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Review

Methane emissions and air quality: A growing concern

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Abstract: Methane, a potent greenhouse gas, has gained prominence due to its significant contribution to global climate change. Beyond its climate impact, this review recognizes methane's dual role in influencing local and regional air quality, underscoring its growing concern in the context of contemporary environmental issues. The paper aims to provide an overview of methane sources, geographic distribution, long-term health effects, interactions with other pollutants, and the pivotal role of integrated monitoring systems in effective pollution control strategies. The review delves into the primary sources of methane emissions, including anthropogenic and natural processes. Geographically, it identifies high-risk areas, with substantial emissions concentrated in North America, Europe, and Asia. Prolonged exposure to elevated methane levels in urban and industrial settings is associated with respiratory, cardiovascular, and neurological health issues. Furthermore, methane's interaction with other pollutants leads to the formation of secondary organic aerosols and ground-level ozone, exacerbating air quality challenges. Efficient pollution control hinges on integrating satellite and ground-based data into monitoring systems, ensuring accurate and timely information. Managing methane emissions presents a complex dilemma, impacting both local air quality and global climate. Addressing this dual challenge necessitates a comprehensive approach encompassing legislative reforms, technological advancements, increased public awareness, and international collaboration. A swift response is imperative to mitigate the adverse effects of methane emissions on the environment and human health.

Keywords: atmospheric pollution; emission sources; environmental impacts; climate effects; mitigation strategies

1. Introduction

The quality of the air we breathe is intertwined with environmental preservation, public health, and climate change mitigation in an era characterized by expanding industrialization, urbanization, and the persistent pursuit of economic expansion. Methane, a strong greenhouse gas, has become one of the most important pollutants discharged into the environment. It has dual significance since it both has a significant impact on local and regional air quality and increases the rate of global warming [1].

The emissions of methane have drawn greater interest recently because of their important role in both local and global climate change. Methane concentrations in the atmosphere are today around 2.5 times higher than concentrations before industrialization, and they are constantly rising [2]. The effects of this increase on climate change are significant. There is a lot of ambiguity surrounding methane emission estimates, however, the most current thorough assessment points to an annual global methane emission rate of about 570 Mt [3]. Methane is a potent greenhouse gas with an 80-fold higher global warming potential than carbon dioxide (CO_2) for the first 20 years following injection into the environment. Additionally, it is the main cause of ground-level ozone generation, which is a dangerous air pollutant [4]. According to the IEA [5], exposure to ground-level ozone results in 1 million deaths annually. Various natural and man-made sources produce methane emissions. Wetlands, oceans, and wildfires are examples of natural sources, while landfills, livestock, agriculture, the production of fossil fuels. The majority of methane emissions are driven by humans, with the fossil fuel industry and agriculture playing a large role in this. When evaluating these many sources' combined effects on air quality, it is crucial to take them into account. The need for targeted mitigation strategies across all sectors, especially agriculture and energy, to address their significant contributions to global methane emissions is highlighted by the International Energy Agency's estimates that the agriculture sector was the largest source of methane emissions in 2023, contributing approximately 142 million tonnes globally, followed by the energy sector, which released approximately 138 million tonnes, the waste sector, which contributed 71 million tonnes, and the burning of biomass, which contributed an additional 10 million tonnes [5].

It displays a varied geographic distribution, with hotspots found in numerous locations around the world. According to studies, emissions are concentrated in regions with vast wetland ecosystems, extensive natural gas extraction, and intensive livestock farming. Notably, North America, Europe, and Asia are some of the continents that release the most methane [4]. Understanding the impacts of regional air quality on mitigation measures depends on this breakdown. Methane is a powerful greenhouse gas that also helps to create ground-level ozone, a dangerous air pollutant. Methane emissions have a substantial effect on the local air quality. High methane levels can raise ground-level ozone levels, aggravating respiratory conditions and other health difficulties in the afflicted areas. The addition of secondary organic aerosols as a result of methane's participation in atmospheric chemistry can further degrade air quality [5].

Due to its powerful ability to trap heat, methane emissions have a significant global warming impact. Reducing methane emissions can provide a variety of additional benefits, such as better air quality and positive effects on public health, because climate change and air quality are interconnected [3]. While the importance of methane emissions as a significant greenhouse gas and a cause of local and regional air quality issues is becoming more widely acknowledged, a thorough understanding of the intricate interactions between methane emissions and air quality is still required. Methane's effects on the climate or the air quality have frequently been the focus of previous research. When it comes to integrating these elements into a coherent perspective that acknowledges the dual role of methane as a global and regional pollutant, there is a gap in the literature, though.

The majority of research [6–8] on methane emissions and air quality has been dispersed, concentrating either on the regional or global effects on climate. By offering an integrated assessment of how methane emissions affect both global climate change and local air quality, and highlighting the connections and trade-offs between these two dimensions, this research aims to close this gap. There is a need for a more in-depth examination of geographical hotspots and their unique characteristics, even if some studies have looked at methane emissions and air quality at the regional level. The goal of this article is to explore deeper into the geographic distribution of methane emissions, identify the emission hotspots, and investigate how regional characteristics affect the effects of air quality. Research frequently focuses on the health dangers linked to poor air quality brought on by methane emissions, but a thorough examination of the long-term health implications of high methane levels in urban and industrial regions is missing. There is a need to thoroughly discuss the economic and social ramifications of these techniques because the existing research provides insights into a variety of mitigation strategies to minimize methane emissions. The goal of this article is to evaluate the technological advancements and policy changes needed to reduce methane emissions while taking into account their broader societal and economic implications.

This review paper is unique in that it acknowledges methane’s dual function as a large greenhouse gas causing climate change and a regional air quality issue. This comparison emphasizes the need to bridge the gap between climate science and air quality studies in order to address methane emissions as a complex issue with wide-ranging environmental and health repercussions. Also, it highlights the gravity of the situation by referring to it as a “growing concern”, demonstrating a greater understanding of the significance of methane emissions in the context of modern environmental challenges. Furthermore, it offers a thorough framework that combines both technologies, highlighting their complimentary roles in methane detection and management, whereas earlier research frequently concentrated on either ground-based or satellite monitoring alone. The main goal of this study is to close the knowledge gap regarding the comprehensive relationship between methane emissions and air quality, taking into account the importance of this complex issue in the context of environmental preservation, public health, and climate change mitigation.

The article offers insightful explanations of the intricate connection between methane emissions and air quality. It does, however, have some limits that should be recognized as with any research. The following are some of this review’s drawbacks: Due to the breadth of the subject, it’s possible that the study won’t fully address every aspect of methane emissions and air quality. It’s possible that some specific methane emission sources, regional variations, and potential health effects won’t get enough attention. Data on methane emissions and their effects on air quality are subject to large regional and source-specific variations in data quality and availability. The accuracy and thoroughness of the review may be constrained by data gaps and inconsistent reporting. The review’s findings and recommendations might be based on studies completed up to a specific date (for example, until September 2023), thus leaving out more recent research and breakthroughs in this quickly developing subject. Although the review examines how methane interacts with other contaminants, it might not thoroughly examine every possible connection and its effects. It can be difficult to fully represent the intricate chemistry of air processes including methane and other molecules. The report may heavily rely on data and research that is collected at the global or continental level, potentially omitting important findings from localized investigations that could offer a more nuanced view of the implications of regional air quality issues.

The review could be influenced by publication bias, which occurs when studies with important findings or favorable outcomes are more likely to be published. This could distort the review's overall evaluation of methane emissions and air quality. Although the evaluation examines societal and policy ramifications, it may not go in-depth on the difficulties of putting mitigation plans into practice and the difficulties of adopting policies and engaging the public. Methane emissions and their effects are continuously being better understood by science. It's possible that other studies and data will refute or improve the results and suggestions made in the review. Although the article on methane emissions and air quality offers useful information, it is important to be aware of its constraints. For gaining a more comprehensive and precise comprehension of this complex environmental and public health issue, it is essential to address such constraints by taking into account more current data, geographical differences, and potential biases.

Methane emissions and their effects on air quality are urgent environmental and public health concerns, as this article's justification demonstrates. Methane is a strong greenhouse gas, and the effects of its interactions with other pollutants are extensive. In order to handle both regional and global environmental concerns, it is essential to understand this subject. For policymakers, scholars, and the general public to fully understand the issue and make wise decisions, a holistic approach is crucial. This element of the assessment, which highlights the need for public health actions, is appropriate given the potential health consequences linked to poor air quality. An evaluation of the social and economic effects of these measures is important as policymakers look for practical ways to manage methane emissions. The foundation for this field's future research and policy growth is provided by this study as well.

1.1. Research question

1) What are the main sources of methane emissions, where are they distributed geographically, and how do they affect local and global air quality?
2) How can the dangers associated with prolonged exposure to high methane levels in urban and industrial locations be reduced?
3) What are the synergistic impacts of methane on air quality and climate change and how does it interact with other air pollutants?
4) What technological and legislative steps can be taken to lower methane emissions and enhance air quality while taking into account the effects on the economy and society?
5) How can ground-based and satellite monitoring systems be used to offer more precise and timely information on methane concentrations and sources, assisting in the development of pollution management measures.

The review highlights the potential risks to human health in urban and industrial areas while summarizing and synthesizing the body of knowledge currently available on methane emissions, their primary sources, geographic distribution, and impact on regional and global air quality. It also explores the health effects of prolonged exposure to elevated methane levels. At the conclusion of the session, suggestions for resolving the difficulties methane emissions present for air quality.

1.2. Literature review

Staniaszek et al. [9] simulated a zero human-caused methane emissions scenario (ZAME) using a new, methane emissions-driven version of the UK Earth System Model (UKESM1) in order to (i) ascribe the role of human-caused methane emission levels on the Earth system; and (ii) bracket the possibility for theoretical maximum mitigation measures. They found significant, immediate, and persistent impacts on the environment and climate compared to a counterfactual forecast (SSP3-7.0, the "worst case" scenario for methane). According to ZAME, worldwide surface ozone will drop to levels last seen in the 1970s and methane will fall to levels lower than pre-industrial levels in 12 years. Anthropogenic methane in SSP3-7.0 will cause 1℃ of warming and 690,000 premature deaths annually by 2050. The study highlights the substantial potential for methane emissions reductions and its co-benefits for air quality, but it also emphasizes the urgency of taking action to reduce carbon dioxide (CO_2) emissions. They demonstrated the necessity of a methane emissions-driven treatment for modeling the effects and feedbacks of methane emissions variations on the entire Earth system.

The review study by Mar et al. [10] explored the physical and chemical properties of methane (CH_4) that are relevant to its impact on climate, ecosystems, and air quality, in addition to how much this plays a role in climate and air quality management. Despite being subject to the UNFCCC's climate regime, CH_4 is only treated there in the ways that it affects the climate in a way that is "CO_2 equivalent" over a 100-year period. The UNFCCC paradigm ignores the effects of CH_4, which are principally mediated via methane's function as a precursor to tropospheric ozone, on short-term climate as well as its effects on human health and ecosystems. Although CH_4 is not specifically regulated in air quality governance frameworks, tropospheric ozone is typically addressed as a pollutant. It is clear that global mitigation of CH_4 emissions needs to be expedited given the effects of methane on the climate and air quality as well as its alarming recent increase in atmospheric concentrations. Within the global governance frameworks for climate change and air pollution, we examine challenges and opportunities for further improvement in CH_4 reduction.

Methane levels in the atmosphere increased at rates not seen since the 1980s in 2014 (12.7 ± 0.5 ppb/year), 2015 (10.1 ± 0.7 ppb/year), 2016 (7.0 ± 0.7 ppb/year), and 2017 (7.7 ± 0.7 ppb/year), according to Nisbet et al. [11]. The global mean mole fraction in remote surface background air increased from roughly 1775 ppb in 2006 to 1850 ppb in 2017, marking the start of the methane load increase. In parallel, the 13C/12C isotope ratio (also known as 13CCH_4) has changed and has been moving downward for more than ten years. In light of this, a change in the ratios (and sums) of biogenic, thermogenic, and pyrogenic releases, especially in the tropical and subtropical regions, or a decline in the environmental sink for methane, or both, are the likely explanations for the recent mole fraction increase in methane. Unfortunately, it is not currently possible to be more certain due to the limited measurement data sets. In order to challenge the Paris Agreement, which calls for drastic reductions in the atmospheric methane load, the observed methane growth over the past decade must continue at a rate of > 5 ppb/year. The Paris Agreement's goals must be realized if anthropogenic methane emissions are to be reduced; nevertheless, they present enticing targets for quick reduction.

In a group of selected Asian countries spanning from 1971 to 2020, Hanif et al. [12] examined how development, shortages of resources, and livestock farming affected the release of carbon. It also looked at the influence of various methane emissions (released by the agricultural, energy, and industrial sectors). The findings indicate that the primary contributing drivers to environmental degradation worldwide are urbanization, animal production, natural resource depletion, and energy-related methane emissions. The causality estimates demonstrate the one-way relationship between livestock production, farm methane emissions, and carbon emissions, as well as the relationships between total methane emissions, carbon emissions, and urbanization. Over the next ten years, carbon emissions are expected to rise as a result of increased urbanization, natural resource depletion, and overall methane emissions, according to forecasting estimations. The study comes to the conclusion that in order to reduce carbon emissions, the energy sector should use renewable energy sources during production. To achieve carbon neutrality, unsustainable resource extraction and urbanization must be reduced.

The methane releases from the distribution of the natural gas chain, according to Allen [13], are a crucial factor in determining the greenhouse gas profile of the gas's generation and use. The most recent projections for these emission levels have been extremely varied owing to the huge number of avenues, different evaluation and prediction methods, and severe emission rates from particular sources that are substantially greater than the general average emission rates from avenues in the same class (a "fat-tail" distribution). Identifying the release of methane from the natural gas supply chain requires resolving variations among top-down techniques for determining ambient levels of methane and bottom-up approaches that quantify emissions from individual sources. Both top-down and bottom-up approaches should be used.

Following a thorough description of the former, Johnson et al. [14] presented storage tank emissions in the context of all location's emissions. A complete emission rate of 57.5 ± 2.89 kg/hr for all locations was calculated from the quantification of 224 well pad emission sources over 15 sites. The geometric and arithmetic means of site-specific emissions were 3.8 and 2.2 kg/hr, respectively, and varied from 0.4 to 10.5 kg/hr. Pneumatic devices (35 kg/hr or roughly 61% of the total) and tanks (14.3 kg/hr or roughly 25% of the total) were the two main types of emissions by mass. At all locations, emissions control devices were used in the produced water and condensate tanks. Nevertheless, as this study's findings show, gas can still seep from tanks through component leaks. There were 153 tanks in total across all locations. Due to safety concerns, direct tank measurements were not taken at one site that had a significant malfunction and might have been a super-emitter as found in another research. 42 emissions sources came from the 143 tanks at the remaining sites. ERVs, PRVs, and thief hatches were linked to leaks on controlled tanks. It was challenging to precisely estimate true capture efficiencies because measurements only served as snapshots in time and could only be contrasted with data on tank emissions that had been modeled. According to our calculations, the capture effectiveness for controlled tanks ranged from 63% to 92%.

Riddick et al. [15] studied, monitored and classified emissions from conventional oil and gas wells that were both operating and abandoned. Additionally, by contrasting our West Virginia (WV) emissions compared to other states in the US, they were able to reconcile disparate regional CH_4 emissions estimates. They discovered that in West Virginia, the CH_4 emission factors from 147 unplugged wells and 112 plugged wells were 0.1 g CH_4 h^{-1} and 0.1 g CH4 h^{-1}, respectively. Most recently abandoned wells in West Virginia are the ones with the highest emissions, with a mean output of 16 g CH_4 h^1 in relation to a mean of 3103 g CH_4 h^1 for those abandoned before 1993. They estimated the number of neglected wells in West Virginia from 60,000 to 760,000 wells using field measurements in a former mining location as a proxy for state-wide drilling activities in the late 19th and early 20th century. The predicted methane emission parameters from operational conventional wells were 138 g CH_4 h^1. The EPA’s emission factor for traditional oil and gas wells was only half as large as the CH_4 emission factor for current traditional wells, which were 7.5 times more polluting. They did not detect an emission pattern related to the operator or well age for active wells. They discovered that well emission variables can vary across both active and inactive wells within the same geologic deposit and may be affected by differences in state laws. Correct accounting for state-level differences is essential since greenhouse gas emissions assessments are utilized to guide programs for lowering emissions. They discovered that well emission variables can vary across both active and inactive wells within the same geologic deposit and may be affected by differences in state laws. Correct accounting for state-level differences is essential since greenhouse gas emissions assessments are utilized to guide programs for lowering emissions.

Alvarez et al. [16] used facility-scale data acquired at ground level and verified with satellite imagery in areas that generated roughly 30% of the country’s gas to compute the emissions of methane from the U.S. oil and natural gas supply chain. Our facility-based estimate of supply chain emissions in 2015, extrapolated nationally, is 13.2 teragrams annually, or 2.3% of overall U.S. gas output. This amount is almost 60% greater than the inventory estimate from the U.S. Environmental Protection Agency, which is probably due to the fact that current inventory methods don’t capture pollutants generated during unusual operating situations. In terms of radiative forcing over a 20-year time horizon, methane emissions of this size produce a similar amount of CO_2 from natural gas burning as does the consumption of a unit of natural gas. Rapid identification of the underlying causes of excessive emissions and the implementation of less-prone-to-failure systems make significant emission reductions possible.

Angaye et al. [8] used a portable air quality meter (AEROQUAL-Series 300) to measure the amounts of methane emissions from 6 dumpsites. The results showed that the methane concentration in the area varied between 1.00 and 6.44 ppm. Methane levels varied across time, ranging from 1.59 to 4.09 ppm ($p > 0.05$), with greater values during the rainy season. In the meantime, the control station showed no signs of methane release. With the exception of stations LE and LF, the majority of methane emissions were categorized as safe or moderate according to the Air Quality Index (AQI) model. Nevertheless, these findings supported the notion that anthropogenic activities were to blame for the methane emissions from the dumpsite. They advocate for measures such as waste stream reduction, recycling, and reuse targeted at sequestering methane emissions.

2. Materials and methods

For the purpose of performing this review, a thorough literature search was done to find pertinent studies and information on methane emissions, their main sources, their geographic distribution, and their effects on air quality. The publications of international organizations, government papers, and scientific journals were studied, among other databases. The search criteria covered research done up through September 2023, ensuring that the most recent results were included. The following terms were used often in searches: “Methane emissions”, “air quality”, “health effects”, “sources”, and “mitigation strategies”. The Environmental Protection Agency (EPA), the United Nations, and academic journals in the areas of atmospheric science, environmental science, and public health were consulted as part of the literature review. Academic databases like PubMed and Google Scholar were also used.

3. The main sources of methane emissions, where they are distributed geographically, and how they affect local and global air quality

The main natural source of methane emissions is natural wetlands. Methane is produced by microbial activities in wet soils. Methane can be dispersed in saltwater and released from ocean sediments, mainly in regions with high biological production. Methane can be released during wildfires as grass and organic material burn. Methane emissions are produced by a variety of human activities, including deforestation and agricultural burning [17]. Significant anthropogenic sources of methane include the extraction, processing, and distribution of fossil fuels, including leaks from oil and natural gas infrastructure. Microbial processes in wastewater treatment facilities can produce methane [18]. Enteric fermentation in livestock (belching), manure management, and rice cultivation all produce methane [19].

Around the planet, methane emissions are not spread equally. Due to the concentration of particular sources, hotspots of methane emissions can be observed in different geographical areas. Particularly in the United States and Canada, the exploitation of fossil fuels and agriculture are major sources of emissions. Agriculture, livestock, and some industrial processes in Europe account for the majority of concentrated emissions. High emissions are caused by livestock, industry, and rice farming in Asia. Wetlands in tropical areas are important natural sources of methane, whereas permafrost thawing in the Arctic poses a risk by releasing methane that has been stored there. Both regional and global air quality can be affected by methane. For instance, increased methane levels in cities might contribute to the production of ground-level ozone, a dangerous air pollutant, in the surrounding areas [20]. Other health difficulties including respiratory problems can be brought on by ozone. In agricultural areas, increased methane emissions may damage the air quality, which may have an impact on locals' health. However, methane has a significantly greater ability to trap heat than carbon dioxide over a shorter period of time, making it a powerful greenhouse gas on a global scale [21].

The need for targeted mitigation strategies across all sectors, especially agriculture and energy, to address their significant contributions to global methane emissions is highlighted by the International Energy Agency's estimates that the agriculture sector was the largest source of methane emissions in 2023, contributing approximately 142 million tonnes globally, followed by the energy sector, which released approximately 138 million tonnes, the waste sector, which contributed 71 million tonnes, and the burning of biomass, which contributed an additional 10 million tonnes (**Figure 1**) [5,6].

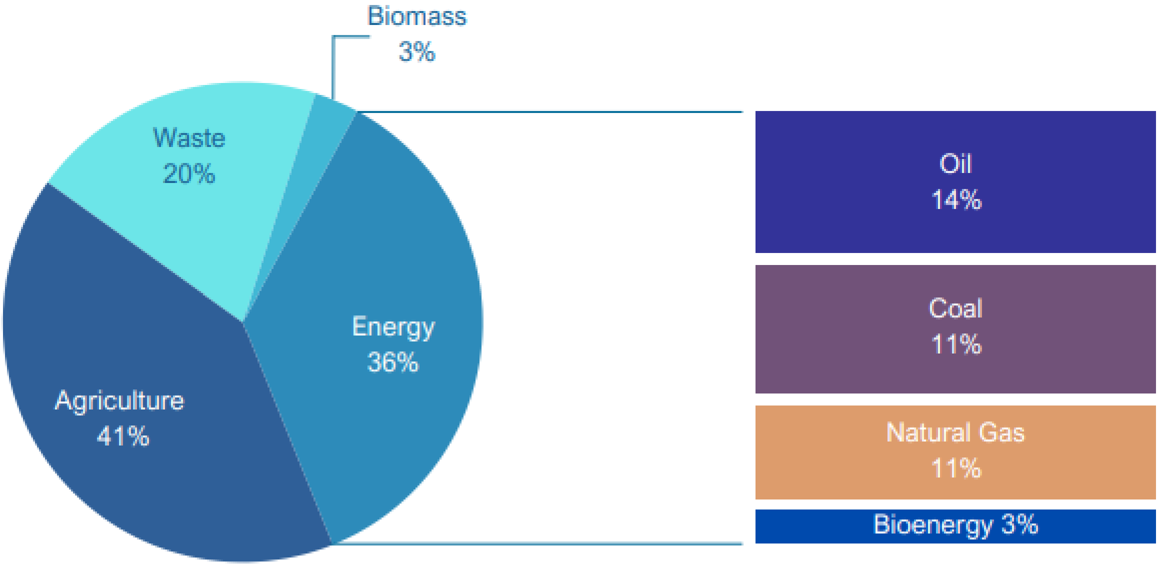


Figure 1. Methane-emitting activities from energy, agriculture and waste sectors.

Source: [5,22].

Methane emissions are a factor in climate change and global warming. Changes in atmospheric methane concentrations can change the atmosphere's chemistry, which can have an indirect impact on global air quality by changing where other pollutants are distributed [2,21]. Methane emissions often come from a variety of main sources and are dispersed globally in different ways. Both local repercussions, such as the creation of ground-level ozone, and global impacts, such as accelerating climate change, are caused by their impact on air quality. Methane emissions must be understood and reduced in order to solve local air quality problems as well as the larger problem of global warming [23,24]. Recently, researchers created a new set of maps that show the location of methane emissions from the burning of fossil fuels utilizing data that is publicly accessible and was published by Jones et al. [25]. Based on the locations of coal mines, oil and gas wells, pipelines, refineries, and infrastructure for fuel storage and transportation, the maps show the areas where these emissions take place. Emissions of methane (CH_4) are expressed in tons of carbon dioxide equivalents (**Figure 2**).

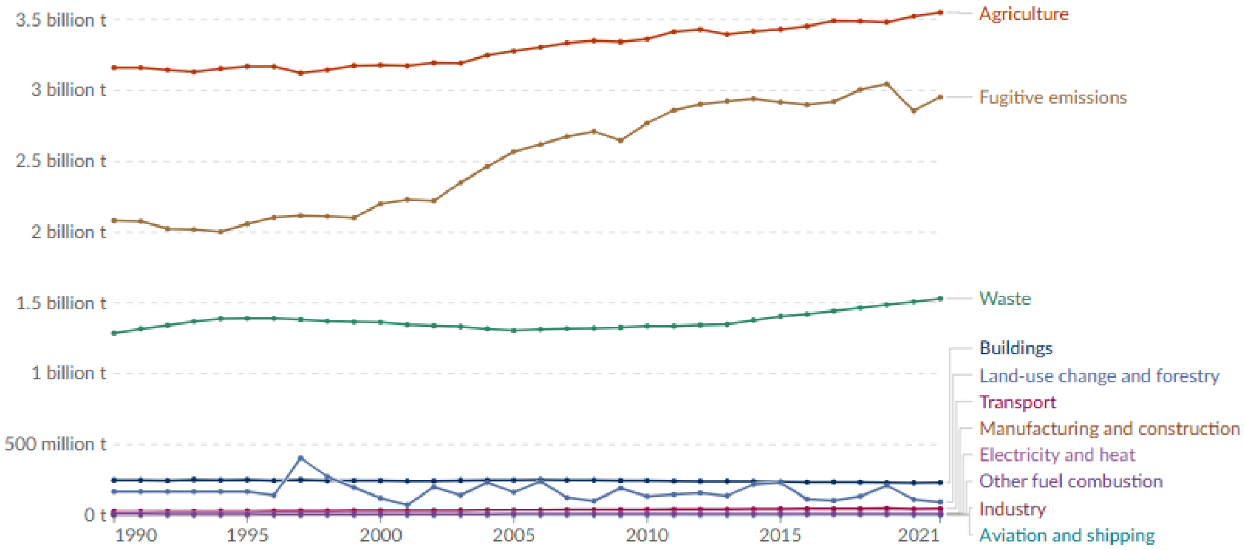


Figure 2. Graph showing contributors to global methane emissions [25].

The map (**Figure 3**) depicts that 1.89 billion t, 683.54 million t, 611 million t, 533.12 million t, and 226.66 million t were reported for China, the United States, Brazil, Russia, and Nigeria respectively.

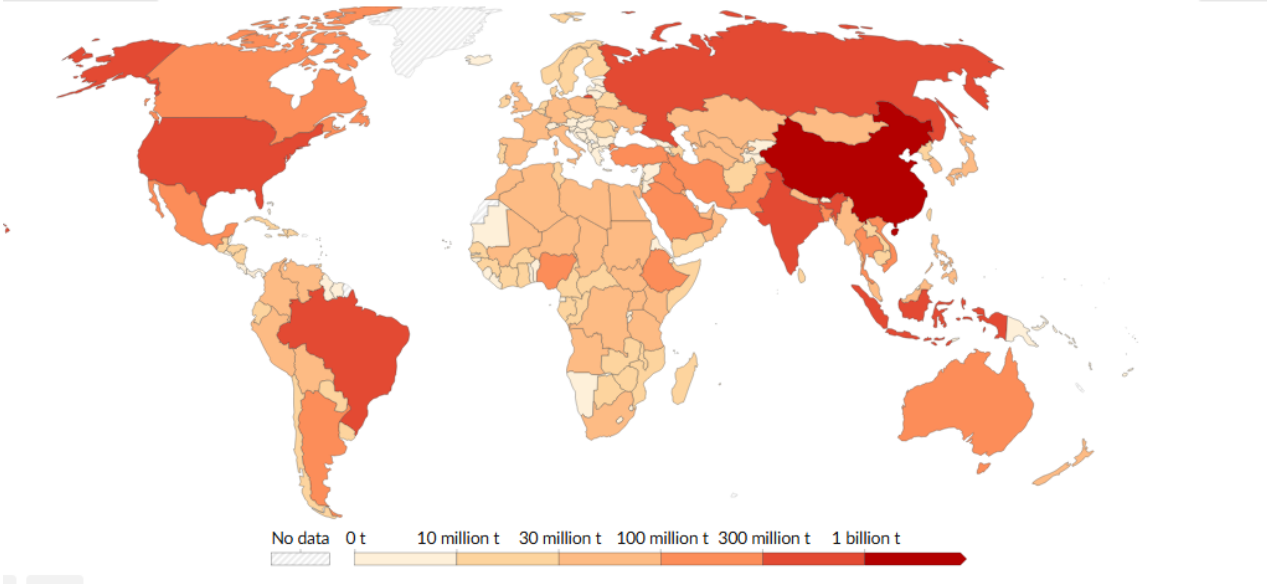


Figure 3. The global CH_4 emission distribution [25].

3.1. The dangers associated with prolonged exposure to high methane levels in urban and industrial locations

It's critical to take steps to reduce the dangers associated with prolonged exposure to elevated methane levels in urban and industrial regions because these exposures can have a number of negative health effects [26]. Although methane by itself is not harmful, it can help to create ground-level ozone, which can irritate the respiratory system. Chronic respiratory conditions such as bronchitis, aggravation of asthma, and decreased lung function can result from prolonged exposure to high ozone levels. Heart attacks and strokes are two cardiovascular disorders that are made more likely by prolonged exposure to air pollution, which includes high methane levels [1]. Although methane has a relatively little direct effect on the nervous system, prolonged exposure to air pollutants, which may be made worse by methane emissions, can have subtle neurological consequences and may have an impact on children's development [27].

The best strategy to lessen the health concerns brought on by elevated methane levels is to stop the emissions of methane at the source. This includes tighter laws and better management techniques in sectors like agriculture and oil and gas extraction, which produce a significant amount of methane. In order to measure methane levels and other pollutants, install reliable air quality monitoring devices in industrial and urban regions. Public health recommendations and regulatory actions can be informed by this data. Increase public knowledge of the health dangers posed by air pollution, particularly methane, and encourage people to adopt preventative steps including limiting their own emissions and remaining indoors on days with poor air quality. Greenery and trees can be used in urban layouts to assist in filtering and absorbing pollutants like methane. Green infrastructure can enhance the quality of the air while lowering the health hazards brought on by air pollution. This statement is supported by several studies that have measured the effects of vegetation on air quality and human health. For instance, according to an investigation by Nowak et al. [28], trees in cities in the United States reduced pollution (particulate matter and gaseous pollutants) in the air by 17.4 million tonnes in 2010, resulting in $6.8 billion in health advantages. Another study by Escobedo et al. [29] found that urban forests in Santiago, Chile reduced particulate matter concentrations by 2.5% to 9.5%, avoiding 1200 to 4000 premature deaths per year. As methane emissions can also come from car exhaust, strict vehicle emissions regulations should be implemented and enforced [26]. The adoption of electric and low-emission automobiles should be encouraged. Invest in tools that can collect and use methane emissions, like landfill and wastewater treatment facility methane recovery systems. In addition to lowering emissions, this can generate business opportunities [27]. Take steps to lower overall greenhouse gas emissions after realizing the connection between methane and climate change [28]. Mitigating methane is crucial for both reducing global warming and improving air quality [22]. Healthcare professionals should be knowledgeable about the possible health impacts of air pollution, particularly methane, and should offer advice to people, especially those who already have pre-existing conditions [29,30]. The development of ground-level ozone and other secondary pollutants as a result of prolonged exposure to high methane levels in urban and industrial regions might have detrimental consequences on health. Reducing methane emissions at their sources, enhancing air quality monitoring and control, and increasing public knowledge of the value of clean air and its effects on health are all necessary to mitigate these dangers.

3.2. The synergistic impacts of methane on air quality and climate change and how it interacts with other air pollutants

Methane and other air pollutants interact (**Figure 4**), and these interactions may be advantageous for climate change and air quality [31]. Following is a summary of methane's impacts and interactions with other pollutants: Ground-level ozone (tropospheric ozone) is created when methane and nitrogen oxides (NO_x) mix in the presence of sunlight [32,33]. This complex chemical reaction may result in the production of ozone, a serious respiratory irritant and air pollutant. Respiratory problems, decreased lung function, and a worsening of conditions like asthma are all consequences of increased ground-level ozone on the well-being of people. Through photochemical processes, methane can indirectly contribute to the generation of secondary organic aerosols (SOAs). Small atmospheric particles known as SOAs can have an impact on climate and air quality. By limiting visibility and creating dangers to respiratory health, SOAs can have an impact on air quality. Also, by diffusing and absorbing sunlight and serving as cloud condensation nuclei, which can change cloud properties, they can also have an impact on regional and global climate [32].

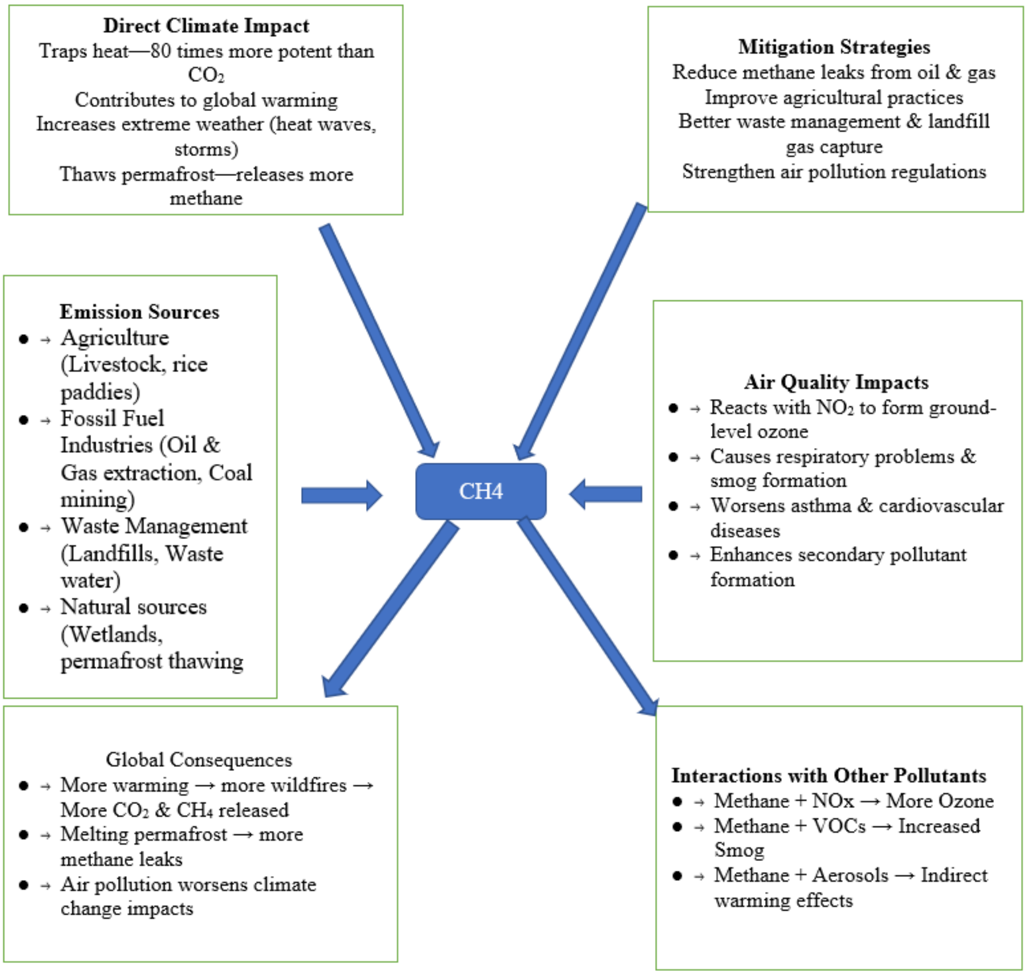


Figure 4. Synergistic impacts of methane on air quality and climate change.

Methane is a powerful greenhouse gas with a far larger capacity to trap heat over a short period of time (a decade or two) than carbon dioxide. It contributes to global warming when it is released into the atmosphere. Black carbon (soot) is a type of aerosol that absorbs solar radiation and contributes to global warming. It is mainly produced by the incomplete combustion of fossil fuels and biomass [33]. According to a study by Zhuang et al., black carbon can interact with other pollutants, such as ozone and sulfate, to increase their warming effects by enhancing their optical properties and lifetime in the atmosphere. The study also found that black carbon has a significant influence on the East Asian monsoon, causing changes in precipitation and circulation patterns. The authors used a regional climate model (RegCM$_4$) to simulate the interactions between the black carbon warming effect and the monsoon system in both winter and summer seasons [34]. The ice-albedo feedback is a phenomenon whereby black carbon can collect on snow and ice, lowering their reflectivity (albedo), and hastening melting. Black carbon is a light-absorbing aerosol that originates from human activities such as biomass burning and fossil fuel combustion. It can be transported over long distances and deposited on snow and ice surfaces, where it reduces the broadband surface albedo and increases the absorption of solar radiation [35,36]. This can initiate or accelerate snowmelt and expose darker underlying surfaces, which further enhance the warming and melting in a positive feedback loop [37,38]. Methane and other greenhouse gases cause the Earth to warm, which may have an impact on the concentration and dispersion of air pollution and exacerbate existing problems with air quality. For example, warming may increase the frequency and intensity of stagnation events, which trap pollutants near the surface and worsen their health effects [37]. Warming may also alter atmospheric circulation patterns and affect the transport and removal of pollutants, such as black carbon, from the atmosphere [38].

Feedback networks may be produced by methane emissions from warming Arctic regions and thawing permafrost. Methane that was once contained in permafrost may be released as the Arctic warms, increasing climate change. On both the local and global scales, these feedback loops may have complicated and even unanticipated consequences on the climate and air quality. Regional variations and local factors, such as the availability of NO_x, volatile organic compounds (VOCs), and sunshine, affect how methane interacts with other pollutants. The effect on air quality and ozone production can be greater in areas with large releases of methane and a lot of precursor contaminants, such as NO_x [32,33]. Both direct and indirect effects on air quality and climate change are caused by interactions between methane and other atmospheric pollutants. Some of the manifestations of these interactions include the development of ground-level ozone, the generation of aerosols, and feedback loops in the Arctic. The development of sensible mitigation measures for both poor air quality problems and the larger problem of climate change depends on an understanding of these complexities.

4. Technological and legislative steps that can be taken to lower methane emissions and enhance air quality while taking into account the effects on the economy and society

It takes a combination of technological and governmental solutions to reduce methane emissions and enhance air quality while taking into account economic and social ramifications. It is important to utilize technologies for methane capture and utilization in sectors like oil and gas production, landfills, and wastewater treatment facilities. Methane that has been captured can be utilized as a fuel, lowering emissions and having positive economic effects. It is good to use cutting-edge leak detection tools like infrared cameras and drones to locate methane leaks in pipelines and infrastructure rapidly and fix them. The adoption of agricultural techniques that cut down on methane, such as better manure management, the use of methane digesters, and alterations to livestock diets should be encouraged. Treatment facilities for wastewater to lower anaerobic processes' methane emissions ought to be improved. To cut down on methane emissions from anaerobic processes, upgrade the wastewater treatment facilities, implement anaerobic digestion and other methane-capture technologies for wastewater treatment, and to reduce methane emissions from transportation sources, it will be necessary to promote the use of low-emission cars, such as electric and natural gas vehicles.

Setting and implementing strict methane emission regulations for sectors and industries that produce a considerable amount of methane emissions, such as the oil and gas industry should be enforced. Reporting and monitoring should be necessary on a regular basis. Ideally, there is a need to encourage the deployment of methane collection and reduction technologies by providing financial incentives, tax breaks, or subsidies, especially for small and medium-sized businesses. Methane is a potent greenhouse gas that contributes to global warming and climate change. It is emitted by various human activities, such as fossil fuel production, agriculture, and waste management [39]. According to the United Nations Environment Programme, reducing methane emissions is part of the most important methods to slow down global heating in the short term. Therefore, it is important to monitor and disclose the pathways and methane emissions levels from different sectors and activities. One possible policy measure to achieve this goal is to mandate businesses to register and disclose their methane emissions in order to track emissions and promote transparency in efforts to reduce emissions [16]. This would help identify the major emitters and hold them accountable for their environmental impacts [40]. It would also encourage businesses to adopt best practices and technologies to prevent or capture methane leaks from their operations. Another possible policy measure is to control the location and management of landfills and livestock activities as examples of land use planning and zoning restrictions that minimize methane emissions. Landfills and livestock are significant sources of methane emissions, as they produce methane from the decomposition of organic waste and the enteric fermentation of ruminant animals, respectively [41]. By regulating where and how these activities can take place, the government can reduce the amount of methane released into the atmosphere. Methane emissions should be taken into account when developing carbon pricing schemes, which can offer financial incentives for emissions reductions.

Support for mitigation measures can be done by informing people about the effects air pollution and methane emissions have on human health and the ecosystem [42]. The inclusion of local communities in the creation of methane reduction programs and regulations is important, especially for those who are most impacted by poor air quality. By doing this, local issues can be addressed. Workers in methane-emitting companies should receive training and education to ensure effective leak detection and repair procedures as well as safety precautions. Think about the effects on the communities and workers who depend on methane-emitting enterprises from an economic and social standpoint. Adoption of measures that promote a fair transition to recognizing that methane is a worldwide issue that calls for coordinated measures, working together at the international level to create agreements and commitments to limit methane emissions are necessary. Encouragement of the transfer of know-how and solutions for reducing methane to developing nations, where emissions may be rising quickly. The provision of financial assistance to underdeveloped countries is needed so they can adopt methane reduction measures while taking into account any economic difficulties they may encounter [43–45]. Methane emissions reduction and air quality improvement necessitate a multifaceted strategy that takes into account the economic and societal ramifications. Methane's negative effects on the environment and society can be lessened by combining technology developments with carefully crafted policies and active community involvement.

4.1. Ground-based and satellite monitoring systems are used to offer more precise and timely information on methane concentrations and sources, assisting in the development of pollution management measures

A potent method for improving the precision and real-time monitoring of methane concentrations and sources, enabling more efficient pollution management measures, is the integration of satellite and ground-based monitoring systems [46]. The conceptual framework is depicted in **Figure 5**. These systems can be combined in the following ways: Remote sensing tools aboard Earth-observing satellites, such as satellite-based monitoring systems, offer extensive coverage and regular data collection across vast areas. They can provide a global perspective and identify methane plumes from space. They might, however, lack the spatial precision required to identify specific locations [47]. Ground-based monitoring devices, such as stationary analyzers and mobile measuring platforms, have superior spatial and temporal resolution, which makes them perfect for pinpointing specific sources and real-time monitoring of emissions. Methane concentrations should be verified and cross-referenced using both satellite and ground-based data. For the purpose of validating and calibrating satellite observations and assuring accuracy, ground-based measurements give ground truth data [48]. To identify the precise origins of methane emissions, combine the extensive coverage provided by satellite data with source-specific information provided by ground-based data. This can assist government agencies in locating and prioritizing pollution sources for reduction. Create platforms that provide reporting and data sharing in almost real-time. This could improve pollution management tactics by enabling regulatory bodies and stakeholders to react rapidly to methane emission incidents or leaks.

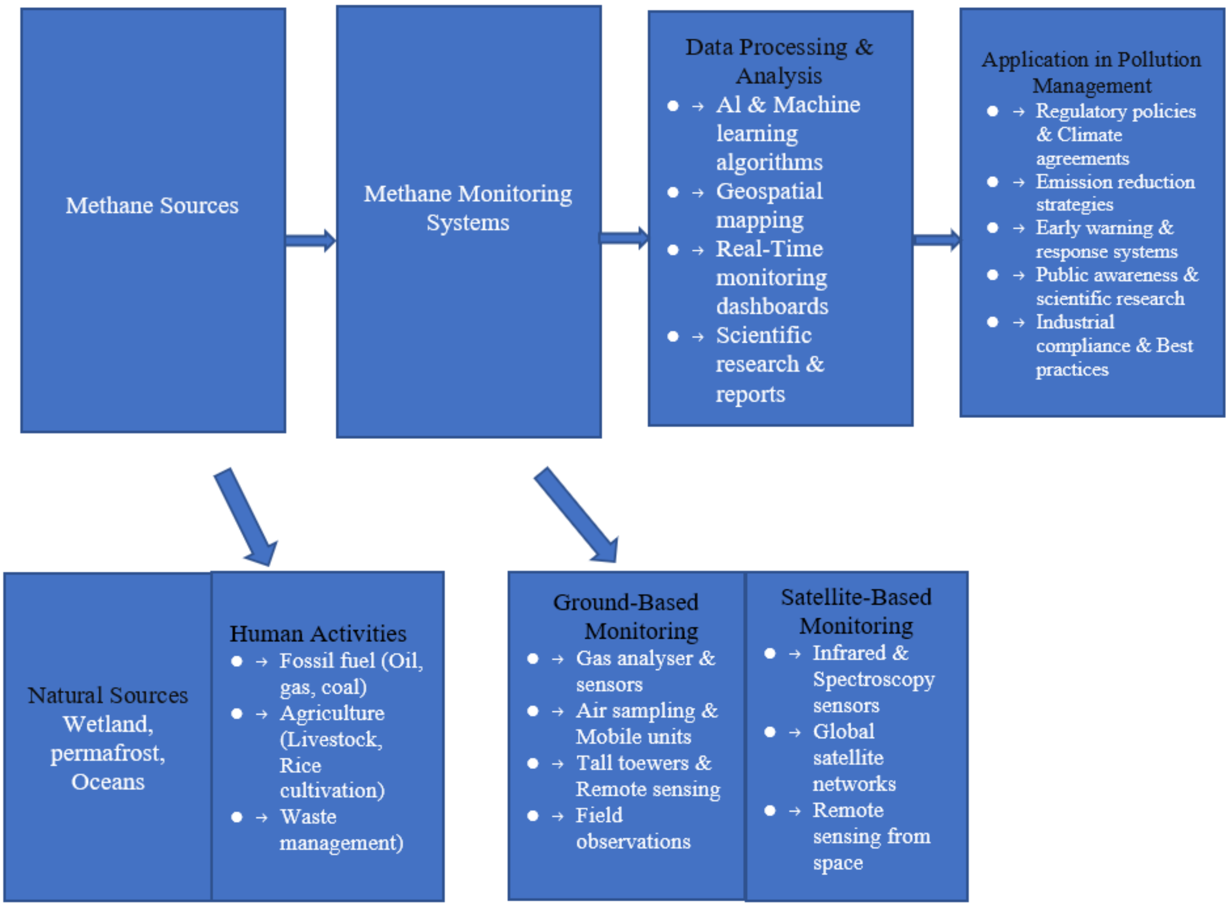


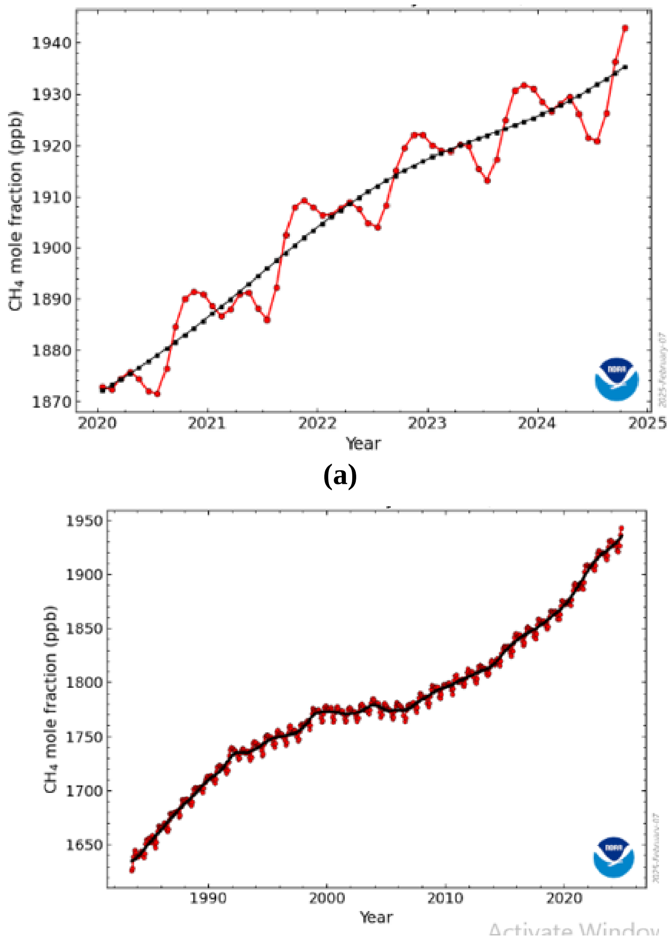
Figure 5. Flow chart of the conceptual framework of methane monitoring and pollution management.

Utilizing ground-based monitoring devices for ongoing, localized measurements in regions with a high potential for methane emissions, such as oil and gas facilities or agricultural areas, is an idea. These observations can be enhanced by satellite data, which offers a wider perspective. Again, it is possible to utilize the potential of satellite data to offer early warning of anomalies in methane emission, enabling quick reaction and mitigation. Also, the creation of systems or tools that integrate satellite and ground-based data is necessary. This will make it available to the public and the appropriate authorities. These systems may offer analytics and visualization capabilities for enhanced decision-making [47,49]. To ensure regulatory compliance, one may use integrated data. Authorities can identify sources that are not in compliance with emission restrictions using the combined data and implement the necessary enforcement measures. In order to improve emissions inventories and atmospheric models, the combination of satellite and ground-based data will make sense. This paper could improve our knowledge of how methane behaves in the atmosphere and guide the development of pollution prevention measures that are more successful.

To increase public knowledge of methane emissions and their effects, dissemination of integrated data to pertinent stakeholders and the general public should be enforced. Public involvement can help pollution control efforts succeed. The creation of a global network for methane monitoring should be sought after by working with other nations and international organizations to share data. Global methane emissions are a problem, and better control measures may result from international cooperation [50]. We can greatly improve our capacity to monitor methane emissions, identify sources, and more successfully implement pollution management methods by integrating satellite and ground-based monitoring systems and utilizing cutting-edge data processing and sharing mechanisms. This strategy is essential for resolving the problems with the ecology and the climate brought on by methane emissions.

4.2. Trends in global CH_4

Globally averaged monthly mean atmospheric methane abundances derived from marine surface sites are displayed in graphs (**Figure 6a**,**b**). Lan et al. [51] state that graph B displays the whole National Oceanic and Atmospheric Administration (NOAA) time series beginning in 1983, while graph A displays monthly means for the previous four years plus the current year. Preliminary values for the previous year are subject to normal gas recalibrations and other quality control procedures. The following describes other effects on the data over the last several months:



(a)

(b)

Figure 6. Recent global monthly mean CH_4. **(a)** Recent global monthly mean CH4; **(b)** Global monthly mean CH_4.

Source: [51].

Since 1983, methane has been detected at a worldwide dispersed network of air sampling sites by NOAA's Earth System Research Laboratory's Global Monitoring

Division [52]. The data for each site is first smoothed as a function of time, and then the smoothed values are plotted as a function of latitude for 48 equal time steps annually to create a worldwide average. At each time step, global means are computed using the latitude plot [53]. Following the removal of water vapor, the number of methane molecules divided by the total number of molecules in the sample is known as the "dry air mole fraction". nmol mol-1, or "ppb" (parts per billion; 1 ppb means that one out of every billion molecules in an air sample is CH_4), is the abbreviation for the mole fraction.

The graphs' black lines and squares (**Figure 6a**,**b**) depict the long-term trend, which is theoretically comparable to a 12-month running mean, after the average seasonal cycle has been eliminated. The red lines and circles in the graphs represent globally averaged monthly mean values centered on the middle of each month.

The most current methane papers from various nations are shown in **Table 1**. These studies all demonstrate the global trends in CH_4.

4.3. Annual global increase of CH_4

Once the seasonal cycle has been eliminated, the rise in atmospheric CH_4 abundance (mole fraction) from 1 January of one year to 1 January of the following year is the annual increase in atmospheric CH_4 (**Figure 7**). It is the total of all CH_4 that is released into and taken out of the atmosphere throughout the year as a result of both natural and human-caused processes. Using the available data from the prior year, we generate our initial preliminary estimate for the yearly rise of a given year in April of the following year. It is crucial to understand that as more data are incorporated into the analysis, the initial estimate of the annual increase from April is probably going to shift considerably.

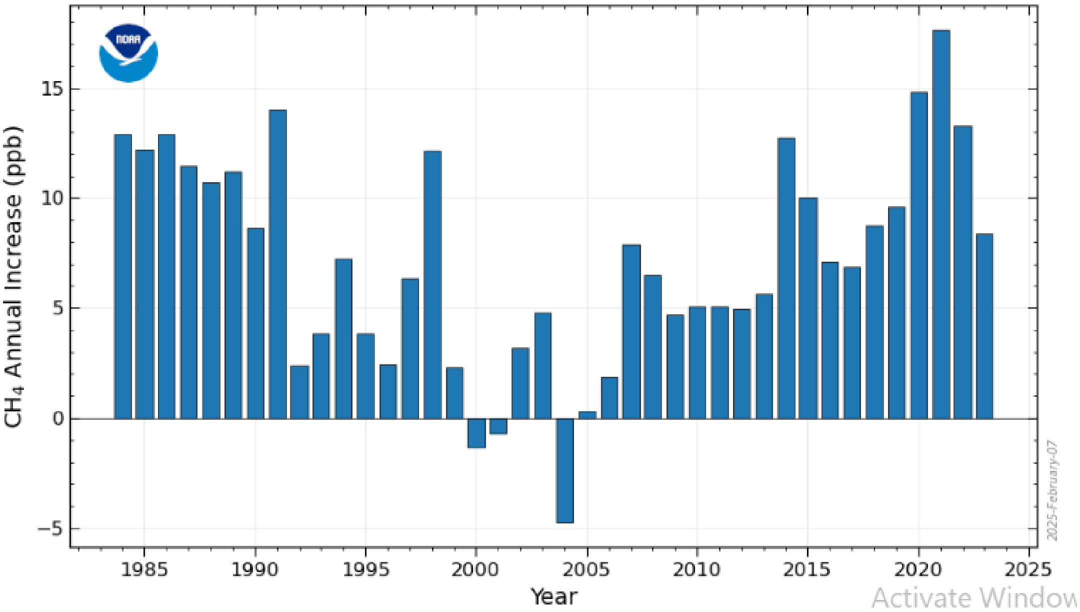


Figure 7. Annual monthly mean CH_4.

Source: [51].

Every month, as new samples are brought back to Boulder, analyzed for CH_4, and included in the analysis, estimates of the globally-averaged CH_4 abundance (monthly-and annually-averaged averages) and the annual growth are updated. By boosting the geographical density of the data and removing “end effects” from the curve-fitting techniques, adding fresh, more recent data increases the accuracy of the initial estimate. Each year has a different projected level of uncertainty in the global yearly CH_4 growth. Two terms are used to estimate it: The first is a resampling technique called “bootstrap” that changes the locations inside NOAA network. The NOAA/GML cooperative global air sampling network’s current maritime boundary layer sites are randomly selected, with restitution, to create each bootstrap realization of the network [52].

Table 1. Recent publications on methane from different countries.

Countries	Title	Methods used	Conclusion and Implications	Source
Brazil	First order models to estimate methane generation in landfill: A case study in south Brazil.	Research Article (Ground based)	According to this study, landfills will produce the most CH_4 gas in 2026; estimates range from 107,000 to 28,000 cubic meters annually. The potential for CH_4 gas generation can be estimated using first-order decay models, although waste disposal and landfill characteristics may have an impact on accuracy. The study has implications for CH_4 gas capture and usage, landfill design, and landfill operation. Landfills can be planned and run to reduce emissions and optimize energy recovery potential by knowing the potential for CH_4 gas generation.	[54]
China	Current status and effective suggestions for efficient exploitation of coalbed methane in China: A review. Energy Fuels.	Literature review method	The results of the study have a number of ramifications for China's future CBM exploitation. First, in order to create new technologies that can increase the effectiveness of CBM exploitation, research and development expenditures must be sustained; second, the government must put laws into place that encourage the growth of CBM, like tax exemptions and subsidies for CBM manufacturers; lastly, the industry must collaborate to create best practices for the exploitation of CBM. China can play a major role in the global energy market and realize the full potential of its enormous CBM resources if these suggestions are put into practice.	[55]
India	Methane sources from waste and natural gas sectors detected in Pune, India, by concentration and isotopic analysis.	Research Article (Ground based)	Compared to maritime background concentrations, high CH_4 concentrations were found, with an average of 2100 ± 196 ppb (1844–2749 ppb). Over the course of the investigation, the $\delta 13CH_4$ averaged −47.41% ± 0.94%, with a range of −45.11% to −50.03%. Typically, the morning (08:00–09:00 local time) saw the highest values of CH_4's diurnal fluctuation, whereas the afternoon (15:00 local time) saw the lowest. In winter (December–February), the deepest diurnal amplitude was over 500 ppb; in summer (March–May), it was less than half, at about 200 ppb. Pune's CH_4 content (470 ppb) was significantly greater than Mauna Loa, Hawaii, and had a marked seasonality. However, at Pune, there was no discernible seasonality in the $\delta 13CH_4$ records. According to the $\delta 13CH_4$ readings, the trash sector (which was augmented during the monsoon season; it had a signature of depleted $\delta 13CH_4$) and the natural gas sector (which had a signature of enriched $\delta 13CH_4$) were Pune's main suppliers of CH_4. The isotopic study revealed a temporary change in the CH_4 source to the waste sector, but our investigation of the impact of the COVID-19 shutdown (April to May 2020) on the CH_4 variability revealed no evidence.	[56]
China	High resolution assessment of coal mining methane emissions by satellite in Shanxi, China.	Research article (Satellite)	The 2019 and 2020 emissions are predicted to be 8.5 ± 0.6 and 8.6 ± 0.6 Tg CH_4 yr-1, respectively, which is near the top bound of the most recent bottom-up estimations. The monthly changes in emissions, including the decline and recovery in reaction to COVID-19 legislation, are accurately replicated. At the prefecture level, our projected emission factors—that is, the CH_4 emission per volume of mined coal—increase dramatically with coal mining depth, according to data from over a thousand individual mines. This finding implies that continued deeper mining will raise the intensity of CMM emissions in the future, necessitating immediate mitigation. Our findings demonstrate the reliability of predicting CMM emissions from TROPOMI photos and point to the possibility of tracking methane emissions and leaks from satellites.	[57]

Table 1. (*Continued*).

Countries	Title	Methods used	Conclusion and Implications	Source
United Arab Emirates (UAE)	Trends and variability in methane concentrations over the Southeastern Arabian Peninsula.	Satellite and reanalysis data	In terms of the spatial pattern, the reanalysis data agrees well with the satellite-derived estimates, but, because of flaws in the data assimilated, the magnitudes are reduced by as much as 50 ppb. Because of uncertainties in the emissions inventory, surface CH_4 concentrations in the reanalysis data show a seasonal cycle with the opposite phase and account for over 50% of the corresponding XCH_4 values. In order to fulfill the anticipated net-zero greenhouse gas emission target by 2050, the findings may help local authorities propose the best emission reduction measures. The results gave an overview of the current condition of CH_4 concentration in the UAE and the surrounding region. This study emphasizes the necessity of establishing a ground-based greenhouse gas concentration observational network in the Arabian Peninsula region, which is currently absent.	[58]
United States	Daily Satellite Observations of Methane from Oil and Gas Production Regions in the United States.	Satellite space-based TROPOspheric	Methane columns in the Permian Basin in Texas and New Mexico showed maxima over regions with the highest natural gas production and were correlated with nitrogen-dioxide columns at a ratio that is consistent with results from in-situ airborne measurements. In the Uintah Basin in Utah, TROPOMI methane columns correlated with in-situ measurements, and the highest columns were observed over the deepest parts of the basin, consistent with the accumulation of emissions underneath inversions.	[59]

4.4. Health effects of prolonged exposure to elevated methane levels

Even though methane (CH_4) is not directly harmful at normal environmental concentrations, it can have a negative impact on health via degrading air quality. The indirect effects of prolonged exposure to high methane concentrations, such as oxygen displacement, degradation of indoor air quality, and its role in ground-level ozone generation, are the main causes for worry. Although methane is not particularly harmful in and of itself, extended exposure to high concentrations can have detrimental effects on health, mainly through the displacement of oxygen, the creation of ozone, and health effects associated with climate change.

4.4.1. Oxygen displacement and asphyxiation risks

High methane concentrations can displace oxygen and cause hypoxia in small spaces or locations with large methane leaks. This may result in symptoms like headaches, lightheadedness, disorientation, and, in extreme situations, asphyxiation [60]. Suffocation danger is increased by methane buildup in poorly ventilated regions, such as mines or industrial sites, especially for workers there [61].

4.4.2. Contribution to ground-level ozone and respiratory issues

A dangerous air pollutant associated with respiratory diseases, tropospheric (ground-level) ozone, is formed from methane. According to West et al. [62], prolonged exposure to high ozone levels has been linked to a higher risk of developing asthma, lung inflammation, and impaired lung function. People with pre-existing respiratory disorders, the elderly, and children are most susceptible to these consequences.

4.4.3. Climate change and indirect health impacts

Methane is a key contributor to climate change, causing heat waves, harsh weather, and changed disease patterns, all of which can have a detrimental effect on human health. Increased air pollution, the growth of vector-borne illnesses, and heat-related illnesses are all made worse by rising temperatures, which also cause more respiratory and cardiovascular problems [63].

4.4.4. Indoor air quality and explosive hazards

Explosion hazards and poor indoor air quality can result from methane leaks from natural gas pipelines and appliances. Headaches, nausea, and exhaustion can result from prolonged exposure to leaking methane, which is frequently accompanied by other dangerous pollutants such as volatile organic compounds (VOCs) [64]. These leaks are especially dangerous in houses with poor ventilation.

4.5. Efforts that are necessary to advance the relationship between methane and air quality

More focus is needed in a few crucial areas to enhance our comprehension of how methane affects air quality and to create practical mitigation plans. First, to precisely measure methane emissions and their interactions with other air pollutants, improved monitoring systems are required. Although detection capabilities have been enhanced by developments in satellite and remote sensing technologies, ground-based measurements are still necessary for validation and localized evaluations [65].

Second, further atmospheric modeling is required to assess the role of methane in the production of ozone and other secondary pollutants. Although methane's function as a precursor to tropospheric ozone is taken into account in existing models, air quality predictions would be enhanced by improving these models with more accurate emission inventories and reaction processes [66].

Third, methane mitigation needs to be incorporated into larger air quality management plans through policy and regulatory frameworks. Although methane's position as a greenhouse gas is the main focus of current climate strategies, acknowledging its effects on air quality may have positive effects on both public health and climate change [67]. Important first steps will be to fortify global collaboration and enforce more stringent emissions regulations on industries like agriculture and the production of fossil fuels.

To provide a more complete picture of methane's environmental impact, future studies should also examine how it interacts with newly developing atmospheric stressors like urban air pollution and emissions from wildfires. To reduce methane's impact on air quality, scientists, legislators, and industrial stakeholders must work together across disciplinary boundaries to address these issues.

5. Limitations

The following are some of the limitations noted during the methane monitoring:

i) While high resolution satellites can identify finer details but have limited coverage, some are unable to detect small-scale methane leaks. There will be gaps in data collection for rapidly changing emissions since some satellites do not regularly pass over the same areas [68].

ii) Natural occurrences such as dense clouds, intense rain, and snow can obstruct methane signals, decreasing the efficiency of satellites. In the tropics, where cloud cover is common, this is a significant difficulty. Additionally, methane detection is hampered by water bodies, dense vegetation, and deserts with surfaces that reflect sunlight. Natural methane sources may mix with other emissions, making it difficult to distinguish between them [69].

iii) Satellites can identify methane levels, but they might not be able to pinpoint the precise source, such as the difference between emissions from livestock and landfill leaks. It is necessary to validate using ground-based approaches in order to confirm. Once more, satellites are limited in their ability to detect low-level emissions from diffuse or dispersed sources.

iv) Inaccurate signal interpretation may result in underestimations.

v) While some satellites deliver data instantly, others take days or weeks to process and verify. Rapid-response pollution control measures are less effective as a result of this delay [70].

vi) Although they are costly to launch and maintain, advanced satellites (such as GHGSat and MethaneSAT) offer detailed methane tracking. High-resolution proprietary data is not available to all nations or organizations [71]. There are limitations on data sharing because many methane-tracking satellites are run by commercial businesses or space agencies (NASA, ESA, etc.). Developing nations frequently may not have direct access to reliable methane monitoring data.

6. Conclusion

The quality of the air we breathe is crucial to maintaining the environment, protecting public health, and preventing climate change in a time of increasing industrialization, urbanization, and the constant pursuit of economic growth. Methane emissions have become a rising problem in this complex environment, their significance being highlighted by their double impact as a strong greenhouse gas and a destabilizer of local air quality.

This in-depth investigation of methane emissions and air quality has uncovered a complex web of interactions, ramifications, and difficulties that go beyond the usual confines of scholarly investigation. As methane, previously a supporting character, now plays a crucial role in accelerating the warming of our globe, it has highlighted the complex relationship between methane emissions and global climate change. It has also revealed the complex relationships between methane and local air quality, showing how this seemingly harmless molecule can have a significant impact on ecosystems and human populations. This investigation has covered a wide range of topics, from the analysis of primary sources and geographic distribution to the health impacts of prolonged exposure, from the intricate interactions with other atmospheric pollutants to the technical and governmental strategies for mitigation. It has emphasized the importance of holistic measures that take into account the economic, social, and environmental aspects of the methane crisis as well as the urgency of integrated assessment.

One insight becomes very clear as we come to the end of this journey: Tackling methane emissions and air quality is not only a moral and societal necessity but also a scientific one. Global cooperation, inventiveness, and dedication are required. It exhorts decision-makers to implement strict rules and rewards that encourage carbon reductions. It exhorts businesses to adopt greener procedures and technologies. Communities are encouraged to promote healthier environments and cleaner air. It necessitates that people consider their carbon footprint and promote change. The way forward in this attempt is obvious: Policy must be informed by science, technology must support regulation, and society must demand accountability. Methane emissions and air quality are causing increasing concern, and this serves as a sharp reminder of how interrelated our world is and how equally responsible each of us is for protecting it for future generations.

We see both hope and determination in this group effort—a determination to pave the way for improved communities, better weather patterns, and cleaner air. We can address the mounting concern over methane emissions and air quality via information, action, and unshakable dedication, taking steps toward a more sustainable and prosperous world for all.

Recommendation

These suggestions are put out in light of the findings: Reduce methane emissions from important sources, including the energy industry, agriculture, and landfills, by implementing strong regulatory standards and incentives. Boost air quality monitoring networks by fusing satellite and ground-based technologies to deliver real-time information for strategic decision-making. To gain support for mitigation initiatives, increase public understanding of the health and environmental dangers connected with methane emissions. Recognizing that this is a shared duty, work together to create global agreements and commitments to minimize methane emissions. The protection of the planet's climate and the welfare of its inhabitants depend critically on addressing methane emissions. We can all work together to address the rising concern about methane emissions and their effect on air quality by implementing varied methods.

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