Sustainable transformation of the global energy system: Natural gas in focus

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Abstract. The global energy system is experiencing a transformation. An analysis of the dynamics of global energy production and consumption indicates that a paradigm shift is occurring toward more reliable and sustainable energy sources with the dominance of natural gas. Even though the reserves-to-production ratio for hydrocarbons is declining, it is natural gas that can ensure the sustainable development of the energy system to meet the growing energy needs of humankind. Natural gas can also significantly reduce the environmental burden. In the medium term, it will be the main source of energy along a gradual transition to renewable energy. Natural gas can serve as a transition fuel within a broader deployment of hybrid energy technologies. Hybridization—the generation of energy using both fossil fuels and renewable energy sources—is one of the most promising areas of energy system development, contributing to a significant reduction in greenhouse gas emissions. In our opinion, hybridization based on natural gas is a “bridge to the future” for the world energy system.

1. Introduction

The global rapid growth of energy consumption during the last century, advancing energy technologies, and the overall importance of the energy industry have accelerated transformation processes in the global energy system [1, 2]. Current trends and shifts in the global energy system are, for example, changing its market design, pushing the growth electrification, creating global competition in the energy sector with a strong geopolitical component, and affecting commodity prices [3]. In addition, there is a strong influence from new technological solutions [4], which allow for more efficient decentralized and distributed electricity generation, increased energy access, and renewable energy production.

An analysis of global energy production and consumption shows the main trends in the energy system transformation, and observes a general trend in the decreased consumption of energy generated from fossil fuels. However, the share of natural gas in the world energy balance is constantly and steadily increasing. In the short term, natural gas is likely to be the dominating source of energy in the structure of the global energy balance [5-7].
2. Natural gas in focus

The dynamics of the energy production in the world from 1980 through 2018 as presented in figure 1 shows that fossil fuels remain the main source of energy in the mid-term [8]. Their share of the global energy balance is almost 85%. During the same period, the share of oil decreased by 13.8%, since oil consumption is being constantly and significantly reduced in centralized electricity generation. Currently, oil is mainly used to produce fuels, lubricants, and petrochemicals. The share of natural gas has considerably increased by 5.7%. There is also a 5.1% increase in renewable energy production, which is a result of significant investments in renewable energy development [9, 10]. These investments are, to a large extent, associated with an understanding of the negative environmental consequences of the accelerated development of fossil fuel-based thermal energy, as well as the limited fossil fuel reserves [11].

Figure 1. The dynamics of the energy production in the world, 1980–2018 [5].

The dynamics of the petroleum market in general could be evaluated by a “reserve-to-production ratio” (RPR). RPR is calculated as the ratio of the amount of known hydrocarbon reserves to the amount of hydrocarbons produced per year [8]. Figure 2 shows the dynamics of reserves in the “proved reserves” (1P) category, calculated using the Petroleum Resources Management System (SPE-PRMS), [12] and hydrocarbon production from 1980 through 2018 [8]. In this period, the increase in hydrocarbon reserves amounted to 255 billion tonnes of oil equivalent (toe) or 161%. The increase in production in the same period amounted to 3.48 billion toe or 81%. Thus, the reserves growth rate is two times higher than the production growth rate. However, as it is possible to see from figure 2, RPR has significantly decreased during the last eight years, which indicates a lag in the growth rate of reserves in relation to the growth rate of production.
Figure 2. Proved hydrocarbon reserves, production, and RPR in the world, 1980–2018.

The distribution of proved hydrocarbon reserves (1P) with a probability of at least 90% of extraction to the surface in the different regions and continents is shown in table 1 [8].

Table 1. Proven hydrocarbon reserves in 2018 [8].

| Region             | Oil     | Natural gas | Total    |
|--------------------|---------|-------------|----------|
|                    | billion toe | trillion m³  | billion toe | billion toe |
| North America      | 35.4    | 13.9        | 12.5     | 47.9       |
| South and Central  | 51.1    | 8.2         | 7.4      | 58.5       |
| America            | 21.5    | 66.7        | 60.0     | 81.5       |
| Europe & Eurasia   | 113.2   | 75.5        | 68.0     | 181.2      |
| Middle East        | 16.6    | 14.4        | 13.0     | 29.6       |
| Africa             | 6.3     | 18.1        | 16.3     | 22.6       |
| Asia Pacific       |         |             |          |            |
| Total World        | 244.1   | 196.8       | 177.1    | 421.2      |

These data indicate that natural gas reserves are 40% of the total hydrocarbon reserves. Russia has the largest reserves of natural gas (19.8%) in the world, followed by Iran (16.2%) [8].

2.1. More natural gas to come?

It is necessary to underline the fact that data on reserves only account for conventional natural gas resources. It is based on the assumption that these reserves are limited. The assumption derives from the concept of the biogenic genesis of hydrocarbons. According to this concept, all hydrocarbons on our planet—oil, natural gas, oil shales, bitumen, malt, asphalt, etc.—were formed from organic matter at a depth of 6–8 km [13, 14].

Experimental data received by independent groups of researchers in different laboratories in recent years [15, 16] as well as geological observations [17] confirm the modern concept of the abiogenic deep genesis. This concept recognizes that hydrocarbon compounds are generated in the mantle and migrate through the migration channels into the Earth’s crust where they form oil and gas deposits in any kind of rock in any kind of structural position [17]. This concept allows for a reconsideration of the structure, size, and distribution of the world's hydrocarbon reserves, accounting for unconventional sources of hydrocarbons, and especially unconventional natural gas reserves.
Estimates of the unconventional natural gas reserves–shale gas and gas hydrates–vary significantly, but even the most conservative estimates are significant. According to the U.S. Energy Information Administration (EIA) [18], technically recoverable shale gas reserves in the world are estimated to be 207 trillion m$^3$. Estimates of methane hydrate reserves are even more impressive. One cubic meter of gas hydrate can contain up to 180 m$^3$ of methane. The estimated methane hydrate reserves vary from $0.7 \times 10^{16}$ to $2 \times 10^{16}$ m$^3$ [19].

2.2. The era of natural gas
The above-mentioned data indicate that the natural gas reserves in our planet are almost inexhaustible. Developed networks of gas pipelines and widely used technologies of natural gas compression and liquefaction offer the possibility of delivering this source of energy to almost any place, and to produce energy relatively cheaply. The combustion of natural gas releases very small amounts of sulphur dioxide and nitrogen oxides, and virtually no ash or particulate matter. It is possible to state that natural gas is the most environmentally friendly fuel of all organic fuels [20, 21].

The existing natural gas transportation and distribution infrastructure is constantly developing, making natural gas the cheapest, most affordable, and energy-efficient type of fossil fuel for generating heat and electricity.

3. Renewable energy and hybrids
Energy production by renewables (geothermal energy, biomass, solar, and wind) has increased by 50 times over the last 35 years (Figure 1). At the regional level, renewable sources are already playing an important role in the energy supply. Among the largest EU economies, the share of renewables in the total energy production has already reached 14.6% in Germany, 12.4% in the UK, and 9.7% in Italy [8].

Despite such significant growth, the share of renewables in the global energy balance is still insignificant (about 4%) and is approximately 11% with the inclusion of hydropower [8]. According to British Petroleum’s forecast, the share of renewable sources (including hydropower) in the global energy balance will not exceed 22% by 2040 [5]. ExxonMobil has presented the similar numbers: nuclear and all renewables will cover 25 percent of global energy demand in 2040 [22]. This means that hydrocarbons will continue to dominate in the global energy balance.

3.1. Hybridization of energy system
Can technologies for generating energy from fossil fuels, in particular natural gas, and renewable energy technologies work together? Hybridization—the joint generation of energy using fossil fuels and renewables—is one of the most promising areas of the development of energy generation technologies, which contributes to a significant reduction in greenhouse gas emissions. Hybrids have already shown their efficiency and wider applicability for decentralized and remote energy consumers and in harsh climate conditions, and have considerable environmental and economic benefits [23]. Hybrids are also applicable within the oil and gas industry to minimize losses and optimize hydrocarbon production. Several existing and functioning examples of such kinds of hybridization support the statement.

Chevron Texaco installed a 500–kW photovoltaic (PV) system at the Midway–Sunset oil field in California (USA). The electricity produced from the PV system supplies approximately 5% of the total electricity demand at the Midway–Sunset oil field [24]. Two 5 MW wind turbines were built at the Beatrice oil field, located 24 km off the northeast coast of Scotland. The electricity produced from wind turbines supply approximately 30% of the total electricity demand of the Beatrice Alpha platform [24]. Chevron Texaco, together with Bright Source Energy, installed a 29 MW centralized solar thermal system at the Coalinga oil field located in western California. According to the reports, using solar thermal technology instead of natural gas reduced the cost to create steam for enhanced oil recovery (EOR) by approximately 120 MM$\text{Btu}/h$ [24].

Hybrids have wider applicability far beyond the decentralized application and energy industry itself and can serve as a “bridge to the future” for the global energy system.
4. Discussion
Natural gas proposes a complementary value for renewable energy generation. However, to capitalize on this value, there is a need for financial support. Specifically, proper investment sends a signal that energy companies should be created through the establishment of well-designed capacity remuneration mechanisms.

Natural gas and renewables’ combined usage via hybrid technologies appear complementary in many respects:
- low capital costs and variable fuel costs for natural gas electricity generation complement higher capital costs, but there are generally zero fuel costs (excluding bioenergy) for renewable energy generators;
- hybrid natural gas–solar and natural gas–wind technologies could significantly improve the stability of the electricity system by mitigating intermittency;
- power-to-gas hybrid solutions allow for the conversion of surplus renewable generation to hydrogen using electrolyzers, which is then stored in the natural gas infrastructure as an efficient storage technology [25];
- natural gas can play a key role in supporting the grids’ voltage and frequency by providing critical services for energy storage;
- hybrid systems established in autonomous combined power plants are among the most promising solutions for the energy supply of remote and hard-to-access regions [26, 27].

According to a study published in [28], the development of natural gas–renewable hybrid technologies “have led to deep and still-evolving changes to market structures, physical systems, business practices, and regulatory policies”. Such hybrid technologies can play leading roles in the electric power sector in the near future.

During energy system transformation towards sustainability, active partnerships between the natural gas and renewables sectors can lead to efficient and flexible electricity markets, which are also better adapted to reaching the long-term energy system goals of increasing energy security and mitigating climate change.

5. Conclusions
Hydrocarbon reserves, specifically of natural gas, are significant despite the decreasing RPR. Unconventional natural gas reserves are even more dramatic. The existing natural gas transportation and distribution infrastructure is constantly developing, making natural gas the cheapest, most affordable, environmentally friendly, and energy-efficient type of fossil fuel for generating heat and electricity. Therefore, it is natural gas that can become the main energy source in the 21st century. The increasing share of natural gas in the global energy balance will be accompanied by the growing shares of renewable energy in the form of hybrid technologies. Thus, long-term energy strategies should be directed toward further and more intensive production and use of natural gas, and increasing investments should be made in the development of hybridization.

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