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Satellite and Other Aerial Measurements – A Step Change in Methane Emission Reduction?

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Highlights

- Measuring, reporting and then accounting for fugitive methane emissions will be an important part of any decarbonisation strategy in the future. Natural gas is a relatively low-carbon fossil fuel and will play a major role in reducing emissions during the decarbonising 'transition' phase, notably to substitute coal. Furthermore, it can be expected to play an important role in a very low- and even zero-carbon energy system in the longer term through its role as an energy source for low- and potentially zero-carbon hydrogen.
- Discussions during two webinars organised by the Florence School of Regulation showed a rapidly evolving and impressive development of the ability and potential for satellites to monitor and detect methane emissions. While they are not a panacea, the use of satellite instruments could substantially strengthen global monitoring of methane emissions close to real time.
- Different regulatory models exist today to ensure that companies monitor and are then incentivised to eliminate emissions. Further work is needed to benchmark and compare these models, not least to determine which incentivises technological development.
- In any event, methane emissions are a global issue and require a global solution. A framework is already in place: the UN Guidelines on Peaceful Uses of Outer Space could, for example, facilitate the specification of procedures related to the discovery of a large methane leak. Continued work and progress through the Oil and Gas Methane Partnership can be important in this context.
- The EU will issue its Methane Strategy in the coming months. This will be an excellent opportunity to set out a process to accelerate international cooperation over using satellite measurements in methane emission detection and measurement. Satellite technology can be one of two 'pillars' of any emission detection and reduction policy, the second being local monitoring actions implemented at the national or regional level. Once this has been achieved, effective measures can be adopted through diplomatic action, standards or pricing.
- The EU has considerable economic and political power and influence, and an established energy dialogue with all its major energy suppliers. Combining action at home and collaboration abroad, and given the state of technological development and its continual improvement, the pieces are gradually falling into place that should permit a (cost-) effective approach to accurately measuring and significantly reducing emissions that will in turn permit accurate accounting of them in GHG emission policies and actions.

Introduction

The Covid-19 pandemic has hit energy investment around the world hard. Only in the oil and gas sector, investment is expected to decrease by 30% this year, and the situation is likely to continue well into 2021.[1] While companies are forced to revise their planned spending, policymakers are putting in place socio-economic recovery plans. However, in contrast to the response to the 2008/9 economic crisis, clean energy spending is likely to play a more important role in many recovery strategies,[2] particularly in the European Union (EU), where the revised long-term budget proposed by the European Commission at the end of May was reinforced with a €750 billion recovery instrument to "make Europe clean and digital."[3]

Currently, a quarter of the EU's energy is produced from natural gas, mostly imported from diverse geographical regions. Although the role of gas has been recognised in the European Green Deal, there is an understanding that fugitive methane emissions resulting from gas production and transport need to be fully factored into Europe's GHG intensity values. Otherwise, this could compromise the role of natural gas in the energy transition and also cast doubts about the greenhouse gas (GHG) intensity of low-carbon alternatives such as biomethane. The risk is that if the EU is not able to accurately identify, track and account for fugitive methane emissions and then integrate the cost of all relevant externalities in the gas supply, it will end up either (1) artificially limiting the contribution that natural gas and low-carbon gases can make to future energy; or (2) using it while failing to properly take into account its GHG externalities.[4] Neither of these options is acceptable if EU policymakers want to pursue a cost-effective technology-driven decarbonisation policy. However, cleaning up methane emissions is not an easy task, partly due to the need to significantly improve the bottom-up calculation of emission inventories. Top-down methane emission measurements such as satellite and other aerial measurements involving the use of aircraft, drones or towers could potentially provide a step change allowing emissions to be tracked globally close to real time, thus decreasing the cost of emission monitoring from single facilities. Although their use is still limited, post-Covid-19 climate investments, both private and public, could increase their importance.

The potential of 'unorthodox' methane observations, and satellite observations in particular, was investigated during a series of two webinars organised in June 2020 by the Florence School of Regulation with a group of distinguished experts from academia, the oil and gas sectors, non-governmental organisations, international and EU institutions and regulatory authorities.[5] This paper discusses the main findings from the discussions and is divided into three parts: part 1 presents the technological landscape and the capabilities and limitations of satellite observations; part 2 proposes three regulatory and non-regulatory approaches to fostering further technology innovation; and part 3 discusses the global nexus and the need for better coordination of methane observations from space. The final part draws some conclusions.

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1. https://www.iea.org/reports/world-energy-investment-2020/key-findings#abstract (accessed 09/07/2020).
2. C. Hepburn et al., Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change? Oxford Review of Economic Policy, graa015, https://doi.org/10.1093/oxrep/graa015.
3. https://ec.europa.eu/info/strategy/eu-budget/eu-long-term-budget/2021-2027_en (accessed 09/07/2020).
4. Ch. Jones intervention at the Stakeholder workshop "Limiting methane emissions in the energy sector" on 10 June 2020.
5. https://fsr.eui.eu/highlights-from-the-methane-emissions-two-webinar-series (accessed 09/07/2020).

The Technological Landscape

According to data gathered in the Index of Objects Launched into Outer Space under the auspices of the United Nations Office for Outer Space Affairs (UNOOSA), a total of 4,655 satellites were circulating around Earth's orbit in mid-June 2020.[6] It is likely that the number of satellites launched into space will break a new record this year, with 562 objects launched in the first six months of 2020 – only 18 less than during the whole of 2019. The increase observed is linked to the Starlink project, which aims to provide a space broadband internet connection, a project carried out by Space Exploration Technologies Corp. (SpaceX) led by Elon Musk[7]. The cost and ease of satellite use has significantly reduced over time.

Satellites can observe vast parts of the Earth at one time, and therefore collect more complete data in a shorter time span. This feature has mainly been used for communications (telephone and television and radio broadcasting), navigation (the Global Positioning System, GPS) and weather forecasting. Since the early 2000s, satellites have been used more frequently to monitor concentrations of GHGs, including methane.

SCHIAMACHY was the first solar backscatter measuring methane, and it was followed by GOSAT and GOSAT-2.[8] TROPOMI, launched in 2017, became the first satellite instrument providing complete daily global coverage with 7 x 7 km^2 resolution. The microsatellite Claire, owned by the Canadian company GHGSat Inc. and launched in 2016, offers the greatest precision with 50 x 50 m^2 pixel resolution over selected point sources. Synergy between TROPOMI and the fine-resolution GHGSat instrument allowed a large source of methane emissions in western Turkmenistan to be spotted. This will be discussed in more detail in part 3 of this policy brief.[9]

As a result, more and more satellite instruments are planned for launch in the early 2020s. GHGSat Inc. schedules the launch of its second GHG monitoring satellite Iris, with a 25 x 25 m^2 resolution, for mid-2020[10] and the Environmental Defense Fund's subsidiary MethaneSAT is planning to launch a satellite in 2023 with the objective of observing and quantifying methane emissions mostly from oil and gas sources on the regional scale, starting with 200 oil and gas priority areas around the world and with the potential to be expanded to observe methane emissions from agriculture.[11]

Satellite Instrument Capabilities

The data retrieved from satellite instruments provide information on atmospheric concentrations of GHGs, yet observations are conducted at different levels of accuracy and precision. We can distinguish three major parameters which help us to characterise satellite observations: spectral resolution, spatial resolution and temporal resolution.

Spectral resolution "refers to the ability of a satellite sensor to measure specific wavelengths of the elec-

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[6] UN Office for Outer Space Affairs, Online Index of Objects Launched into Outer Space (accessed 09/07/2020).

[7] For more information, see https://www.space.com/spacex-starlink-satellites.html (accessed 09/07/2020).

[8] D.J. Jacob et al., Satellite observations of atmospheric methane and their value for quantifying methane emissions, Atmos. Chem. Phys., 16, 14371–14396, https://doi.org/10.5194/acp-16-14371-2016, 2016.

[9] Satellite Discovery of … Varon et al., 2019.

[10] https://www.ghgsat.com/our-platforms/iris/

[11] S. Hamburg's presentation at the FSR webinar "How can aerial measurements aid methane emission reduction?" 1 June 2020.

tromagnetic spectrum."[12] Sensors with more bands and narrower spectral widths are considered to have finer spectral resolution. Each object and type of surface has a characteristic spectral fingerprint. Therefore, instruments with higher spectral resolutions provide information on the mineral content of rocks, the moisture in soil, the health of vegetation and the physical composition of buildings. There is usually a trade-off between spectral and spatial resolution. For instance, panchromatic systems characterised by several hundred nanometre bandwidths provide far better spatial resolution than multispectral (around ten bands) or hyperspectral (hundreds of bands) systems.[13]

Spatial resolution, or pixel resolution, describes the size of a pixel on the ground. The higher the number of pixels constituting a picture is, the higher the spatial resolution, allowing us to obtain more detailed pictures. Satellite images can be subdivided into: low resolution images, where one pixel corresponds to an area of 60 x 60 m or more on the ground; medium resolution with 10-30m per pixel; and high to very high resolution with 30cm-5m per pixel.[14] Currently, GHGSat's satellite Claire acquires images with the highest spatial resolution of 50 m, allowing even modest leaks from individual wells to be detected. However, this comes at the expense of a limited field of view of approximately 12 km x 12 km, which means it targets specific sources of emissions in sectors such as oil and gas, power generation, mining, waste management and agriculture.[15]

Temporal resolution, also referred to as revisit time, is the time difference between the acquisition of two images of the same area.[16] The higher the temporal resolution is, the shorter the timespan between acquisitions of images. On average, temporal resolution is in the range 1 to 5-10 days in the case of so-called polar orbiting satellites, such as TROPOMI, which allows for daily global coverage. In contrast, geostationary satellites like geoCARB, which observe the same areas of Earth's surface, take only a few minutes to a few hours. However, this comes at the expense of lower spatial resolution than polar orbiting satellites.

As we can see, the choice of a specific satellite instrument and its capabilities is determined by both the objective and the object of observations. Space observation can provide global coverage of emissions in near real time, allowing for continuous methane emission observation. Like a fire alarm system which helps to detect smoke, satellite observations could establish a warning system which could be activated automatically once a significant source of methane is detected.[17] However, satellite observations also have a number of important limitations.

Satellite Instrument Limitations

Satellite observations can be subject to errors resulting from: light collection by the instrument; dark current spectroscopic data; the radiative transfer model; or cloud contamination. We can distinguish two types of error: random error related to precision; and systematic error related to

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12. Satellite Applications for Geoscience Education, https://cimss.ssec.wisc.edu/sage/remote_sensing/lesson3/concepts.html

13. D. Newland, Evaluation of Stepwise Spectral Unmixing with HYDICE Data, Center for Imaging Science, Rochester Institute of Technology, 1999. Available at: https://www.cis.rit.edu.

14. https://eos.com/blog/satellite-data-what-spatial-resolution-is-enough-for-you/

15. https://www.ghgsat.com/our-platforms/claire/

16. http://www.fis.uni-bonn.de/en/recherchetools/infobox/professionals/resolution/temporal-resolution

17. S. Hamburg's presentation at the FSR webinar "How can aerial measurements aid methane emission reduction?" 1 June 2020.

accuracy.[18] The former can be eliminated or reduced with repeated observations and averaging, while the latter is irreducible. Therefore, it is important to validate satellite data with suborbital observations of methane from towers, aircraft, drones or balloons.

Moreover, solar backscatter measurements in the shortwave infrared (SWIR) require a reflective surface, which means that the observation is largely limited to land areas. It is technically possible to retrieve some ocean data from so-called sun glint, that is, specular reflection at the ocean surface. Moreover, clouds can also impact observations in two ways: by reflecting solar radiation back to space; and by impeding detection of the air below them. Data retrievals are, however, possible for partly cloudy scenes. The success rate of such retrievals is 17% for GOSAT and 9% for SCIAMACHY.[19]

Another limitation is the emission detection threshold. In principle, satellite observations allow spotting of very large leaks which may result from equipment failure such as at a gas compressor station or from several sources located in one area. In these cases, the challenge is not only to detect a leak but also to attribute it to the right source, which may require the aid of aircraft observations.

Another group of obstacles is related to the process of inferring methane emissions from satellite data, which requires extra data analysis skills and additional time. One of the most popular inverse methods requires the use of high-quality fine-gridded bottom-up inventories, and so far EDGAR has been the key inventory used for this purpose. However, the EDGAR inventory relies on IPCC default tier 1 methods, which are not always accurate and provide limited information concerning the classification of methane emissions by source sector. Therefore, the quality of satellite measurements is in a way influenced by the quality of the bottom-up inventories serving as the basis for methane emission inversion.[20]

To sum up, the use of satellite instruments could provide a step change in methane detection and measurement allowing for continuous emission monitoring with global coverage close to real time. However, it does not provide a 'solution' to the issue of detecting and measuring emissions and would require coordination between satellite instruments with different spatial, spectral and temporal resolutions together with airborne observations.

Could regulation foster technology innovation and the further development of unorthodox methane observations?

The panellists participating in the second FSR webinar on satellite and other aerial measurements agreed that regulation could foster further technology innovation, particularly in terms of methane detection, measurement and quantification.[21] In principle, the choice is between three options: (1) technology-neutral policy and regulatory instruments; (2) built-in flexibility mechanisms as part of regulation; or (3) non-regulatory approaches and incentives underpinning technology innovation.[22]

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18. D. J. Jacob et al., Satellite observations of atmospheric methane and their value for quantifying methane emissions, Atmos. Chem. Phys., 16, 14371–14396, https://doi.org/10.5194/acp-16-14371-2016, 2016.

19. Ibid.

20. D. J. Jacob, Methane in the Climate System: Monitoring Emissions from Satellites, presentation at Caltech workshop "Towards Addressing Major Gaps in the Global Methane Budget," 24 May 2017. Available at Youtube (accessed 09/07/2020).

21. Webinar 2: How can aerial measurements aid methane emissions reduction?, 8 June 2020. The recording is available at: https://fsr.eui.eu (accessed 06/07/2020).

22. K.C. Michaels, Flexible methane policy and regulation, presentation at the FSR webinar 2: "How can aerial measurements aid methane emissions reduction?" on 8 June 2020.

The three options are not mutually exclusive and therefore could be applied in combination.

First, policy instruments to address methane emissions could be designed in a technology-neutral way by creating regulatory or economic incentives to innovate, that is, to continually look for abatement options, which is the least costly.[23] This approach recognises the fact that the methane abatement cost is different for different types of facilities. Therefore, the regulated entity is responsible for assessing the available options and choosing the one with the best cost-benefit ratio, as long it enables certain performance standards or reduction objectives to be met.

In some cases, command-and-control regulations incorporate a list of the best available technologies (BATs) and best practices. The 2018 Mexican regulation allows regulated companies to pick and choose methane reduction technologies from a list suggested in Title III of the regulation as long as the company is able to meet a methane reduction target specified in the methane prevention and control plans (Program for the Prevention and Integral Control of Methane Emissions in the Hydrocarbon Sector, PPCIEM).[24] Moreover, regulated companies are allowed to use new equipment and components not included in Title III. Article 86 specifies that this innovative technology should have an equivalent or superior environmental effect and is subject to case-by-case "detailed technical justification," which should constitute an annex to the annual compliance report with the PPCIEM.

An alternative to the 'regulatory approach' could be to use market-based policy instruments, which create economic incentives to innovate and are both technology- and source-neutral. The carbon tax introduced in Norway in 1991 also applies to methane emissions from offshore oil and gas facilities. The tax is paid for each tonne of methane released into the atmosphere, adjusted on an annual basis.[25] According to IEA data, the Norwegian oil and gas sector emitted only 26 kt in 2019, a record low for a major oil and gas producer.[26] Regulated companies need to assess the cost and the environmental performance of the available methane abatement options and decide which works best for their operations, taking into account the conditions on individual installations.

Companies can also consult a 2016 report on best available technique (BAT) assessments prepared for the Norwegian Environment Agency.[27] The report recognises that the cost of modifying existing installations to ensure compliance with BAT solutions could be high and "[s]ince all individual facilities are constructed differently, the reconstruction work could vary significantly from facility to facility, to supposedly solve the same problem."[28] For instance, the report suggests recovery by re-compression and re-circulation of the waste gas as a BAT to reduce

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[23] U.S. Environmental Protection Agency, National Center for Environmental Economics, Guidelines for preparing economic analyses, 17 December 2010, updated May 2014. Chapter 4 Regulatory and Non-Regulatory Approaches to Pollution Control, pp. 1-22.

[24] Disposiciones Administrativas de carácter general que establecen los Lineamientos para la prevención y el control integral de las emisiones de metano del Sector Hidrocarburos. Diario Oficial de la Federación: 06/11/2018.

[25] The 2020 tax rate for emissions of natural gas is NOK 7.93 (EUR 0.094) per standard cubic metre, which is roughly 24 times the CO2 tax rate. Source: https://www.norskpetroleum.no/en/environment-and-technology/emissions-to-air/ (accessed 06/07/2020).

[26] IEA Methane Tracker: https://www.iea.org/reports/methane-tracker-2020/interactive-country-and-regional-estimates (accessed 06/07/2020).

[27] https://www.miljodirektoratet.no/globalassets/publikasjoner/M665/M665.pdf

[28] Ibid., p. 1.

emissions from reciprocating compressors at new installations, while it recognises that the same solution could have a high abatement cost for existing installations. Ideally, such lists incorporating BATs should be regularly updated in order to include technology developments.

One factor which could discourage the use of economic instruments is that they require accurate estimates of methane emissions before the mechanism is introduced in order to set an appropriate price for methane. The advantage of the regulatory approach adopted in Mexico is that it can be used even if there are only limited data on the emissions at the facility level at the time the regulation is adopted since the emission monitoring obligation and the obligation to reduce emissions was introduced with the same regulatory instrument.

The second option is to apply built-in flexibility mechanisms while designing methane regulations. Such mechanisms could allow regulated companies to use different technologies or methods to those suggested in the regulations as long as the alternative technologies are considered equivalent. Regulated companies are usually responsible for proving equivalency to the regulator. However, if the administrative burden is considered too high or the procedure is too complex, the motivation to look for alternatives and to innovate could be compromised. Therefore, it is crucial for the regulation to include a realistic path for approval of innovative technologies and for continual innovation to go hand in hand with enhanced emission reduction targets.[29]

An example of such built-in flexibility can be found in the Alberta Energy Regulator (AER) Directive 060, which introduces a double flexibility mechanism concerning the conduct of fugitive emission surveys.[30] A responsible party[31] can use an organic vapour analyser in line with US EPA Method 21, a gas-imaging camera or "other equipment or methods that are equally capable of detecting fugitive emissions." In that case, the duty holder is obliged to assess and demonstrate the equivalency, when requested by the AER.

Moreover, the AER regulation opens a way to seek other alternatives: "[t]he AER will consider innovative and science-based alternatives to the fugitive emissions management program prescribed in this directive."[32] The list of alternative technologies includes: "unmanned aerial vehicles; vehicle-mounted sensors; and continuous monitoring devices to detect, track, repair and report fugitive emissions." This provision recognises the potential of unorthodox methane detection methods involving the use of drones, vehicles, aircraft and even satellite instruments. Operators willing to use such alternatives are required to "submit a proposal to the AER for review and possible approval." The duty holder is obliged to follow the regulation unless the alternative programme is approved.

The third option is to use non-regulatory approaches and incentives to underpin technology innovation. Here the possibilities are much more abundant and are not necessarily restricted to one jurisdiction. It is a common practice to combine them with policy instruments. Examples include: early-stage research and development funding provided by U.S. DOE for methane abatement R&D (2014, 2016, 2019); public funding of new technology 'infrastructure' such as TROPOMI, funded by the Dutch government; tax reliefs for R&D purposes used in Norway; loans and

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[29] R. Kleinberg, presentation at the FSR webinar 2: "How can aerial measurements aid methane emissions reduction?" on 8 June 2020.

[30] Alberta Energy Regulator Directive 060: Upstream Petroleum Industry Flaring, Incinerating and Venting. Released on 12 May 2020, Section 8.10.2.2 Available at: https://www.aer.ca

[31] Or duty holder, e.g. licensee, operator, company, applicant, approval holder or permit holder.

[32] Section 8.10.6 Alternative Fugitive Emissions Management Program.

grants to support technology deployment and regulatory compliance; and international market-based funding mechanisms to incentivise methane abatement.[33]

One example is the 2019 Methane Action Plan (MAP) proposed by the Government of Saaskatchewan.[34] It combines regulation (output-based performance standards) with 10 complementary policies and programmes, including ones supporting investment in new technologies: the Technology Fund[35] and the Saskatchewan Petroleum Innovation Incentive (SPII).[36] The former, which is currently being developed, will accrue the penalties for non-compliance with the regulation and prioritise an investment in emission management projects in the oil and gas sector. The latter offers transferable royalty/freehold production tax credits for qualified innovation commercialisation projects at the rate of 25% of eligible project costs. The SPII programme targets both pilot projects and commercial scaling projects, allowing both innovations to be tested and then deployed on larger commercial scales.

How to Enhance Global Cooperation in Space?

In the course of the last few years, satellite observations have proven their value in terms of identifying and monitoring methane emissions at the facility level.[37] The potential of technology development, growing interest in satellite methane observations and increasing activity by private-sector and non-governmental organisations in the area raise new questions. How should the space activities of private-sector and non-governmental entities be coordinated? Are satellite data a public good? Once a large methane leak is detected, who has the responsibility to act?

In order to address these questions, let us look at a concrete example of synergy between the private and public sectors which led to the discovery of very large methane point sources from oil/gas production in Turkmenistan by a satellite belonging to the Montreal-based company GHG Sat Inc. The increase in methane concentrations across Turkmenistan was observed as early as 2004 by the SCHIAMACHY satellite instrument launched by the European Space Agency and also a few years later by the TROPOMI instrument launched by ESA and the Netherlands Space Office.[38]

Publicly-available data from SCHIAMACHY and TROPOMI observations prompted GHGSat Inc. to focus its observations on the area of western Turkmenistan with the aim of searching for methane emissions from a mud volcano. In January 2019, the GHGSat-D satellite instrument discovered a large methane plume. A more thorough analysis allowed it to be connected to three likely sources in the Korpezhe oil/gas field: venting from the compressor; a blowdown or malfunctioning isolation valve in the pipeline connection between the compressor station

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[33] World Bank Pilot Auction Facility.

[34] https://www.saskatchewan.ca/business/environmental-protection-and-sustainability/a-made-in-saskatchewan-climate-change-strategy/methane-action-plan (accessed 06/07/2020)

[35] https://www.saskatchewan.ca/business/environmental-protection-and-sustainability/a-made-in-saskatchewan-climate-change-strategy/methane-action-plan (accessed 06/07/2020)

[36] https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/oil-and-gas/oil-and-gas-incentives-crown-royalties-and-taxes/saskatchewan-petroleum-innovation-incentive (accessed 06/07/2020)

[37] D. J. Varon et al., Satellite Discovery of Anomalously Large Methane Point Sources from Oil/Gas Production, Geophysical Research Letters 10.1029/2019GL083798.

[38] Ibid.

and the gas production unit; and a leak at the production facility.

It has been estimated that in the course of nearly a year (between 24 February 2018 and 27 January 2019) the three sources detected by GHGSat-D emitted a total of 142 +/- 34 kt. The total emissions from the sources detected by the TROPOMI instrument between 17 December 2017 and 31 January 2019 have been estimated at 446 (189-750) kt[39]. To put this into context, the 2015 Aliso Canyon blowout released 97kt of methane into the atmosphere over a period of 4 months, while the total emissions detected by TROPOMI were nearly equal to the annual methane emissions from the Australian oil and gas sector, estimated at 497 kt, or 0.6% of global methane emissions from the oil and gas sector.[40]

The company employed US, Canadian and European diplomatic channels to inform the Turkmenistan field operator about the discovery. Satellite images confirm that the leak was stopped by May 2019.[41] This means that it took almost 3 months from the discovery of the leak to stop it.

GHGSat is expanding its business activities. We can expect more companies to follow suit, raising the issue of the responsibilities of private companies in space, especially once a large methane plum is discovered. Cooperation between public and private entities in space was the focus of 21 guidelines aiming to ensure the long-term sustainability of outer space activities adopted by the UN Committee on Peaceful Uses of Outer Space (COPUOS) in 2019.[42]

Guideline A.3 specifies that it is a state's responsibility to ensure that non-governmental entities under its jurisdiction conducting outer space activities apply appropriate procedures while planning and conducting space activities. States should also ensure that non-governmental entities demonstrate the necessary technical competencies, establish safety procedures and assess all risks related to the long-term sustainability of outer space activities. The guideline suggests that states should seek to establish procedures for planning and conducting space activities, along with communication and consultation mechanisms to oversee space activities.

Guideline C.3 invites states and international intergovernmental organisations to establish appropriate procedures for exchanging information. Information coming from space-based data with appropriate spatial and temporal resolution should be "freely, quickly and easily available for countries" affected by natural disasters or other catastrophes.

These guidelines provide a good basis for the relevant national authorities to establish special procedures for planning and conducting space activities with clearly defined responsibilities for non-governmental entities and government agencies. Procedures related to the discovery of a large methane leak should specify information exchange with a clearly defined time frame. This will allow the time between leak detection and informing the facility operator to be minimised. Rules concerning the exchange of information in the case of natural disasters should also be relevant in the case a large methane leak is detected. The satellite data concerning such discoveries should be publicly available.

To facilitate international cooperation, a UNEP International Methane Emissions Observatory should be funded by governments. The Observatory

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[39] Ibid.

[40] https://www.iea.org/reports/methane-tracker-2020/interactive-country-and-regional-estimates#abstract

[41] https://www.bloomberg.com/news/articles/2019-11-22/satellite-studying-volcanoes-finds-giant-oilfield-methane-plume

[42] These voluntary guidelines concentrate on five areas: policy and regulatory frameworks for space activities; safety of space operations; international cooperation; capacity-building and awareness; and scientific and technical research and development.

would process and aggregate methane data. Reconciliation of bottom-up inventories, top-down estimates and satellite observations could serve as the basis for raising the alert to take the necessary actions to deal with fugitive methane emissions. In cooperation with UNOOSA and national space agencies, the Observatory could also gather information and best practices concerning satellite methane observations.

Conclusions

Globally, there is growing understanding of the need to address the issue of methane emissions, and the EU is committed to taking action. However, in order for effective mitigation efforts to be made, accurate monitoring and reporting is essential.

Alongside more accurate measurement and reporting, actions to deal with methane emissions are growing in number and impact. Methane intensity production standards are being proposed, and a debate is growing on methane-intensity-based methane procurement standards.[43]

In addition, with accurate monitoring the scope for international action and collaboration increases. A large proportion of methane emissions can be removed cost-effectively and new technologies are developing that will increase this. Satellite and other aerial measurements provide new opportunities to identify and then reduce emissions quickly and cost-effectively. The oil and gas sector has a real potential to decrease a substantial part of the emissions that it is causing.

However, to scale up existing actions, political will and political decisions are necessary. The EU is preparing a Methane Strategy. Even though the EU's share of global methane emissions from oil and gas operations is rather limited, it is a major oil and gas market. The EU has the opportunity to be a global trendsetter in fighting methane emissions. Putting a European measurement and monitoring system in place would be an essential starting point. This was also recently included on the list of the IEA's policy recommendations to the EU.[44]

In this context, the EU would be well advised to put into place an ambitious external dimension to its Methane Strategy. The EU has active energy dialogues with most energy producers and enormous global political and economic power, which it rarely uses to full effect. The example of Turkmenistan outlined above demonstrates what can be achieved when a monitoring system is used to provide data, and political action is taken through 'soft diplomacy' to achieve results: eliminating emissions very often saves the emitter money.

The use of satellites can be an important element in establishing a global monitoring system and a basis for collaboration. It is far from a panacea and will require on-the-ground monitoring too, but it will be a vital link in the chain. In this context, the EU can use both multilateral and bilateral fora to raise awareness of the options coming from new technological solutions to effectively deal with methane emissions.

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[43] Methane policy recommendations for the European Union signed by BP, Eni, Equinor, the Environmental Defense Fund, the Florence School of Regulation, Repsol, the Rocky Mountain Institute, Shell, Total and Wintershall Dea, 8 May 2020.

[44] International Energy Agency (2020) European Union 2020. Energy Policy Review. Paris, https://www.iea.org

Annex

Table 1. Satellite instruments for measuring tropospheric methane.

INSTRUMENT	DATA PERIOD	AGENCY[d]	SPECTRAL RESOLUTION [nm]	SPATIAL RESOLUTION [km^2]	TEMPORAL RESOLUTION [coverage]	PRECISION	DETECTION THRESHOLD [kg/h][b]	EMISSIONS OBSERVED[c]
SCHIAMACHY	2003–2012	ESA	1630–1670 (1.4)	30 x 60	6 days	1.5%	68,000	CO_2 CH_4
GOSAT	2009 –	JAXA	1630–1700 (0.06)	10 x 10	3 days	0.7%	7,100	CO_2, CH4, O_3, H_2O
GHGSat	2016 –	GHGSat Inc.	1600–1700 (0.1)	0.05 x 0.05	12 x 12 km^2 grid with revisit time of 2 weeks	0.4%	25[e]	CO_2 CH_4
TROPOMI	2017 –	ESA, NSO	2310–2390 (0.25)	7 x 7	1 day	0.6%	4,200	CO CH_4
GOSAT-2	2018 –	JAXA	1630–1700, 2330–2380 (0.06)	10 x 10	3 days	0.4%	4,000	CO_2, CH_4, O_3, H_2O, CO, NO_2
MethaneSAT[a]	2022	EDF	1650	1.4 x 1.4	7 days	0.1%	100	CH_4
geoCARB	2022	NASA	2300 nm band	4 x 5	2-8 h	1.0%	4,000	CO_2, CH_4 and CO
CarbonSat	2023	ESA	1590–1680 (0.3)	2 x 2	5-10 days	0.4%	80	CO_2 CH_4

Sources: Jacob, D. J., Turner, A. J., Maasakkers, J. D., Sheng, J., Sun, K., Liu, X., Chance, K., Aben, I., McKeever, J. and Frankenberg, C., Satellite observations of atmospheric methane and their value for quantifying methane emissions, Atmos. Chem. Phys., 16, 14371–14396, https://doi.org/10.5194/acp-16-14371-2016, 2016. [a] S. Hamburg presentation (2020); [b] MethaneSAT: Putting the Brakes on Climate Change, Key Technical Considerations, May 2019; [c] ESA Earth Observation Portal (eoPortal) Satellite Missions Database; [d] ESA – European Space Agency, JAXA - Japan Aerospace Exploration Agency, NSO – the Netherlands Space Office, EDF – Environmental Defense Fund, NASA - National Aeronautics and Space Administration; [e] assuming 5% precision.

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