Leak Detection and Repair in the Russian Federation and the United States: Possibilities for Convergence

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Highlights:

- The Russian Federation and United States significantly contribute to the global methane emission budget
- Uncontrolled and underreported leakages are institutional and economic in nature
- Existing gaps in regulation and technological adaptation can be significantly reduced
- There is room for cross-national improvement of regulatory frameworks
- High potential exists for collaborative efforts and exchange of best practices

Abstract. This study focuses on the mitigation of methane emissions from large-scale oil and gas infrastructure. It is built on two complementary cases of the Russian Federation and United States, who are two of the largest oil and natural gas producers, possess the most extensive oil and natural gas pipeline networks, and both deal with the emerging problem of high-level methane emissions. The paper attempts to identify differences and similarities between the countries' approaches in mitigating methane emissions. Analyzing open data on methane emissions, legislation, corporate standards, and reports of state agencies, this research seeks to answer the question of whether there is space for cooperation and exchange of experiences and best practices between the two countries in methane leak detection and repair (LDAR). Our analysis shows a considerable lack in corresponding regulation in both countries and identifies a dramatic misalignment between international, national, and corporate actions. However, we see the opportunity to significantly reduce the existing gaps in regulation and technological adaptation through international cooperation and exchange of best practices. The paper supports corresponding policy and practical implications that rely on bilateral and multilateral initiatives and a cooperative approach between oil and gas companies and the government.

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1. Introduction

The past decade has witnessed considerable growth in global energy production and consumption, where natural gas is taking a leading role as a cleaner 'transition fuel' (BP, 2019b). In 2018, the production of natural gas increased by 5.2% from the previous year, more than double the average ten-year growth rate (BP, 2019a). Both the Russian Federation and United States contributed to that growth as large consumers and as world-leading natural gas producers.

The natural gas sector is expected to continuously grow worldwide, because of increasing consumption patterns and the replacement of other less climate-friendly fuels like coal (Bessel et al., 2020). The critical reasons for that growth stem from direct causal relationships between rising natural gas consumption and expanding national economies (Aydin, 2018; Fadiran et al., 2019; Ummalla and Samal, 2019), as well as the replacement of coal by natural gas, which serves as a so-called 'bridge fuel' (Levi, 2013; Yuan et al., 2018; Zhang et al., 2016).

Yet for all the apparent advantages (Tollefson, 2013), the natural gas surge may seriously exacerbate global climate change through emissions of methane (CH_4), the primary component of natural gas, which possesses one of the highest global warming potentials of all the major greenhouse gases (GHG). Evidence shows methane emissions have a higher impact than other industrial GHG (UNCC, 2014). With less molecular weight, methane quickly migrates and spreads into the upper layers of the atmosphere, and also traps radiation more efficiently than carbon dioxide (CO_2). Consequently, the impact of CH4 on the climate exceeds that of CO_2 by twenty-five times (IPCC, 2007).

Methane may leak from oil and natural gas equipment during normal operations, routine maintenance, and system upsets. Natural gas leakage is a common phenomenon in all elements of the value chain: production, transportation, storage, and consumption (cf. Fevre, 2017). Such 'fugitive emissions' are generally accidental and difficult to detect and measure. The detection and mitigation of leakages is an issue of long-term sustainability and instrumental in decreasing the climate and environmental burden of the global energy industry. More importantly, neither the Kyoto Protocol (UNFCCC, 1997) nor the Paris Agreement (UNFCCC, 2015) regulates such non-industrial losses.

In relation to methane emissions, the Russian Federation and United States face some common challenges. The most important are those related to: large-scale oil and natural gas infrastructure; the growing role of natural gas for both countries; corresponding international environmental obligations (e.g., Paris Agreement); and the damages, losses, and inefficiency that leakages cause to oil and gas industrial processes (Hausman and Raimi, 2019; ICF International, 2014a, 2014b). Therefore, cooperation between the two countries in managing LDAR seems highly necessary and relevant. Oil and gas companies, as well as U.S. and Russian federal regulators, may benefit from collaborating with each other on mitigation efforts. Moreover, the most recent data on global methane emissions by the International Energy Agency (IEA, 2020) signals the possibility that cooperating on the international level can significantly contribute to the mitigation of methane emissions.

However, certain restrictions prevent the Russian Federation and United States from sharing and exchanging their LDAR technologies and experience directly. Among these are that the oil and gas industry is a strategic sector of both economies, which causes strict rules of commercial confidentiality, as well as national security concerns. Furthermore, there is intense competition between Russian and U.S. oil and gas companies in global energy markets.

Scholars have paid considerable attention to the problem of mitigating methane emissions from the oil and natural gas infrastructure (cf. Waxman et al., 2020), including simulation studies along supply chains (cf. Alvarez et al., 2018; Höglund-Isaksson, 2017; Ren et al., 2017). Several researchers have studied policy and regulation within both countries (cf. Evans and Roshchanka, 2014; Lechtenböhmer et al., 2007; Ravikumar and Brandt, 2017). However, to the best of our knowledge, there is only one comparative cross-national study within the English- and Russian-language literatures, a report commissioned by Gritsevitch and Kutepova (2009). This gap demands scholarly attention, especially in light of global climate challenges.

Therefore, this study sets up the following question: is there a place for cooperation between the Russian Federation and United States to strengthen national LDAR programs and reduce methane emissions?

We analyze the issue of mitigating methane emissions from large-scale oil and gas transportation systems from both regulatory and technology perspectives, which allow us to infer reliable practical and policy implications. Despite apparent barriers to U.S.-Russian cooperation in LDAR, related to historically defined differences, we argue that the potential economic and social benefits not only transcend those divides, but also bring a cleaner energy future within close reach of all.

This research unfolds in five parts, investigating specific subsections of the stated questions. Section 2 introduces the historical background of the U.S. and Russian natural gas grid development to illuminate their organizational differences. Section 3 analyzes the current state of emission volumes from large-scale oil and gas transportation infrastructure in the Russian Federation and United States. Section 4 focuses on the regulatory aspects that currently govern methane emissions in both countries. Section 5 is devoted to technological aspects of LDAR, including best practices and the current state of technology. Section 6 discusses the policy and practical implications of possible regulatory convergence or adopting set of standard guidelines, practices, and procedures, and it outlines a series of broad policy recommendations, followed by final conclusions in Section 7.

Following this structure and logic, our research attempts to investigate the issue from various perspectives and arrives at conclusions that might be of particular interest to various beneficiaries, including those in government, business, academia, and society in general.

2. Historical Background

Decades after coal and oil began powering the industrialized world, natural gas emerged as a vital fossil fuel in its own right, thanks in large part to U.S. and Soviet industries. Born in the 1880s, the U.S. natural gas industry coalesced gradually after World War I to supply domestic farms, homes, and factories with "clean, cheap heat" before expanding into foreign markets (Herbert, 1992, p. 43). By contrast, the Soviet industry came together rapidly during the Cold War to facilitate economic recovery and expansion, adopting an export strategy early on to absorb record-breaking discoveries in Siberia (Högselius, 2013, pp. 14-15). Below, we trace these converging historic patterns of development across roughly three periods: 1) mid-twentieth-century expansion, 2) late-twentieth-century stagnation and, 3) early-twenty-first-century revival. Figure 1 depicts this periodization in terms of production.

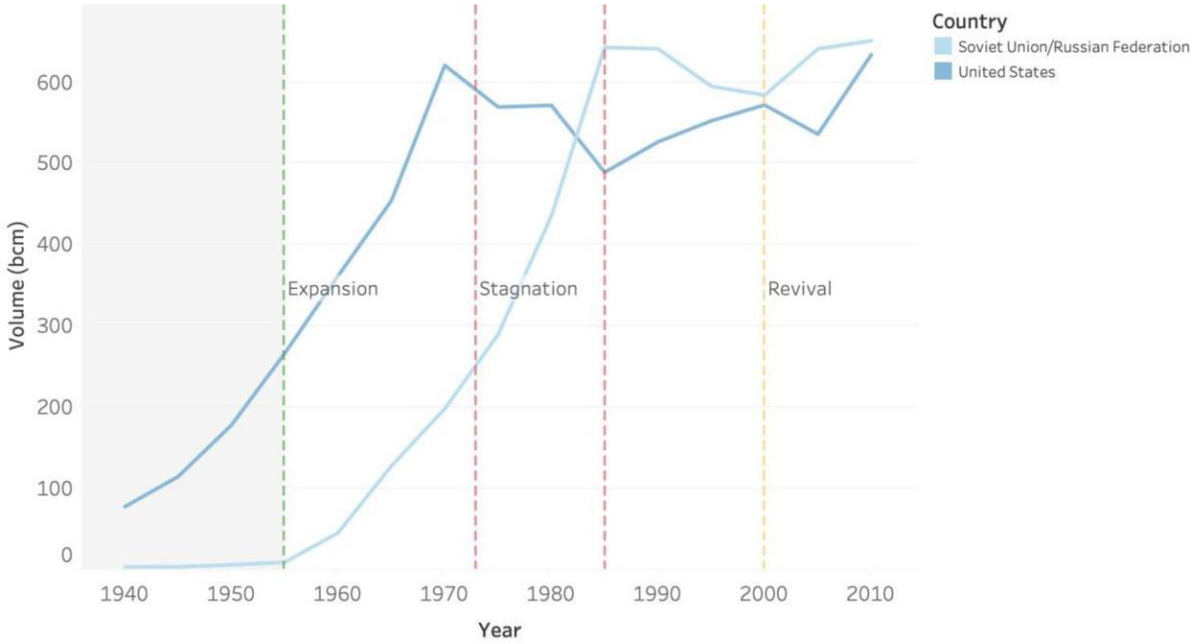

Figure 1. Natural Gas Production in the Soviet Union, Russian Federation, and United States, 1940-2010 (EIA, 2020; Goscomstat USSR, 1988; Rosstat, 2019)

2.1 Mid-Twentieth Century: Expansion

Between 1950 and 1960, natural gas burst onto the domestic energy scene of the globe's two superpower rivals with comparable dynamism for different reasons. Growth in the U.S. resulted from a combination of adequate government regulation and powerful market forces, specifically from homeowners replacing coal-fired furnaces with cleaner gas-fired alternatives in the suburbs across the country. Aided by generous subsidies, an already mature industry based primarily along the Gulf Coast extended its reach for the first time into the northeast, southeast, and northwest. The total number of residential customers almost doubled (Herbert, 1992, p. 116).

In contrast, growth in the Soviet Union occurred by administrative fiat in response to coal shortages wrought by wartime destruction. A burgeoning oil industry replicated successful experiments with gas mains in Moscow across cities in Ukraine, the Volga Region, and the Urals, laying the groundwork for larger projects. In November 1957, A. K. Kortunov, the leading Soviet gas expert, formulated the challenge of surpassing the U.S. in production. Khrushchev responded favorably, mandating higher output by formal decree in August 1958 (Högselius, 2013, p.14,37).

The 1960s and 1970s saw the two industries adopt divergent operating strategies in the face of complex geopolitical forces. In the U.S., some two hundred natural gas firms not only doubled down on residential consumers, reaching all fifty states by 1966, but also lavished attention on industrial ones, reaping windfall profits due to low prices. By 1970, the amount of natural gas relative to the amount of oil used in the U.S. economy reached 74 percent. Only the country's "enormous fleet" of gasoline-guzzling automobiles prevented natural gas from surpassing oil altogether (Herbert, 1992, p. 111).

Simultaneously in the Soviet Union, Kortunov and top-level policymakers began to consider partnering with buyers of their country's gas outside of the Communist Bloc. The revelation of supergiant deposits in the Tyumen region, as well as the successful completion of the Druzhba or "Friendship" oil export pipeline, the first trans-European petroleum artery, served as powerful motivators. However, relaxation in East-West relations, or détente, ultimately set the stage for the first gas Soviet deal with a Western European country, Austria, in 1968 (Högselius, 2013, pp. 63–66).

Throughout these bonanzas, both industries constructed pipeline networks that reflected competing modes of economic organization. The U.S. network developed from two interrelated trends. The first involved the conversion of antiquated infrastructure in large cities built initially to transport manufactured gas or gaseous fuel created by burning coal (Tarr, 1999). The second involved the building of more modern, large-diameter pipelines from producing states in the south to growing markets in the northeast and west. Taken together, the trends resulted in a patchwork of state systems bridged by interstate trunk lines, one that proved inefficient by Soviet reckoning. Indeed, Kortunov conceived the Soviet network as a foil for its U.S. counterpart. Instead of connecting individual gas fields with specific user regions, he proposed linking multiple sources to major urban centers to ensure reliability and security. The scheme became official policy around 1960, generating an integrated grid of transmission lines that later fed major export arteries (Högselius, 2013, p. 21).

2.2 Late Twentieth Century: Stagnation

A series of Cold War disputes punctuated the golden age of U.S. and Russian natural gas development before abiding structural problems led to its abrupt end. Fearful of communist influence, the White House turned to economic sanctions aimed at sales of large-diameter line pipe and other technologies to the Soviet Union on two separate occasions. The Kennedy administration imposed an embargo through NATO in 1962 to slow the building of Druzhba; the Reagan administration, precisely twenty years later, thwarted progress on the Yamal Pipeline, a major natural gas export artery to Ukraine. Both failed to achieve any meaningful slowdown in Soviet pipeline construction (Graebner, 2008, pp. 29–33; Stent, 1982, p. 102). By way of evidence, Figure 2 illustrates the contemporaneous expansion of the two countries' natural gas grids.

In the interim, unanticipated developments in the Middle East halted the U.S. industry in its tracks. In 1973, an embargo on the region's oil shocked U.S. consumers into conserving fuel of every kind. A significant percentage of homeowners who used natural gas as their primary heating source immediately began taking measures to reduce their energy costs, including weatherproofing windows, adding storm doors, and closing off rooms. Demand plummeted almost overnight, exacerbating the effects of a declining customer base that had already been precipitated by production shortfalls (Herbert, 1992, pp. 128–129).

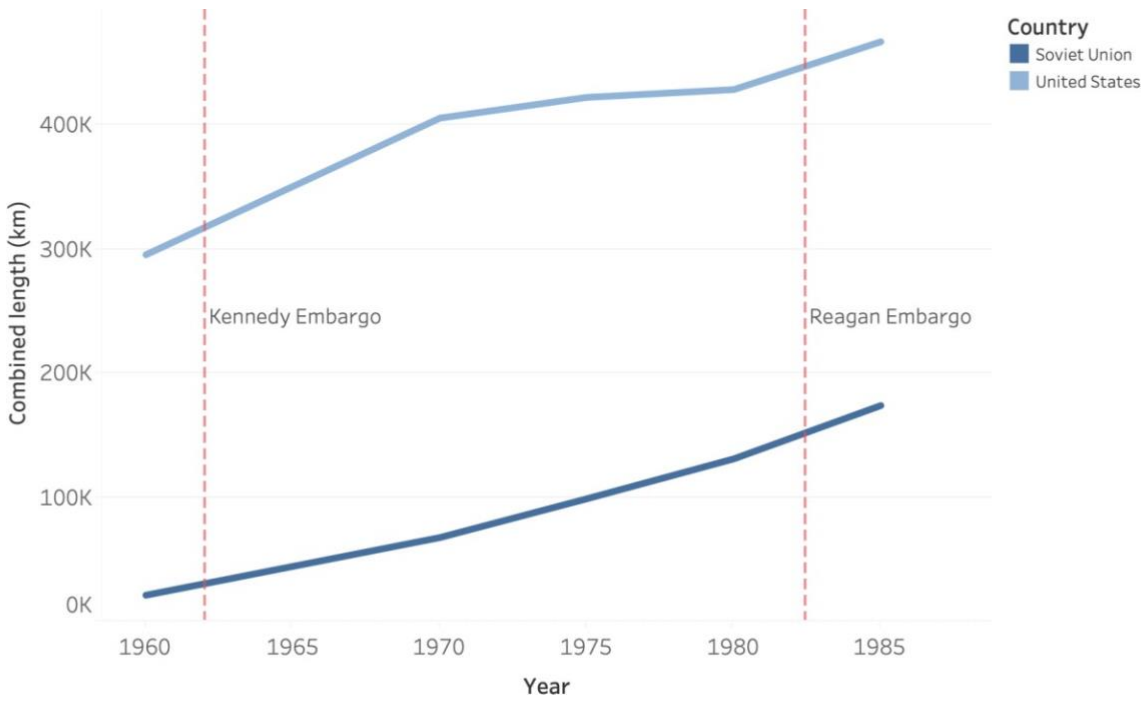

Figure 2. Combined Length of Soviet and U.S. Natural Gas Transmission Lines, 1960-1985 (Bureau of Transportation Statistics, 2018; Central Statistical Office of the USSR, 1986)

Regardless, by the early 1980s, the Soviet and U.S. industries both reeled from painful recessions. World oil prices collapsed in 1986, slashing Soviet export revenues. The budget shortfalls weakened the Soviet government's ability to realize policy agendas, including major socio-economic reforms like perestroika and glasnost, setting the stage for communism's fall from 1989 through 1991.

Fraught restructuring efforts condemned both industries to suffer instability from the mid-1980s to early 2000s. In 1989, the U.S. Congress capped a decade-long effort to deregulate natural gas prices, bypassing the Natural Gas Wellhead Decontrol Act. The legislation integrated previously independent inter- and intra-state markets, ending regulation-induced shortages within just three years. It also reconfigured distribution systems too quickly, enabling a so-called "overhang" in supply that kept market prices low and thereby discouraged growth. Between 1991 and 2000, domestic production increased only 6 percent, while imports grew 15 percent (Joskow, 2013, pp. 339–340).

Around the same time, the first post-Soviet government in Moscow decided to preserve Gazprom, the successor to the Ministry of Natural Gas Industry USSR, as Russia's dominant gas supplier (Talipova et al., 2019), despite restructuring and privatizing most of its Soviet inheritance. The underlying infrastructure proved a crucial factor, defying attempts to partition it among the new Commonwealth of Independent States. As a result, the Russian economy became increasingly gas-powered. Between 1990 and 2000, the share of natural gas in Russia's total primary energy consumption grew from 42 to 53 percent (Gustafson, 2020, p. 242). Production declined, however, stymied by inflation, corruption, and capital flight.

2.3 Early Twenty-First Century: Revival

Stagnation gave way to revival in the early 2000s, as the ongoing U.S. shale gas revolution, along with European efforts to combat climate change, unexpectedly aligned markets and policy agendas. Defined as a gas trapped in low-permeability source rocks, shale gas first became economical to develop at scale in 1998 when Mitchell Energy, a Texas-based production firm, successfully combined several new extractive technologies at sites near Fort Worth. Shortly after that, directional drilling and hydraulic fracturing, or "fracking", found full application. Shale gas production skyrocketed from "almost nothing" in 2000 to more than 140 million cubic meters per day in 2010 (Joskow, 2013, p. 340).

Crucially for Russia, the boom coincided with the formalization of the Kyoto Protocol by eighty-three signatories, including the European Union (EU). The resultant turn toward lower-carbon energy in EU member-states spurred developing gas pipeline projects like Nord Stream to Germany, which survived disputes between Russia and Ukraine in 2006 and 2009 to come to fruition in 2011. Since then, member-states have continued to import large volumes of Russian gas, seemingly elevating its role in their decarbonization efforts. At present, Russia appears poised to complete yet another pipeline, Nord Stream 2, by early 2021 (Gustafson, 2020, pp. 372–379).

To summarize, the Soviet and U.S. natural gas industries ultimately constructed transportation grids that represent opposites in terms of structure, regulation, and composition. Today, the U.S. grid comprises more than 485,000 km of transmission lines, some fifty-six constituent systems, and mostly medium-diameter line pipe (500+ mm) (Folga, 2007). The Russian grid comprises about 180,000 km of transmission lines, an extensive integrated system, and mostly large-diameter line pipe (1400+ mm) (Gazprom, 2020a). Moreover, the two grids also differ in ownership structure. Whereas dedicated companies generally own and operate each of the many U.S. systems, a single dominant supplier, Gazprom, controls the primary Russian system. Figure 3 illustrates the contrast.

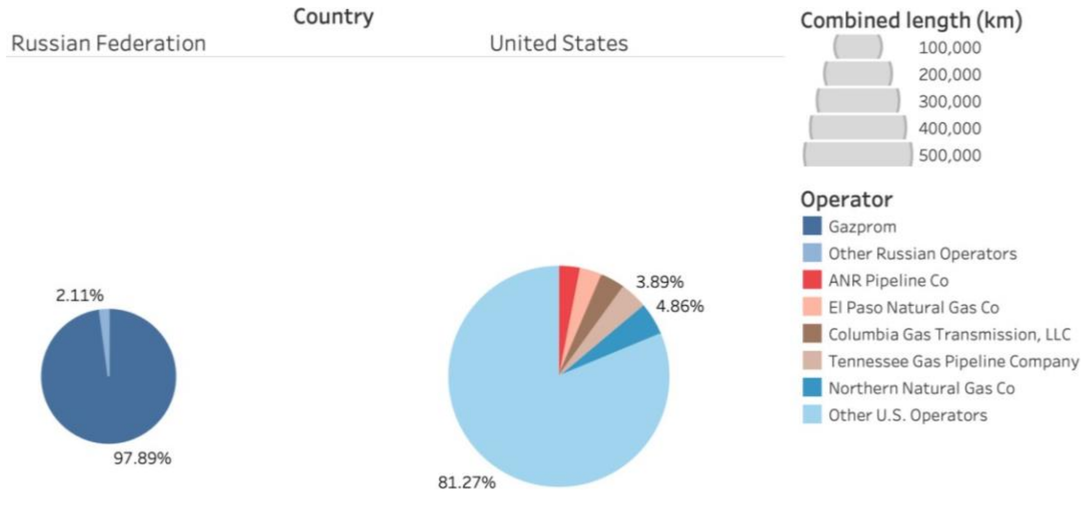

Figure 3. Length and Ownership Structure of Russian and U.S. Natural Gas Grids, 2018 (Bureau of Transportation Statistics, 2018; Gazprom, 2020a; Rosstat, 2019)

Today, the construction of natural gas infrastructure in Russia and the U.S. proceeds apace. The expansion has focused the attention of stakeholders on questions of regulation, mainly concerning matters of permits, inspection, and environmental risk. We explore these questions in further detail in the following sections.

3. Methane Emissions from Large-Scale Oil and Gas Transportation Infrastructure

Natural gas contains a mix of heavier hydrocarbons in its composition (98% of pure methane and 2% of ethane for natural gas, and 70% of pure methane and 30% of heavier hydrocarbons for associated gas). Due to the lightest gaseous form, pure methane tends to leak from the oil and natural gas infrastructure. The reasons operators do not adequately control leakages may be both institutional and economic in nature, e.g., low gas prices. Methane leaks are generally accidental, difficult to detect, and even more challenging to measure. According to government estimates, transportation and storage processes in 2016 accounted for 86.7% and 36.8% of total methane emissions from Russian and U.S. natural gas systems, respectively (EPA, 2020, p. 3.87; Rosgidromet, 2018, p. 79). The shares are disputed, and in any case, appear likely to increase as the systems enlarge to accommodate rising demand. In the following Section, we analyze the current state of methane emissions on the national level and discuss their origin.

3.1 National Methane Emissions

Statistics on methane emissions from oil and natural gas activities in the Russian Federation and the United States show that the amounts are significant. Total annual methane emissions for the Russian Federation reach 12361 kilotons (kt), and 11377 kt for the United States, which constitute 15.2% and 14.0% of total global emissions, respectively (IEA, 2020). From these amounts, 30% of Russian and 33% of U.S. emissions are fugitive (Figure 4).

Most methane emissions derive from five primary sources: onshore conventional oil and gas, unconventional oil and gas, and downstream gas. In turn, oil contributes nearly 36% and 30% to methane emissions from the Russian Federation and United States, respectively. The structure of methane emissions differs in the two countries, predominantly due to the origin of oil and natural gas production. Figure 4 shows that the onshore conventional gas industry provides nearly 50% of total methane emissions in Russia. In the United States, a tremendous ramp-up of unconventional production has caused high volumes of emissions, making unconventional natural gas production the most significant source for methane emissions. Over the past two decades, the volume of vented methane (including flares) across the U.S. reached a record high level at 36 MMCFD, according to estimations of the U.S. Energy Information Administration (EIA, 2019a).

Experiencing a continuous increase in volume of associated gas extraction (Vorobev and Shchesnyak, 2019), the Russian Federation mostly focuses on associated gas utilization. Still, the broader problem of methane emissions is unresolved (cf. Røland, 2010). New pipelines and LNG export projects without proper regulation, for example in the environmentally sensitive Arctic region, make future leaks more likely. Emissions from the Russian natural gas long-distance network is around 0.7% of all deliveries (Lechtenböhmer et al., 2007, p. 392).

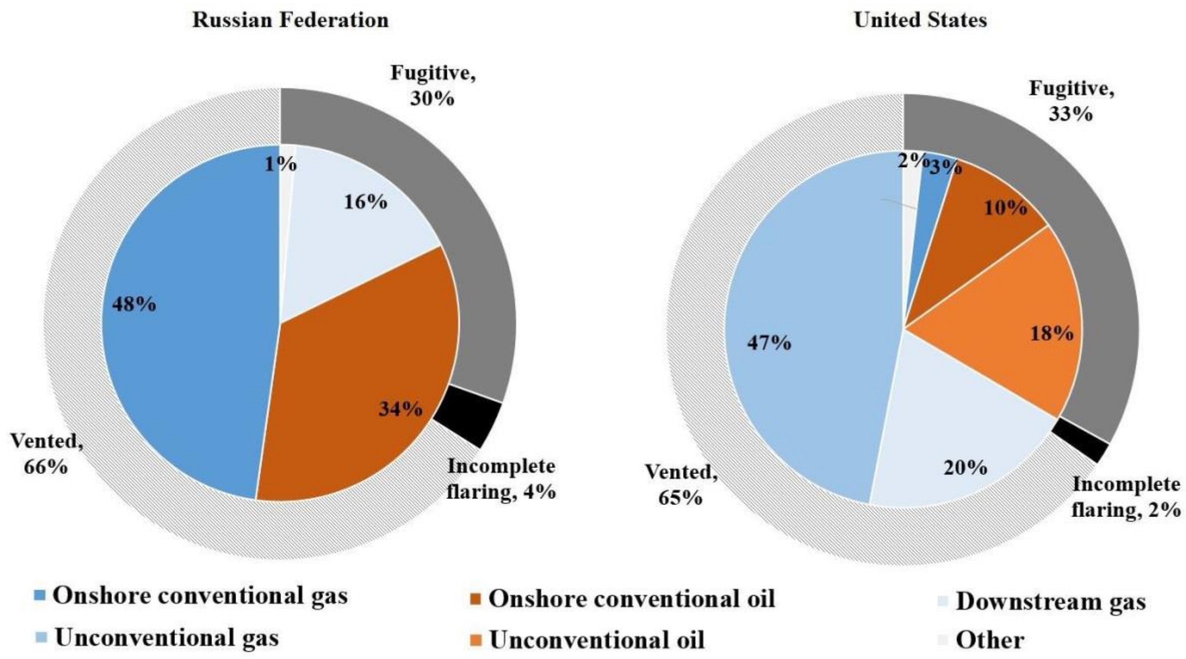

Figure 4. Estimated total methane emissions from oil and natural gas activities (IEA, 2020, conducted by authors)

In the United States, the energy sector (including natural gas systems, petroleum systems, and stationary and mobile combustion) is the leader in methane emissions, as compared to agriculture, waste management, or industrial processes (EIA, 2011, p. 35). The existing petroleum infrastructure contributes almost a third to the volume of emissions (EPA, 2019). State agencies in the United States claim that methane leakage can be identified in various stages of the industrial process in the oil and gas sector, including drilling (U.S. Forest Service, 2011, p. 7). However, the unconventional gas production sector remains the most critical methane emitter (Omara et al., 2016; U.S. Department of Energy, 2016).

3.2 Contribution to Methane Emissions by Oil and Gas Companies

According to the origin of methane emissions, oil and gas companies have a direct role in mitigating those. Some oil and gas companies report that they are already actively engaged in methane emissions reduction, or are taking other related measures to be environmentally and climate responsible. Nevertheless, recent data shows that 20 oil and gas majors are responsible for 35% of all the GHG emissions worldwide (including methane) (Taylor and Watts, 2019). Among the 'leaders' are Chevron, Gazprom, ExxonMobil, BP, and Shell. Below, we analyze these selected companies (Table 1).

Russian oil and gas companies, Gazprom and Rosneft, have reported reducing their overall GHG emissions. Despite this, data reveals that Gazprom has worse methane emissions in comparison to other companies, both in absolute and relative numbers (27% from the total volume of the company's GHG emissions). However, it operates almost all of the natural gas infrastructure in the Russian Federation. Gazprom reports having nearly zero methane emissions across their supply chain (Gazprom, 2020b, p. 4), and suggest that their methane emissions from production, transportation, and storage are 0.02%, 0.26%, and 0.03%, respectively. Despite this controversial portfolio, Gazprom also sees the possibility for further

GHG reduction along the natural gas infrastructure, specifically through the use of methane-hydrogen fuel (EU, 2018). Rosneft stepped into the fight against methane emissions when part of it was acquired by BP and it joined the international initiative on their reduction (Rosneft, 2019). According to the company's Sustainability Report (Rosneft, 2018, p. 73), emissions were reduced by 46% during 2017, while the fugitive emissions went down by 63%. Nevertheless, CO_2 emissions have increased by 6%.

Table 1. Direct GHG and methane emissions by some oil and gas companies, 2018*[2]

Company	Gazprom	Rosneft	ExxonMobil	Chevron	Shell	BP
GHG emissions, million tonnes (CO2 equivalent)	120	76	124	59-66	71	49
Methane emissions, thousand tonnes	1317	164	284	179	92	90
Percent of methane emissions from total GHG emissions, %	27	5.3	5.6	6.8	3.2	4.5

* Data collected from companies' environmental and sustainability reports and official web pages

U.S.-based companies also show somewhat controversial results. ExxonMobil reports a high commitment to GHG and methane emissions reduction (ExxonMobil, 2020), including increasing investments in lower-emission energy solutions and intensifying deployment of carbon capture and storage. Interestingly, ExxonMobil concluded that there is substantial economic potential in reducing 15-20% of the company's total methane emissions with existing technologies (WorldOil, 2020). Chevron (2018) reports no GHG or methane emissions reduction during the last two years since 2017, when, according to the company's environmental performance, direct methane emissions were reduced by 20%. However, the company underlines short-term targets to reduce the methane emissions intensity by 25-30% by 2023. At the same time, GHG emission mitigation plans look less ambitious, as Chevron targets, on average, a 5% reduction by 2023 (a three-year plan) (Chevron, 2019), despite it having the lowest reported GHG emissions among the companies investigated (Table 1).

With the aim to compare emission volumes with European-originated oil and gas companies, this study also includes data on Shell and BP. European-based companies have, in general, more detailed emission reports, as well as reportedly lower methane emissions and intensity, whereas Russian and U.S. companies show a higher imbalance. One of the critical reasons for this are stricter governmental GHG and methane mitigation measures (Dietz et al., 2020).

Both the U.S. and Russia experience issues of underreporting actual methane emissions. Methane emissions by Gazprom from the overall gas sector are more than five times less than the latest IEA estimates (2020). In the United States, most underreporting occurs in unconventional gas production, due to the technical nature of those operations (flaring, venting, and continuous drilling of new wells) and the lack of pipeline infrastructure in unconventional fields, which comprise 17% of total gas production in the U.S. as of 2018 (EIA, 2019b).

[2] It is important to underline that companies have different approaches to reporting GHG and methane emissions, and some data (e.g. methane emissions intensity) is missing.

The analysis of methane emissions of oil and gas companies in both countries shows that much clearer and stricter regulation and coordination is required in order to achieve visible results. Oil and gas companies do not correctly report their actual volume of emissions, which makes their assessments irrelevant (further detailed discussed in Section 4.3) and complicates corresponding governmental measures. Nevertheless, despite the dramatic situation of methane leaks both in the Russian Federation and United States and overall differing structure of emissions of the two countries (Figure 4), there is shared abatement potential in the downstream gas segment (which encompasses refining, transmission, and distribution). Finally, the analysis signals that joint efforts between companies (e.g., BP and Rosneft) during acquisition can have significant results. There are grounds to believe that such individual initiatives, as well as joint collaboration, may bring positive outcomes and highlight the necessity of parallel mitigation. Parallel mitigation solutions could be efficiently applied to this segment in both Russia and the United States.

4. Regulatory Aspects

Current legislation of the Russian Federation and United States demonstrates different approaches to LDAR, based on a variety of factors: historical background, economic necessities, and various market approaches. Despite the regulatory differences, we find a lot of commonalities in practice and problems when applying each set of laws. This is explained both by the technical difficulties of regulating leaks and demonstrates a field for cooperation between oil and gas entities and the government.

The Russian and U.S. federal regulations governing methane emissions from oil and gas industries already share much in common. The U.S. regulations fall under the Environmental Protection Agency (EPA), an organization that, while constitutionally managed by the President, wields considerable independent rule-making power. Similarly, Russian regulations fall under the Federal Service for the Supervision of Natural Resources (Rosprirodnadzor). This executive organ reports to the Ministry of Natural Resources and Ecology, which reports to the Prime Minister. These state agencies implement similar control obligations and powers.

Consequently, both sets of regulations mandate component-directed LDAR programs, meaning that they require firms to conduct routine, site-by-site inspections of individual parts or machines susceptible to leakages like valves, flanges, and compressors. Both systems also appear likely to change in the near future, as a result of rule changes. In this Section, we explain the legal foundations, essential requirements, and tenuous status of each country individually before comparing them. We then provide conclusions, per the research of these regulatory aspects.

4.1. LDAR Regulations in the United States

The U.S. methane-specific regulations entered into force in 2016 as the Code of Federal Regulations, Title 40, Part 60, Subpart OOOOa (40 Code of Federal Regulations (CFR) 60 OOOOa), or what officials informally call "quad-O-a" (Kleinberg, 2020). Operating under the Obama Administration, the EPA developed "quad-O-a" while revising rules for volatile organic compounds (VOCs), a separate class of pollutant that contributes to the formation of ozone. At the time, the agency sought to build on performance standards for new oil and gas facilities that it had issued several years earlier in 2012. More importantly, it also sought to act in accordance with findings of the dangers of GHG promulgated in 2009, findings made pursuant to section 202(a) of the Clean Air Act of 1970, a comprehensive federal law that covers all sources of air emissions (EPA, 2016). Thus, the U.S. regulations represent an extension of authority granted to the EPA fifty years ago, despite their recent provenance.

The "quad-O-a" regulations approve two specific leak detection methods, as well as a process for proposing and certifying alternatives. The first method, optical gas imaging (OGI), requires inspectors to use devices that resemble handheld video cameras. The devices display plumes of methane and VOCs as dark clouds in infrared on small view-screens, working best at distances of less than three meters from targeted components. The second, EPA Method 21, involves instruments that meet strict specifications set forth in 40 CFR 60, Appendix A-7, Section 6.0. Some models resemble so-called "walkie talkies" or two-way radio transceivers capped by long wands or probes and other large flashlights with long hoses attached. Cosmetic differences aside, all of these instruments provide accurate readings only after physically contacting component surfaces. Often unreliable in windy conditions, Method 21 has largely fallen out of use, but remains the sole detection method approved in California (Kleinberg, 2020, pp. 10–11). To comply with "quad-O-a" regulations, natural gas firms must ensure that trained LDAR teams inspect their entire inventories at prescribed frequencies. While still in force as of mid-May 2020, the "quad-O-a" regulations may soon be weakened or reversed entirely.

Notably, the EPA's "quad-O-a" regulations represent only a small fraction of those which govern the operation of U.S. natural gas pipelines. At the same time, federal U.S. regulations impose safety requirements to ensure that gas pipeline leaks are compliant with public safety, without considering the risk of so-called "non-hazardous methane leaks" and their impact to the environment (Paranhos et al., 2015, p. vii).

In the United States, federal laws should be analyzed together with state regulations. The most important include: the Clean Air Act of 1963; Energy Policy and Conservation Act of 1975; Comprehensive Environmental Response, Compensation, and Liability Act of 1980; along with many others.

Further, U.S. legislation provides a vast number of bills related to the control of emissions, including the following bills with amendments to the Internal Revenue Code:

- Bill # S. 843 Carbon Capture Improvement Act of 2017
- Bill # S. 1535 Furthering Carbon Capture, Utilization, Technology, Underground Storage, and Reduced Emissions Act
- Bill # S. 2602 Utilizing Significant Emissions with Innovative Technologies Act

While not necessarily focusing on methane leaks, these bills are necessary for research, as they provide a system of financial measures towards the use of advanced technologies for capture of emissions (Congressional Research Service, 2018).

More specific regulation may be found at the state level. The U.S. Supreme Court of the United States has confirmed that states are entitled to regulate oil and gas activities (*Case: the Ohio Oil Company vs. State of Indiana*, 1900) (Institute for 21st Century Energy, 2012).

4.2. LDAR Regulations of Russia

According to the Russian legal system, this issue is regulated by federals laws, as well as by the so-called "subordinate acts" of state bodies that have to comply with legislation, but also have obligatory force for actors as well.

The Russian Federation has adopted a wide number of program documents related to methane emissions, general control of GHG, and climate change, such as: the Energy Strategy until 2030; Concept for the Formation of Monitoring, Reporting and Verification System for GHG Emissions; and the Climate Doctrine. Such sources implement the country's obligations on GHG reduction and control of emissions. The detailed action plan is provided by the Comprehensive Plan on Implementing the Climate Doctrine until 2020 and the President's Executive Order on Reduction of Emissions on GHG, among others. This set of regulations provides state authorities the ability to issue initiatives on further actions addressing modern challenges, such as the Draft of the Energy Strategy until 2035 or the Strategy on the Long-term Development of the Russian Federation with Low GHG Emissions until 2050, introduced by the Ministry of Economic Development in March 2020 (Government of the Russian Federation, 2020).[3]

Russian federal legislation includes the Federal Law on Subsoil of 21.02.1992 N 2395-1, Federal Law on Technical Regulation of 27.12.2002 N 184-FZ, Federal Law on Health Protection of Citizens of 21.11.2011 N 323-FZ, and Federal Law on Environment of 10.01.2002 N 7-FZ. Russian methane-specific regulations emerged from the Law on the Protection of Atmospheric Air of 4 May 1999 No. 96-FZ, Article 22, Item 1 (st. 22 p. 1 Law No. 96-FZ 1999).

Russian law requires natural gas firms to account for emissions and their specific sources, according to procedures established by the Government of the Russian Federation and monitored by the state agency Rosprirodnadzor. Governmental institutions, such as Rosprirodnadzor and the Russian Federal Service for Ecological, Technological and Nuclear Supervision (Rostechnadzor), impose liability measures and implement the main supervisory actions and control over companies in the oil and gas sector. To legally work around the current gap in reporting procedures, firms have taken to filing Form No. 2-TP (Air) with data from set standards, rather than actual measurements.

Lastly, in addition to the actions of Rosprirodnadzor mentioned above, the Russian Federal State Statistics Service (Rosstat) collects statistical data under the supervision of the Federal Service for Hydrometeorology and Environmental Monitoring (Rosgidromet), which have assumed the responsibility of reporting Russia's methane emissions to the United Nations.

A detailed list of the regulatory framework of the Russian Federation is provided in **Annex A**.

[3] To access references to these legal acts, refer to Annex A of this study.

4.3 Measurement Accuracy of Methane Leakages and Practical Issues of Law Enforcement

In the United States, two states, namely Texas and North Dakota, have shown dramatic increases in methane emissions along with growing shale oil and natural gas production. The challenge lies in significant emissions and leakage underreporting, as it depends on the precision of emissions calculations and willingness of companies to report voluntarily. Actual numbers may be underestimated by a factor of two (Harrison et al., 1996).

According to the U.S. Department of Energy (DOE), not all states gather and report flaring and venting data. Those who report do not necessarily follow the required reporting standard sheets. Further issues arise along with data gathering algorithms and measurement errors (cf. Elvidge et al., 2013). Therefore, existing data has a considerably exemplary character. For example, variations of estimations by source are given for the state of Texas in Figure 5.

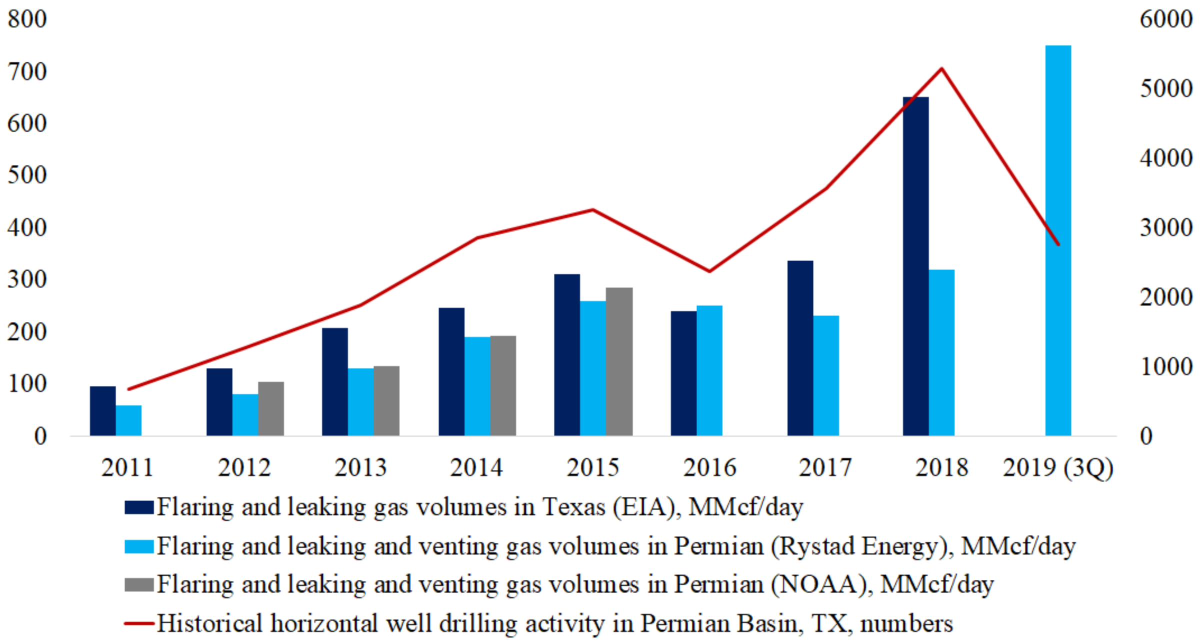

Figure 5. Gas flaring and leaking data by source and number of horizontal wells drilled in Texas, MMCFD (conducted by authors using EIA, 2018; Enverus, 2020; Rystad Energy, 2019; Willyard, 2019; Willyard and Schade, 2019)

The most significant differences in reporting come from oil and gas producers in Texas, which occur due to inefficient taxation at the state level, pipeline infrastructure restrictions, and absence of motivation for proper associated gas utilization. Therefore, despite existing environmental and LDAR regulation, severe underreporting occurs because of existing legislative gaps. In turn, this does not allow one to make adequate assessments of economically efficient options in terms of gas utilization.

In the Russian Federation, the detection of methane leaks within gas infrastructure has been conducted periodically, but with no single approved approach regarding detection, accounting, and rectification of leaks (Akopova et al., 2013). Companies are supposed to seek measures to reduce methane emissions and improve productivity, thereby further decentralizing the mandatory regulations on LDAR (Ministry of Energy, 2019). As a result, the Russian

Federation holds the top place for flaring in the world, annually burning more than 17.1 BCM of gas (Carbon Limits, 2013, p. 13).

Overall, experiences from both countries show the need for a more thorough approach, with a centralized reporting mechanism, followed by broad overview of recommended LDAR technologies, as well as supporting economic measures.

5. State of Technologies

There is no single best practice for LDAR, as corresponding measures are dependent on the operator and many other variables (Magee, 2015). However, infrared cameras, aircraft, drones, lasers, satellites, and site inspections are among the most popular methods of leakage detection, allowing inventory synthesized methods to be implemented (Alvarez et al., 2012).

While emerging technologies (such as satellites, drones, and others) (Veyrier et al., 2017)[4] currently available for detecting methane leaks in midstream infrastructure are considered to be "generally efficient" (Ravikumar et al., 2019)[5], some studies suggest that those should be applied only in addition to established techniques like the EPA's Method-21, optical gas imaging, or bubble test, techniques which companies may have to apply each time to locate a leakage for repairs. Furthermore, some scientists and experts suggest that specific and tailored technologies should be used to perform detection of leaks on different types of infrastructure: "drones are better for sniffing leaks along pipelines, whereas his laser is much better suited to monitoring a dense field of wells or a storage facility" (Mingle, 2019). A comparison of technologies is available in Table 2.

Table 2. Comparison of some technologies

#	Technology	Strengths	Weaknesses
1	Unmanned aerial system equipped with a sensitive and gas-specific methane sensor based on infrared backscatter tunable diode laser absorption spectroscopy (b-TDLAS) (Golston et al., 2018)	gives a reasonable estimate of leak location (in an experiment, localization was achieved within 1 m for 14 of 17 leak cases)	sensor position uncertainty, concentration noise, and wind direction based on a sensitivity analysis
2	Lidar systems, employing pulsed laser as the illumination source for methane detection	able to detect leaks in the absence of temperature variation between the gas and the surroundings	the high cost of execution and relatively high false alarm rate (Adegboye et al., 2019)
3	Utilization of satellites that are able to pinpoint methane leaks. One of the examples is the Tropospheric Monitoring Instrument (Tropomi), a satellite launched by the European Space Agency (ESA) in October 2018 (Fialka, 2018)	Covering vast territories, increasing accuracy	expensive technology (both to startup the project and maintain it); only a few countries have access to space and related infrastructure

4 EPA opines that the following are the primary commercialized technologies used for detecting leaks: (i) Optical Gas; (ii) Portable Analyzers; (iii) Laser Spectroscopy; (iv) Ambient Mobile Monitoring; (v) Acoustic Leak Detection; (vi) Audio-Visual-Olfactory (AVO).

5 This source suggests that six out of ten tested detection technologies could correctly detect over 90% of test scenarios.

Among the many solutions available, LDAR or processes of locating and mending fugitive leaks with equipment, like infrared cameras, have some of the highest potential. LDAR regimes offer natural gas firms low price tags, straightforward implementation, and significant savings. The IEA estimates that improved LDAR regimes could save upwards of five hundred kilotons of methane annually in the United States and Russian Federation at costs of 4.83 and 2.16 U.S. dollars per million Btu (IEA, 2020). Such saving potential, we argue, deserves considerable attention. Therefore, to effectively detect methane leaks, companies should adopt a complex of technologies and methods to cover their entire infrastructure.

Russian scholars note that the main reasons for methane leaks in the Russian Federation are related to technical conditions regarding technological equipment: the utilization of outdated equipment and technology by individual plants and the physical wear-and-tear of equipment (Akopova et al., 2013). It might therefore be challenging to ensure an across-the-technological-board shift; companies and agencies might want to adopt a gradual transition scheme, prioritizing investment in more efficient LDAR technologies. On the regulatory side, a lack of incentives to decrease methane emissions and lack of punitive measures for violating emission-related requirements might be the main reasons why a technology shift to adopt efficient (and often costly) LDAR technologies is quite slow, both in the Russian Federation and the United States.

In August 2019, the EPA announced new rules, effectively relieving U.S. companies from their undertakings to regularly monitor and rectify methane leaks. While some oil and gas companies operating in the United States (BP, ExxonMobil, and Shell) have pledged to implement techniques targeting the reduction of methane emissions voluntarily – e.g. a pilot project by ExxonMobil on the transition from gas-powered pneumatic control systems to compressed instrument air systems (ExxonMobil, 2019) – some industry experts suggest that such voluntary undertakings by companies without federal-level requirements are not enough, evidenced by the low numbers of LDAR technologies being procured.

In Russia, the primary owners of the midstream infrastructure which leak methane (Ministry of Energy of the Russian Federation, 2018)[6] are primarily state-owned energy companies, Gazprom and Transneft. One of the few regulations that was adopted by Gazprom on this topic is outdated, in that it does not address modern technologies (Gazprom, 2007) and is short of details on LDAR technologies. Nevertheless, Gazprom reportedly is making an effort to improve its LDAR infrastructure. With the help of its service provider and software developer Pergam, a methane seeking component, which had been previously used on MI-8 helicopters, was decreased in size to enable its installment on drones, thereby reducing exploitation-related costs. After trials of drone technology by five of its subsidiaries in 2018, the company issued an internal recommendation the following year to introduce this technology into operations (Kuznetsova, 2019). Simultaneously, Rosneft, Russia's largest company in the oil sector and an owner of significant gas infrastructure, reports using drones that can detect leaks in low temperatures (Oil & Capital, 2019).

[6] Information on losses in the course of gas transportation (irrespective of the reason) are only with respect to Gazprom's subsidiaries; for one of its entities, the losses reached 55.63% in 2015.

6. Discussion, Practice, and Policy Implications

Our analysis of the current regulatory and technological state of methane emissions in the Russian Federation and United States, shows a considerable lack of corresponding regulation and suggests there is a dramatic misalignment between international, national, and corporate actions. However, given existing national instruments within the two countries, who possess the most extensive natural gas pipeline networks, existing gaps in regulation and technological adaptations can be significantly reduced. Based on this analysis, the most promising areas to achieve meaningful reductions in methane emissions are: (1) direct upstream venting minimization; (2) improved practices on methane LDAR across oil and gas infrastructure, including operational equipment controls on a regular basis; and (3) mandatory record keeping and reporting to state regulators.

We see high potential for international cooperation and exchange of best practices. Unfortunately, there is currently not much cooperation in GHG regulation and methane emissions on the international level, specifically between the Russian Federation and United States and especially between oil and gas companies. However, existing international cooperation frameworks, such as the Global Methane Initiative ("Global Methane Initiative," n.d.) and Oil and Gas Methane Partnership ("Climate & Clean Air Coalition," n.d.), established in 2004 and 2012 respectively, have already shown significant results in terms of national and corporate methane emission mitigation. The effects are visible, specifically at the corporate level, where oil and gas companies, such as ExxonMobil, Shell, Gazprom, and others, are aiming to reach joint goals. The measures taken by Gazprom only lead to a decrease in the loss of natural gas in a unified system of gas supply by 2.4 times (Ishkov, 2018), including in the detection, prevention, and rectification of leaks.

An example of the joint work being pursued is a document called *"Guiding Principles for Reducing methane emissions across the natural gas value chain"* (Climate and Clean Air Coalition, 2017). The document contains key directions to improve methane emissions in the oil and gas sector, including systematic monitoring; reduction of venting and fugitive emissions; continuous technological improvement; cooperation across companies and the value chain; continuing data reporting, collection and analysis, and improvement of analytical tools; and policy and regulation development.

Other evidence for the importance of cooperation in the mitigation of methane emissions lies in a recent European initiative (following one first implemented in 1996) for reducing methane emissions in the energy sector, which is in line with goals for a zero-carbon economy (EU Directorate-General for Energy, 2020). Already showing considerable effect, the Initiative pursues further significant reductions in venting and flaring, increased use of renewables and natural gas, and efficiency improvements (EU, 2020, p. 6).

International cooperation in mitigating methane emissions has become even more critical, as unexpected global challenges affect the overall energy industry. Following the Covid-19 outbreak and aggravated by geopolitical and other factors, the oil and gas industry is continuing to suffer from descending oil and natural gas demand and a dramatic decrease in oil prices (cf. Mitrova et al., 2020). While the energy industry is surviving this extremely negative price cycle, some climate issues or decarbonization efforts may reduce in importance and fall of from the top of the agenda. However, the global energy industry has been watching a long-term horizon, with investments that extend for decades and the projects delivered today will be iterated through several cycles. Climate and negative emission consequences should not be distracted by structural trends during these cycles. A cleaner atmosphere and energy regime will remain at the forefront of public perception, investor relations, and new technology development. It is even possible that the ongoing crisis may reshape calls for faster action in mitigating and reducing GHG and methane emissions.

6.1 Policy Implications

Given macroeconomic trends, the regulation of methane emission mitigation has become even more significant. Our suggestions include paying considerably more attention to stimulating intense technological penetration and new regulatory approaches. There is a strong need to motivate the oil and gas industry to invest in LDAR, which can be achieved by implementing higher costs for gas utilization or mitigating the lack of necessary gas transport infrastructure. Given the concerns about cleaner energy along with climate change stated in the Paris Agreement and ratified by nearly 200 countries, the future of natural gas and its usefulness for addressing these challenges will depend on reducing emissions and leaks.

To make a considerable impact on the detection and rectification of methane leaks, an-across-the-board shift in LDAR technology is required to close an existing technology gap in both countries. In the Russian Federation, this gap is predetermined by a complex of reasons, including continued underinvestment in LDAR technology and the lack of mandatory requirements in LDAR methods. In the United States, the dramatic change of regulations made by the Trump administration, relieving companies from regular monitoring and rectifying methane leaks, will further lead to a lack of incentive to invest in LDAR technologies. Therefore, due to budget and corresponding limitations, government agencies and companies should adopt a gradual transition scheme, prioritizing investment in more efficient LDAR technologies, with respect to country-specific geographic, climate, and other conditions. Moreover, higher efficiency can be achieved when transitioning from a component check for LDAR to a complex one (different component paradigms).

Given the misalignment in data on methane emissions, a new regulatory approach can be designed from a novel combination of open and commercial sources to estimate gas emissions accurately, map the flaring across licensed areas and companies, and forecast further concentration of methane emissions. These sources can include, for example, NOOA, BEG, and Enverus. The method of matching data is currently missing in DOE reports and will play an essential role in future methane emissions mitigation. This approach can be adapted in both the Russian Federation and United States and may significantly improve their performance and accuracy in calculating natural gas supply and demand, equilibria models, and economic and environmental analyses.

Finally, a unified obligatory reporting of methane emissions and venting, separate from methane utilization or flaring data, should be based on standard forms for all operating companies, regardless of the minimum level of emissions.

6.2 Practical Implications

Among practical tools, there are bilateral and multilateral initiatives between oil and gas companies and governments. Indeed, the current structure of fugitive methane emissions from the United States and Russian Federation suggests that stakeholders in the natural gas industries of both countries stand to benefit from collaborating in their mitigation efforts. Despite the fact that the largest production sources of emissions in each country vary according to the IEA (see Section 3), a shared abatement potential can be realized in practice through standard mitigation solutions and technological cooperation. One example is Gazprom, which drew on the experiences of Mexico, Canada, and Indonesia in seeking a relevant technology for methane detection and elimination (Gazprom - EPA, 2008).

There is also room for joint initiatives between the oil and gas business and governments. The Methane Detectors Challenge (for details: see Environmental Defense Fund, 2019) may be a successful example of such cooperation to seek a solution for methane detection and elimination, using the experience of U.S. based technology developers.

7. Conclusions

LDAR is an ongoing issue that is relevant for the Russian Federation and the United States, two of the world's top oil and natural gas producing countries. Given the escalating rhetoric over climate change, new controversies over oil and natural gas infrastructure present unique opportunities to redress historical grievances between the Russian Federation and United States by launching new collaborative efforts.

Our analysis shows that both states have similar profiles of large-scale oil and gas infrastructures and both face an emerging problem of high-level methane emissions during oil and gas extraction and transportation. Methane emissions concern the economy of the oil and gas sectors, as well as the environmental policies of the two countries. Further, these volumes tend to grow. Despite demands from national governments for action in imposing direct regulations on oil and gas companies, there is risk of considerable underreporting and a lack of motivation for oil and gas companies to invest in LDAR. At the same time, the current dialogue on this matter faces objective obstacles, as well as modern challenges, such as the Covid-19 outbreak. This study attempts to find a place for interstate cooperation or exchange of scientific research, as well as best practices and state policies, for mutual benefit to the Russian Federation and United States.

This study underlines three levels of LDAR action: international cooperation (such as the Global Methane Initiative or Oil and Gas Methane Partnership), possibilities for regulatory convergence in the Russian Federation and United States, and cooperation at the corporate level. The key direction for international cooperation includes developing and sharing best practices for systematic monitoring; reduction of venting and fugitive emissions; continuous technological improvement; cooperation across companies and the value chain; continuous data reporting, collection, and analysis; improvement of analytical tools; and policy and regulation development. Historic and geopolitical conditions, along with a lack of regulatory conformity, challenge cooperation between the Russian Federation and United States, providing, however, that there is room for cross-national improvement of regulatory frameworks. We see high potential for technological exchange and attribution of best corporate practices. The countries should pay considerably more attention to the transfer of best technological practices.

The practical and policy implications of this study rely on bilateral and multilateral initiatives and cooperative approaches between oil and gas companies and governments, as well as sustained technological dialogue between the United States and Russian Federation. Exchange of best practices and aligned state policies, methods, and initiatives might be the key to successful and mutually beneficial action.

Credit Author Statement

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ANNEX A

Regulatory framework in the Russian Federation				
#	**Type**	**Date**	**Number**	**Title* *translation to English is made by the author**
1	Constitution of the Russian Federation	12.12.1993		Article 42 of the Constitution: "Everyone shall have the right to favourable environment, reliable information about its state and for a restitution of damage inflicted on his health and property by ecological transgressions."** **Text of the Constitution translated to English: http://www.constitution.ru/en/10003000-03.htm
I. Federal laws (as amended)				
2	Federal Law	30.11.1994	51-FZ	Civil Code Of The Russian Federation (Parts I-IV)
		26.01.1996	14-FZ	
		26.11.2001	146-FZ	
		18.12.2006	230-FZ	
3	Federal Law	13.06.1996	63-FZ	Criminal Code Of The Russian Federation
4	Federal Law	30.12.2001	195-FZ	Code Of Administrative Offences Of The Russian Federation
5	Federal Law	29.12.2004	190-FZ	Town-Planning Code of the Russian Federation
6	Federal Law	21.02.1992	2395-1	On the Subsoil
7	Federal Law	23.11.1995	174-FZ	On Ecological Expertise
8	Federal Law	24.06.1998	89-FZ	On the Production and Consumption Waste
9	Federal Law	04.05.1999	96-FZ	On the Protection of Atmospheric Air
10	Federal Law	10.01.2002	7-FZ	On the Protection of the Environment
11	Federal Law	27.12.2002	184-FZ	On the Technical Regulation
12	Federal Law	21.11.2011	323-FZ	On the Basics of Protection of Health of Citizens in the Russian Federation
II. Subordinate acts (as amended)				
Acts of the President of the Russian Federation				
13	Decree	30.09.2013	752	On Reduction of Emissions on Greenhouse Gases
14	Executive Order	17.12.2009	861-rp	On the Climate Doctrine of the Russian Federation
Acts of the Government of the Russian Federation				
15	Decree	02.03.2000	183	On the standards of emissions of harmful (polluting) substances into the atmospheric air and harmful physical effects on it
16	Decree	21.04.2000	373	On approval of the Regulation on state registration of harmful effects on atmospheric air and their sources
17	Decree	16.02.2008	87	On the composition of sections of project documentation and requirements for their content
18	Decree	24.03.2014	228	On measures of state regulation of consumption and circulation of substances that destroy the ozone layer
19	Decree	15.04.2014	326	On approval of the state program of the Russian Federation "Environmental Protection"
20	Decree	16.05.2016	422	On approval of the Rules for the development and approval of methods for calculating emissions of harmful (polluting) substances into the air by stationary sources

21	Decree	23.06.2016	572	On approval of Regulations for creating and maintaining a state register of objects that have a negative impact on the environment
22	Executive Order	31.08.2002	1225-r	On Ecological Doctrine of the Russian Federation
23	Executive Order	13.11.2009	1715-r	On Energy Strategy of Russia until 2030
24	Executive Order	25.04.2011	730-r	On approval of the Comprehensive Plan of Implementing the Russian Federation's Climate Doctrine for the Period until 2020
25	Executive Order	22.04.2015	716-r	On approval of the Concept for the formation of a monitoring, reporting and verification system for greenhouse gas emissions in the Russian Federation
26	Executive Order	08.07.2015	1316-r	On approval of the list of pollutants, in respect of which, measures of state regulation in the field of environmental protection shall be applied
Normative acts of federal bodies of executive power				
Ministry of Natural Resources and Ecology				
27	Decree	09.01.2017	3	On approval of Procedure for submitting a declaration of payment for negative environmental impact
28	Decree	15.09.2017	498	On approval of the Rules for the operation of gas treatment plants
29	Decree	07.08.2018	352	On approval of the Procedure for inventarization of stationary sources and emissions of harmful (polluting) substances into the air, adjusting its data, documenting and storing data obtained as a result of such inventarization and adjustment
30	Executive Order	16.04.2015	15-r	On approval of guidelines for a voluntary inventory of GHG emissions in the constituent entities of the Russian Federation
Federal Service for Hydrometeorology and Environmental Monitoring of Russia (Rosgidromet)				
31	Decree	02.03.2016	77	On entry into force of the regulatory document RD 52.44.816-2015 "Mass concentration of methane and carbon dioxide in surface layer of atmospheric air. Measurement method by gas chromatography"
32	Decree	27.09.2019	497	On entry into force of the regulatory document RD 52.04.875-2019 "Molar fraction of methane and carbon dioxide in samples of atmospheric air. Measurement method by gas chromatography"
Ministry of Economic Development of the Russian Federation Russian Federal State Statistics Service (Rosstat)				
33	Decree	08.11.2018	661	On approval of statistical tools for the Federal Supervisory Natural Resources Management Service for organization of the federal statistical monitoring of protection of atmospheric air
Federal Service for Ecological, Technological and Nuclear Supervision (Rostechnadzor)				
34	Decree	12.03.2013	101	On approval of federal norms and rules in the field of industrial safety "Safety rules in the oil and gas industries"

ANNEX B. Abbreviations, measurements and chemical formulas

AVO – Audio-Visual-Olfactory
CFR – Code of Federal Regulations by the Government of the United States
Covid-19 – Coronavirus disease
DOE – U.S. Department of Energy
EPA – United States Environmental Protection Agency
ESA – European Space Agency
FZ – Federal Law of the Russian Federation (Federalny zakon)
GHG – Greenhouse gases
IEA – International Energy Agency
IPCC – Intergovernmental Panel on Climate Change
LDAR – Leak Detection and Repair
LNG - Liquefied natural gas
NOAA – U.S. National Oceanic and Atmospheric Administration
Quad-O-a – Code of Federal Regulations by the Government of the United States, Title 40, Part 60, Subpart OOOOa
RD – Regulatory document of Rosgidromet
Rosgidromet – Russian Federal Service for Hydrometeorology and Environmental Monitoring
Rosprirodnadzor – Russian Federal Service for the Supervision of Natural Resources
Rosstat – Russian Federal State Statistics Service
Rostechnadzor – Russian Federal Service for Ecological, Technological and Nuclear Supervision
Tropomi – Tropospheric Monitoring Instrument
UNCC – United Nations Climate Change
VIIRS – Visible Infrared Imaging Radiometer Suite
VOCs – Volatile organic compounds
b-TDLAS - Backscatter tunable diode laser absorption spectroscopy
p. – Part of the Article of the Federal Law of the Russian Federation (Punkt)
st. – Article of the Federal Law of the Russian Federation (Statya)
No. – Number
– Number
2-TP – Form No. 2-TP (Air), approved by Rosstat

BCF – billion cubic feet
BCM – billion cubic meters
BTU – British thermal unit
km – kilometers
kt – kiloton
m – meters
MMCFD – Million Cubic Feet per Day
MMt – Megatons
mm – millimeters
psi – pound-force per square inch

CH_4 – Methane
CO_2 – Carbon dioxide