides, and mercury emissions than shale gas production. It's even fewer greenhouse emissions than coal and oil (Burnham, 2012). It has been seen that shale gas use has heavily reduced the intensity of emissions of the national power grid of the U.S.A. on the whole as it has switched from using coal to shale gas for energy production (Sovacool, 2014).

Economic development
In the case of the American economy, shale gas has generated a lot of revenue and created many jobs for the American workforce. Production of shale gas at Barnett shale in Texas in 2011 has accounted for around $11.1 billion worth of revenue annually which is almost 8% of the entire region's economy and has generated approximately 100,000 jobs or around 10 percent of the employment in the region (House, 2013; Sovacool, 2014). In the case of Pennsylvania in America, in 2008, it generated around $2.3 billion and tax revenues of $238 million for the government and created 28,000 jobs (Kargbo et al., 2010; Sovacool, 2014).

Disadvantages/challenges of shale gas production

Water contamination
Hydraulic fracturing, the primary method of shale gas extraction, uses large volumes of water (both groundwater and surface water). So, the main concern is groundwater and surface water contamination due to the activities of hydraulic fracturing. Sometimes due to hydraulic fracturing, there is a migration of naturally occurring elements or compounds. This can include migrating methane gas from the shale formation to the aquifers at shallower depths (Osborn et al., 2011; Werner et al., 2015). It can also lead to increased levels of naturally occurring radioactive material (NORM) in the subsurface (Kargbo et al., 2010; Werner et al., 2015). These radioactive materials can get concentrated, which can cause health risks for workers on the site, who handle drill cuttings, refurbish equipment, and remove solids from tanks and pits. Fracking uses chemical mixtures generally kept secret to the public as trade secrets. This has led to constant demands for complete disclosure of the chemicals used in fracking fluids and low-toxicity additives. Even though chemical additives make up only 2 percent of the total volume of the fracturing fluid (Eaton, 2013; Werner et al., 2015), each well, on average, requires almost 5 million gallons of fracturing fluid for proper functioning (Finkel et al., 2013; Werner et al., 2015) which leads to the usage of nearly 105 gallons of chemical additives per well.

Some studies have discussed how exposure to certain chemicals used in fracking could result in various health effects if inhaled, ingested, or even absorbed through the skin (Colborn et al., 2011; Werner et al., 2015). Some examples of such chemicals used in fracking are ammonia, methanol, acetic acid, ethylene glycol, sodium nitrate, ethylene glycol monobutyl ether (2-butoxyethanol), and isopropanol (propan-2-ol). These can cause many effects on the skin, eyes, sensory organs, gastrointestinal system, respiratory system, and liver. It can also severely impact the brain, nervous system, and immune system (Kargbo et al., 2010; Colborn et al., 2011; Werner et al., 2015). Some studies noted that, due to improper measures of containment, fracking fluid often spills out into the surface or groundwater, contaminating it. It was seen in another study that the levels of total dissolved solids, selenium, barium, arsenic, and strontium in samples taken from some private water wells within a 3 km range had exceeded the Drinking Water Maximum Contaminant Limit (MCL) set by the Environmental Protection Agency (EPA) (Fontenot et al., 2013; Werner et al., 2015).

Air Quality degradation or Air Pollution
Many kinds of volatile components, such as volatile organic compounds (VOCs), are released to the atmosphere during various stages of shale gas production activities such as drilling of wells, flow back of fracturing fluid, compression of gas, condensation and transportation of the extracted gas (McKenzie et al., 2012; Werner et al., 2015). Some studies show that tight and shale gas development releases a lot of pollutants that are of immense concern, most of which are related to combustion. Some of these air pollutants that are associated with the functioning of equipment used in fracking and are released to the atmosphere during shale gas production

include carbon monoxide, sulfur dioxide, hydrogen sulfide, nitrogen oxides (NOx), benzene, VOCs, and particulate matter (Colborn et al., 2011; Werner et al., 2015). Other significant sources of air pollutants include the venting of condensate tanks; flaring (methane, NOx, PM); and emissions that originate directly from compressors and engines (Kibble et al., 2013; Werner et al., 2015). When there is an interaction between sunlight, VOCs, and NOx, excessive ground-level (tropospheric) ozone is often developed as a secondary contaminant (Walther, 2011; Werner et al., 2015). After a toxicology review of drilling fluids was conducted, it was found that the primary health risks that are associated with inhalation of vapour and aerosol associated with drilling fluid that is oil-based are irritation of mucous membranes present in the human body and neurotoxicity or alteration of neural behavior after exposure to these vapours and aerosols. Exposure to drilling fluids for an extended period is associated with an increased risk of developing chronic respiratory illnesses, impaired cognition abilities, neurological impairments, and in some cases, dementia (Searl and Galea, 2011; Werner et al., 2015). It has been discussed that there are varying levels of air pollution according to the setback restrictions put in place by governments. In countries like Australia where the setback restrictions are high, i.e. the wells are far away from human settlements, the effect on air quality is not as much in those cases where the setback restrictions are low (Coram et al., 2014; Werner et al., 2015). In a health impact assessment study conducted in 2013 in Colorado on the exploration of tight gas, it was seen that inhabitants in the study area had a chance of suffering from health effects related to chemical air emissions. The short-term effects that were seen to occur mostly were headaches, various other neurologic symptoms, mucous membranes, and airway irritation. Long-term health effects such as birth defects, cancer, increased frequency of asthma attacks, and intensifying chronic pulmonary obstructive diseases were also possible (Witter et al., 2013; Werner et al., 2015). A significant leakage is seen in methane gas from the drill site to the processing plants, which is released into the atmosphere and acts as an added factor in global warming. Although methane has a short life in the atmosphere, its global warming potential is much higher than that of CO_2 so it can trigger faster climate change within a shorter time (Sovacool, 2014).

Impact on Soil Quality

Chemicals used in hydraulic fracturing can contaminate the soil with spills, leaks, or other incidents during various stages of shale gas exploration (Zoback et al., 2010; Werner et al., 2015). In some cases, when the drilling sludge is dumped into land farms, it can also contaminate the soil (Finkel et al., 2013; Werner et al., 2015). Pollutants like toluene, benzene, barium, and other petroleum hydrocarbons and metals that may occur in drilling fluids can be absorbed /adsorbed into the soil, which can then create a residue that has a high possibility of leaching with rain and snowmelt (McKenzie et al., 2012; Werner et al., 2015).

Economic Viability

It is seen in some reports that the estimated resource amount is much more inflated than the real resource amount present in that region. So, careful consideration is needed when testing out the viability of a drill site from an economic standpoint (Sovacool, 2014). While gas production from conventional wells can last for more than 40 years, shale gas production is seen to peak within 30 to 40 months. Most shale gas wells show decline rates of 60 to 80 percent in their very first year of operation itself, though afterward, this reduces to around 10 percent per year, which means that essentially, the producers of shale gas exchange an increase in production risk for a reduction in exploration risk (Jacoby et al., 2011; Sovacool, 2014). As a result of these fast rates of exhaustion of shale gas, in some sites, production costs in plays exceed the prevailing market prices of gas, and the maintenance required to generate a substantial yield of shale gas is starting to require even more amounts of capital to be viable.

Induced Seismicity

Hydraulic fracturing and recent advances in drilling techniques have enabled us to extract resources from previously unobtainable fuel deposits like unconventional reservoirs. Still, there have been concerns about the environmental footprint of hydraulic fracturing. Some of these concerns are overuse of freshwater (Chen and Carter, 2016; Schultz et al., 2020), contamination of groundwater, and management of the brines and the flow back fluid that gets produced during hydraulic fracturing (Gregory et al., 2011; Schultz et al., 2020). The flow back fluid is almost 25 percent (varying between 10 to 90 percent) of the total amount of injected water (Haluszczak et al., 2013; Yang et al., 2013; Lee et al., 2016) and can contain chemicals, organics, proppants, excess levels of salts, and naturally occurring radionuclides. In ideal situations, the flow back fluid must be collected and properly treated before disposal (Kargbo et al., 2010; Haluszczak et al., 2013; Lee et al., 2016).

Since it is costly, the most common method of flow back fluid and brine management is the disposal of the produced brine into subsurface formations (Ellsworth, 2013; Lee et al., 2016; Schultz et al., 2020). It has been adequately documented that the disposal of brine into subsurface formations can lead to the possibility of earthquake induction (Healy et al., 1968; Ellsworth, 2013; Schultz et al., 2020). There has also been some research on the direct correlation of earthquake induction with hydraulic fracturing and a positive relationship has been established between them (Atkinson et al., 2020; Schultz et al., 2020). Hydraulic fracturing generally increases the permeability of almost impermeable strata to facilitate gas flow by causing shearing and tensile failures along already present natural fractures (Rinaldi and Rutqvist, 2019; Schultz et al., 2020). Stimulation of sites by using hydraulic fracturing is often occupied by small–scale fracturing events, which are seen to be microseismic (Mw < 0) in nature (Warpinski et al., 2012; Eaton and Schultz, 2018; Li et al., 2019; Schultz et al., 2020). Nowadays, we are focusing more and more on the unique cases where hydraulic fracturing can cause reactivation in a preexisting fault, thereby causing or inducing seismicity in the regions around the fault. This happens because there is a frictional balance between the effective normal and shear stresses on a fault towards its failure condition, and hydraulic fracturing tends to disrupt the balance (Atkinson et al., 2020) by the introduction of fluids which can lead to a drop in effective pressure due to the increase in reservoir pore pressure. If we consider the case of Oklahoma, a tectonically stable state in the USA, it can be seen that from 1973 to 1999, only 1.6 earthquakes were reported per annum; however, since 2009, which is when wastewater injection started in Oklahoma, the number of earthquakes has undergone a drastic increase of up to a maximum of 887 in 2015 (Powers et al., 2021). The risk of the M 6.0+ earthquake in Oklahoma has nearly doubled in the last few years (Lee et al., 2016). We can also note that earthquake hazards in the central USA have generally increased with injection-induced seismicity studies, as seen in the cases of the 2011 M 4.7 earthquake in Guy, Arkansas (Horton, 2012), 2011 M 5.3 earthquake in Trinidad, Colorado (Rubinstein et al., 2014), 2012 M 4.8 earthquake in Texas (Frohlich et al., 2014).

Conclusion

Although shale gas has very positive prospects in replacing coal and petroleum as energy sources, exploration, drilling, and production must be more technologically optimized and made more economically feasible for shale gas to be viable in other countries as it has been in the USA. The environmental footprint of shale gas exploration also has to be reduced significantly so that the surrounding area surrounding the drill sites does not get contaminated and public opinion can be strengthened. Since each drill site in shale gas exploration is unique, it is of paramount importance that the US model of shale gas exploration is not applied everywhere; however, all the other countries with their shale gas prospects develop well-tailored methods of shale gas exploration suitable for the areas present there. For countries like India, such energy resource is entirely unexplored and needs substantial research and development for successful commercial exploration.

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