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Pricing Methane Emissions from Oil and Gas Production

How new methane measurement data and pricing designs can complement direct regulation and enable additional emissions reductions

Maureen Lackner, Jonathan R. Camuzeaux, Suzi Kerr and Kristina Mohlin

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Maureen Lackner, Jonathan R. Camuzeaux, Suzi Kerr and Kristina Mohlin

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Abstract

Nearly a quarter of global greenhouse gas (GHG) emissions are covered by GHG pricing initiatives. However, few methane emissions are priced, even though methane is a significant driver of current warming. To reduce methane emissions from oil and gas production, comprehensive policies and regulations are critical.

Price-based policy instruments offer several attractive features to manage these emissions. They give firms flexibility in terms of who mitigates, and when and how mitigation occurs. On its own, emissions pricing can enable and encourage some reductions. When combined with direct regulations, such as technology standards and mandated leak detection and repair programs (LDAR), pricing can support even deeper reductions. However, price-based policies have not yet been used extensively to address methane emissions from fossil fuel production. The main argument against pricing methane emissions from oil and gas production has been that these emissions are difficult to measure cheaply, frequently, and with precision and accuracy. Direct regulations to address oil and gas methane emissions typically do not mandate emissions measurements, although they also will be even more effective with better data.

While methane emissions from this sector remain difficult to measure on a comprehensive and frequent basis, emissions pricing policies can still be effective complements to existing regulations — especially if they are well designed. Furthermore, methane emissions measurement technologies, including satellite instruments, continue to advance and provide new opportunities for monitoring and enforcement.

This brief provides a preliminary assessment of how a well-designed price on methane emissions from oil and gas production could be implemented in addition to existing regulations in a way that incentivizes oil and gas companies to increase their mitigation efforts and improve their methane detection and measurement practices.

Keywords

Climate policy, emissions pricing, greenhouse gases, methane emissions, methane emissions data, methane monitoring and enforcement.

JEL Classification Numbers

H23, Q35, Q54, Q58

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Contents

1. Introduction

Nearly a quarter of global greenhouse gas (GHG) emissions are covered by GHG pricing initiatives (World Bank, 2020). However, few methane emissions are priced, even though methane is a potent GHG and a significant driver of current warming (IPCC, 2014; Etminan et al., 2016).[1] Recent studies estimate that methane emissions from oil and gas activities represent a fifth or more of total global methane emissions (Schwietzke et al., 2016; Hmiel et al., 2020; Saunois et al., 2020). Projected growth in global demand for oil and natural gas could significantly increase these emissions. The International Energy Agency suggests that a business-as-usual trajectory in natural gas markets could result in a 25% increase above current methane emissions levels by 2040 (IEA, 2018).

In this brief, we focus on oil and gas production (also known as "upstream") activities, as opposed to transmission and distribution activities. In the U.S., upstream activities are estimated to be responsible for close to 60% of the oil and gas sector's total methane emissions. We use the U.S. as a case study in this brief because it is the world's top oil and gas producer and the country with the most detailed methane emissions data available to date.[2] Still, much of the discussion will be relevant to other oil- and gas-producing regions looking to address their methane emissions.

Policy is essential to abating methane emissions. As natural gas is primarily composed of methane, companies that hold title to the gas along the oil and gas supply chain already have some incentive to prevent leaks and thereby emissions. However, private action cannot achieve the magnitude of reductions that is needed according to climate science (Hausman and Raimi, 2019). Recent estimates suggest that societal damages are at least $1,500 per metric tonne of methane emitted today, and possibly twice that (U.S. Government, 2016; Carleton and Greenstone, 2021). At a methane emissions rate of 2% along the U.S. gas supply chain, this translates to social damages that are, at minimum, $0.5 per MMBtu of gas delivered (Alvarez et

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[1] Over a 20-year time horizon, methane traps heat at least 80 times more effectively than carbon dioxide (CO_2).
[2] See Marks, 2018 for a detailed breakdown of the different parts of the U.S oil and gas supply chain and the associated methane emissions at each stage. Note that new data (see Weller et al., 2020) indicate that local transmission and distribution account for closer to 5% of total emissions.

al., 2018). These damages are additional to private costs for lost gas of about $0.06 per MMBtu delivered, based on a 2% loss rate and a U.S. wholesale gas price of $3 per MMBtu.[3]

Current regulations for methane emissions from the oil and gas sector typically rely on technology standards or leak detection and repair (LDAR) programs (Environment and Climate Change Canada, 2018; Baumstark, 2014; Clean Air Task Force, 2018; IEA, 2020a). Such regulations require firms to undertake certain responsibilities, such as installing low-emitting equipment, or to periodically inspect their facilities for leaks and repair any that are detected.

However, modeling suggests that even with optimistic assumptions regarding compliance, such direct regulations on their own are unlikely to be sufficient to achieve methane emissions reductions that are consistent with reaching the Paris Agreement temperature goal.[4]

Methane pricing at the emissions source is attractive because of its ability to incentivize cost-effective abatement and encourage innovation in mitigation technologies and practices, while also providing a price signal to end users and thereby influencing consumption decisions across the economy.

This brief provides a preliminary assessment of how a well-designed price on methane emissions from oil and gas production could leverage recent technological advances in methane monitoring to incentivize oil and gas companies to both improve their methane detection and quantification, and increase their mitigation efforts. We also explain how an emissions price could complement direct regulations as a way to encourage deeper reductions in methane emissions from oil and gas production.

The main argument against methane emissions pricing in the oil and gas sector centers around the challenge in measuring these emissions cost-effectively, with enough precision and accuracy. While it is true that methane emissions from this sector are currently relatively expensive to

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[3] These social damages are also in addition to damages of at least $2 per MMBtu from the CO_2 emissions that occur when the gas is combusted. Moreover, as the concentration of methane in the atmosphere increases over time, so too will the social damage of each additional ton of methane emitted.

[4] For example, modeling suggests that prescriptive requirements for LDAR and the installation of proven emissions control technologies for new oil and gas wells (and other oil and gas equipment, large storage tanks, pipelines and processing facilities) implemented on both existing and new sources in the U.S. would yield significant reductions of at least 35% below baseline methane emissions in 2025 (EDF, 2019, paragraph 10 and table 1). Nevertheless, these requirements would still leave a significant share of baseline emissions unaddressed, illustrating the opportunity for complementary policies to achieve additional reductions.

measure comprehensively, this does not render emissions pricing ineffective. In fact, many existing environmental regulations rely on imperfect emissions estimates. While emissions pricing policies are more cost-effective with more precise emissions measurements, precision is not necessary.[5] A higher degree of accuracy is better, but an imperfect price signal is generally better than no signal at all, even in the case of systematic underestimation of emissions.[6]

In addition, advances in methane monitoring technologies provide opportunities for developing more granular monitoring, reporting and verification (MRV) protocols. If well designed, a methane emissions price can incentivize firms to improve their own methane emissions monitoring and follow more granular reporting protocols, as further described in this brief. This could both improve oil and gas companies' own understanding of their methane emissions, as well as the regulating agency's, and improve the effectiveness of a price-based methane emissions policy.

Importantly, policy makers should not view emissions pricing and direct regulation as an either-or decision. LDAR requirements and technology standards play an important role in ensuring firms locate emissions sources and also reduce other pollution from the oil and gas sector, including health-harming co-pollutants of methane, such as volatile organic compounds (VOCs) and various forms of hazardous air pollutants (HAPs). Addressing these co-pollutants is important to mitigate disparate harmful impacts of oil and gas production on local health, especially when they fall on vulnerable and historically disadvantaged communities. Mandatory LDAR and requirements to install low-emitting technologies lead to reductions in both methane and co-pollutants from all facilities, thereby ensuring that these co-pollutants are also addressed. A well-designed methane emissions price on top of such requirements would incentivize cost-effective additional methane emissions reductions and also further reduce local health impacts from co-pollutants. In addition, it would provide a source of public revenue.

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[5] The U.S. Acid Rain Program, which is widely regarded as an environmental and economic success, was based on a useful simplification. It assumed that sulfur dioxide emissions have equally damaging impact wherever they arise in the U.S. While this is not true, it allowed a coherent and stringent policy to be implemented with cost savings of at least 15% of the costs of alternative command-and-control policies (Schmalensee and Stavins, 2017). Catch shares programs for fisheries (also a pricing mechanism) use catch as a proxy for impact on fish stocks. They are also widely considered effective.

[6] It is possible that there are also cases where emissions are systematically overestimated. In this brief we focus on systematic underestimates as an increasing number of analyses support that U.S. estimates today are consistently too low. Underestimating emissions would also weaken the impact of an emissions price.

The brief is structured as follows. Section 2 examines the reasons why policy makers might want to consider emissions pricing. We argue that, despite limited measurement data, methane from the oil and gas sector exhibits many of the pollution problem characteristics that make an emissions pricing instrument attractive. Section 3 then describes the simplest possible approach to methane pricing, which uses only data that are already reported. This is followed by Section 4, which provides a description of emerging measurement approaches. Section 5 then discusses two other ways policy makers could design an upstream methane price that leverages these new measurement approaches: first, by complementing technical facility-specific data with basin-level measurements that are now available; and second, by also allowing firms to voluntarily measure and report their facility-specific emissions in credible ways using new approaches. Section 6 explains how, with careful design, this second policy instrument could incentivize firms to adopt improved measurement technologies and more granular MRV protocols, thereby accelerating their development. Finally, Section 7 discusses how an emissions pricing instrument would complement existing regulations and thus create a more effective overall policy package for addressing methane emissions from oil and gas production. Finally, Section 8 provides a concluding summary of the brief and potential future research questions.

2. Why a price-based policy for methane emissions?

Price-based emissions policies[7] are attractive for several reasons. In particular, they give firms flexibility around who mitigates, and when and how mitigation takes place. Regulators do not need to know which mitigation options are cheapest or which firms have the lowest cost abatement opportunities. Instead, the uniform price on emissions incentivizes all companies to reduce emissions where it is most cost-effective to do so (and rewards companies that emit less compared to their competitors). Emissions pricing thus leads firms to use their own private information to find the most cost-effective abatement options.

Empirical studies have found that GHG pricing policies have reduced emissions effectively. Martin et al. (2016) synthesize the extensive literature on the European Union's Emissions Trading System (EU-ETS). They report that sector-level studies find that emissions declined by 3% during Phase I and the first two years of Phase II, relative to an estimated counterfactual. Further, they cite firm-level studies that find robust evidence that industrial firms in France and Germany reduced emissions as a result of the EU-ETS by 10–26% during Phase II (Petrick et al., 2014; Martin et al., 2016).

Other effective GHG pricing policies include British Columbia's carbon tax (a 5–15% reduction below counterfactual) (Murray and Rivers, 2015), the United Kingdom's Carbon Price Support (considered a primary driver for the U.K.'s rapid coal phase-out) (Wilson and Staffel, 2018) and Sweden's high carbon tax applied to motor fuels and non-industrial heating fuels (credited with spurring the majority of transport emissions reductions in Sweden) (Andersson, 2019). Researchers have also shown that price-based policies reduced pollution more cost-effectively than would have been the case with non-market-based alternatives, citing examples such as the U.S. Environmental Protection Agency (EPA) initiative to phase down leaded gasoline, as well as its Acid Rain Program (Schmalensee and Stavins, 2017).

In general, price-based policy instruments work best when the following conditions are met:

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[7] Pricing could be implemented through either a tax or a cap-and-trade system, or through a subsidy or tax credit, although the latter two options do not provide cost-effective incentives with respect to levels of production and consumption. There are distinctions between a tax and a quantity mechanism that may be important for choosing the best policy, but these differences are not explored here.

1. pollution impacts are independent of when and where the pollutant is emitted, allowing for a uniform price to be indicative of the social costs;

2. multiple mitigation options are available at costs that vary for different polluters and source categories;

3. individual polluters have much more information than regulators about the cost of emissions control options for their operations; and

4. emissions are measurable and measurements can be verified.

Methane emitted by the oil and gas sector clearly meets the first two conditions. Although it does not stay in the atmosphere as long as carbon dioxide, it is also a uniformly mixed pollutant and does remain for about a decade. This means that it does not matter where or, within a period of several years, when it is emitted. In addition, available data indicate that many mitigation options are available across the entire supply chain and specifically within the production subsector. Abatement costs are heterogeneous across these options and among firms (ICF International, 2014; ICF International, 2016; Munnings and Krupnick, 2017; Marks, 2018). Although mitigation options and costs are uncertain, significant emissions can likely be abated at zero or close to zero net private cost. The third condition is also likely to be met, although it is expected that both operators and regulators have knowledge gaps around methane emissions and related mitigation opportunities, given the tiny private incentive to detect and reduce leaks. However, it is almost certainly easier for operators to collect more granular data and improve their understanding of the emissions profile and mitigation opportunities of their own facilities than it would be for regulators to do so.

Much of the debate around pricing methane emissions from this sector lies with the fourth point: measuring and verifying emissions. Accurate emissions data at the firm level would be useful for the regulator so that individual firms can be held responsible (Munnings and Krupnick, 2017; Gorski et al., 2018; Sweeney, 2018; Marks and Green, 2019; Dunkle Werner and Qiu 2020). In practice, this would require measurement capabilities at geographically separate facilities owned by a particular firm. In many cases, especially within the U.S., there are dense clusters of facilities where many firms operate. Accurate firm measurement capabilities would need to be able to isolate one facility's emissions from those of any nearby facility owned by a different firm. At present, such monitoring capabilities are limited, but they are expected to become more available over the next few years.

More precise emissions data are not necessary to implement an effective pricing instrument. For example, motor vehicle fuel taxes placed on gallons of gasoline or diesel consumed play an important role in reducing local air pollutants, even though fuel consumption is not perfectly correlated with these air pollutants (Knittel and Sandler, 2013). Of course, the more taxes are reflective of actual emissions rates, the more efficient such policies will be at reducing their targeted pollutants (Knittel and Sandler, 2013; Parry et al., 2014).

As will be discussed in the next sections of this brief, policy makers seeking to address methane emissions from the oil and gas sector need not wait for improved firm-level measurement data. They could instead price methane emissions based on default factors or, better still, on basin-level emissions (i.e., aggregated emissions from all facilities in one production basin) where quantification efforts have already been successful (Alvarez et al., 2018; Zhang et al., 2020).

3. One option: a methane price based on default emissions factors

One proposed approach is to rely on default emissions factors (e.g., static estimates of emissions per unit of production) to estimate emissions (Marks and Green, 2019; Munnings and Krupnick, 2017). Default emissions factors are known to be both inaccurate and imprecise.[8] However, this does not mean that a methane price applied to emissions assessed using default factors would be ineffective — even if, in some cases, emissions are systematically underestimated. The price would still bring attention to oil and gas production as a source of methane emissions, generate public revenue and provide a (small) signal that lower gas production (and use by consumers) is associated with lower GHG emissions.[9] Over time, policy makers could also use the framework provided by this approach as a starting point for improvements to the policy design.

Default emissions factors offer two advantages to policy makers seeking to implement a price on methane. First, calculations are simple—average leak rates are applied to individual components

[8] Inaccurate emissions estimates reflect a systematic error that results in bias even when averaged over several estimates. Imprecise estimates result from non-systematic errors. These errors create noisy estimates but not bias.
[9] Biased measurement is not the only reason why the policy would not be efficient. The signal would also be too low if the methane price did not reflect the true social cost or the marginal cost of achieving the regulator’s goals.

or pieces of equipment along with an activity factor, such as the number of wells, production volumes or flaring events. Second, policy makers could adapt a pre-existing framework. For example, in the U.S., such a policy could leverage the existing EPA Greenhouse Gas Reporting Program (GHGRP), which requires firms to estimate and report methane emissions from individual components (EPA 1996). Today, these component-level estimates are valuable to operators and regulators for planning mitigation and designing prescriptive regulations, such as technology standards. For the purposes of an emissions price, the specific component emissions would be aggregated to firm-level emissions estimates by the EPA. A few countries, including New Zealand, Norway and Russia, have already adopted methane pricing based on similar calculations.[10]

However, aggregating component-level default emissions factor calculations produce neither accurate nor precise facility-level emissions estimates. At the national level, several recent estimates of U.S. emissions based on empirical measurements indicate that the GHGRP is inaccurate — it underestimates production emissions by as much as half of the total — and extremely imprecise (Allen, 2014; Brandt et al., 2014; Zavala-Araiza et al., 2015; Alvarez et al., 2018). Accuracy errors arise partly because estimates at the component level do not comprehensively account for total facility emissions, such as emissions in a part of the system for which the GHGRP assumes them to be zero. Precision errors are introduced partly because static factors do not capture the stochastic nature of abnormal process emissions (high and unintended emissions events, which could include things like tank system failures or equipment malfunctions) (Zavala-Araiza, 2018).

As a result of these errors, a methane price instrument based solely on default factors (with no option to provide new measurement-based data to replace them) would incentivize firms to change system components that affect their reported emissions (and thereby their methane payment liability), as opposed to targeting their actual emissions. Firms may, for example, install components with low emissions factors because they result in lower reported emissions,

[10] Russia's Ministry of National Environment introduced environmental charges in the 1990s. Under this policy, firms can submit their own emission estimate methodologies. Not all methodologies are publicly available, but the dominant gas producer Gazprom published a 2010 methodology that relies on average emissions factors (Evans and Roshchanka, 2014). Norway's 1991 carbon tax also covers methane emissions from offshore oil and and gas production (Norwegian Petroleum, n.d.). More recently since 2010, New Zealand has required firms to surrender units for methane emissions from vented and flared natural gas in the country's Emissions Trading Scheme. The emissions may be estimated using an accounting system if they are verifiable (New Zealand Ministry for the Environment, n.d.). To our knowledge, there is no empirical evidence evaluating the effects of these policies to date.

but they would not be incentivized to improve operational and maintenance practices that could lower their actual emissions further. Some of these component upgrades may not, in fact, reduce emissions at all, and firms may bear the costs of investment without actually achieving any reduction in methane emissions.[11] Therefore, emissions pricing designs should leverage recent advances in methane monitoring to improve incentives, as discussed in the following sections.

[11] For example, a firm with poor operations and maintenance procedures may not emit less, even after installing component upgrades. This could occur either through improper use of the new equipment or because the firm has leaks in its system that are not addressed by the upgrades and that continue to worsen. This problem also arises with regulation that requires facilities to meet technology standards but not to implement LDAR.

4. Advances in methane monitoring capabilities

New measurement technologies that provide frequent information regarding actual methane emissions rates enable an alternative to estimating emissions via default factors. Although many of these new technologies are nascent, they have the potential to improve the accuracy and precision of current estimates. Measuring methane emissions from leaks and vents at a facility will never be as straightforward as it is for carbon dioxide from combustion sources (where the carbon content of different fuels is known and almost perfectly correlated with the carbon dioxide emissions from their combustion). Instead, many new methane measurement techniques rely on atmospheric observations to measure concentrations of the gas and require data analysis to translate them into emissions rates. Even so, these technical advances allow for a better characterization of emissions at the facility level than the component-level quantification using default factors. Methane pricing approaches can leverage these techniques to create a more effective policy.

There are two steps to estimating methane emissions in the oil and gas sector by leveraging recent technical advances: the first is direct sampling and atmospheric observation; the second is data analysis and extrapolation. Methane detection methods used today usually entail on-the-ground inspections with devices such as hand-held optical gas-imaging cameras. While this approach is useful for identifying and repairing leaks at the component level, it records only the presence of emissions and does not provide emissions rate estimates. Even when such detection methods are paired with tools capable of quantifying emissions rates, the limited scope of these component-by-component scans makes them ill-suited to estimating total facility emissions. Fortunately, several new technologies and approaches are emerging that are better suited to estimating methane emissions over larger spatial scales (i.e., larger than component level). Atmospheric observations from these tools can, in turn, be translated into facility- or basin-level emissions rates. Although these new approaches are still developing, there are promising signs that they can become cost-effective.

Regulators and operators have different monitoring goals and are therefore likely to focus on different technologies, which vary in their spatiotemporal coverage and detection limit. For example, operators may combine multiple tools, supplementing high-level and frequent scans with targeted facility or on-the-ground inspections to isolate their specific emissions or to pinpoint emissions sources. In contrast, regulators may employ technologies that quantify methane concentrations at the basin level, in order to build accurate estimates of aggregated facility emissions. Regulators can supplement these basin-level estimates with more granular approaches to estimate emissions at the facility level. Here, we focus more on basin-level technologies, as measurements from these provide a foundation for a price design discussed in the next section.

There are several emerging approaches that, while less granular than component-level and facility-level inspections, can provide estimates of methane emissions at the basin level. For example, empirical emissions rates can be estimated using measurements collected from fixed-wing aircraft. These approaches can measure methane concentrations by either sampling upwind and downwind from the area of interest (mass balance approach), or by measuring methane concentrations between the ground and the device (remote sensing). These data are limited by spatial and temporal constraints, but they allow estimation of emissions at both the facility level and basin level. They also provide additional information about emissions hotspots and other spatial characteristics of emissions.

Satellite remote sensing offers another approach for estimating emissions at the basin level. A growing body of recent studies and new satellite missions in development suggest remote sensing has the potential to provide global coverage of emissions with some, but usually limited, resolution (Olczak et al., 2020; see also Jacob et al., 2016). Existing satellites such as the European Space Agency's Tropospheric Monitoring Instrument (TROPOMI) satellite can measure methane concentrations at about the 7×5.5 km^2 scale (i.e., regional and basin level), but do not provide data on methane emissions (European Space Agency, 2019). End users must calculate these themselves via sophisticated computational procedures (Zhang et al., 2020). New satellites will be able to capture much more granular data. GHGSat, a private emissions monitoring company, launched its second satellite Iris on September 20, 2020. Iris has a spatial resolution of 25×25 m^2 (i.e., it is observing at a facility scale, assuming emissions are higher than the detection limit) (GHGSat, 2020).

Although current state-of-the-art methane remote sensing from space already offers valuable monitoring capabilities, there are still several technical, analytical and operational challenges associated with providing robust data on methane emissions quantification. At the facility level, current methane monitoring capacity from space can detect only high-emitting point sources with very sparse global coverage, whereas global mapping capacity is limited to large emissions sources with only very limited granularity (Pandey et al., 2019; Varon et al., 2019). To be able to address these critical gaps in methane measurements from space, and specifically to provide seamless access to quantitative methane emissions data, a new satellite mission, named MethaneSAT, is under development and planned for launch in late 2022 (MethaneSAT, 2021).

The second step, translating concentration data from these new technologies into total emissions estimates, involves complex modeling and data analysis. As none of the aforementioned data-gathering technologies offer continuous monitoring, the methods used to estimate total emissions integrated over the year will need to be based on adequate and representative sampling over time, and also across facilities if regulators want measurements at the basin level (Haugland, 2020). Moving from concentration measurements to emissions rates involves coupling concentration data with other data, such as meteorological data, and making assumptions around atmospheric dispersion (EDF, 2020). Although this is a non-trivial task, it is already being done. For example, researchers are already demonstrating that satellite data can provide aggregated estimates over areas with high emissions. One such scientific study was recently conducted over the Permian Basin, the largest oil-producing basin in the U.S. The estimates, based on TROPOMI data, revealed a basin-level methane emissions rate higher than any previous oil and gas basin-level measurements in the U.S. (Zhang et al., 2020).

As for the costs of quantifying methane emissions, there is evidence that emerging technologies can measure emissions at reasonable costs. Detailed cost data are not available for most detection approaches, but both aerial and satellite scans have an advantage over more granular detection methods in that they can survey multiple sites in a short period of time. This allows them to be more cost-effective, a feature that is particularly visible when comparing LDAR inspection costs with aerial detection costs (Schwietzke et al., 2019; Lyman et al., 2019; Ravikumar et al., 2019). One study of 3,248 oil and gas facilities in Utah's Uinta Basin reported that the costs per aerial scan are about $75,000, but only $22 per facility (Lyman et al., 2019). However, if the goal is to use these data to better quantify facility- or sub-facility-level emissions, there will be additional costs (e.g., from on-the-ground monitoring or drone inspections of facilities, and from scans for on-site components) to isolate site-specific emissions from other sources.

Even though satellites are costly to launch, each additional measurement is costless once they are in orbit and can often be conducted within days of the previous measurement over a given area of interest (Olczak, 2020). Furthermore, raw data from the TROPOMI satellite is publicly available.[12] Finally, even though data analysis of sampled methane concentrations is complex, modeling approaches and skill sets are well developed and the translation is not likely to increase costs substantially on top of data collection efforts (Rosciolo et al., 2015; Yacovitch et al., 2015; Conley et al., 2017; Gorchov et al., 2020).

5. A better option: a methane price based on existing methane reporting and new basin-level monitoring

Despite rapid advances in monitoring technologies, it is still not feasible for a regulator to measure, or require measurement of, methane emissions from thousands of individual facilities (as is, for example, the case with the U.S. oil and gas production sector, which includes thousands of different operators). Measurement capabilities are not quite at the point where every firm can be expected to take on the responsibility of measuring the emissions from their facilities. Both of these options may be possible at some point in the near future, but for now a more practical approach would be to rely on measurements of aggregated emissions over larger areas. Regulators can then explore ways to allocate these aggregated emissions to individual firms.

One such approach could be to use basin-level emissions estimates (derived from frequent aircraft or satellite measurements) in combination with facility-level estimates derived using the default component-level emissions factors.[13] The basin-level emissions measurements would provide regulators with an estimate of total emissions that is more accurate than the estimate provided by the default factor approach and less costly than estimating emissions separately for each facility covered by the price. The component-based factors and associated aggregated emissions for each facility would provide regulators with a means of attributing basin emissions to individual firms.[14] The accuracy of emissions estimates using component-based factors is irrelevant. Instead, this approach would provide policy makers with an imprecise estimate of the relative share of emissions for which each firm is responsible (within that basin, and thereby

[12] Available at: https://scihub.copernicus.eu/
[13] Such a mechanism is featured in a 2021 U.S. Senate Bill proposing a methane fee on oil and gas production. https://www.whitehouse.senate.gov/news/release/whitehouse-booker-schatz-unveil-methane-fee-to-clamp-down-on-potent-driver-of-climate-change
[14] There are other means of allocating basin level emissions. Relying on default emissions factors seems both fair, practical, and transparent.

their share of the total payment liabilities under the methane price policy). Complementing component-based emissions factors and corresponding activity factors with aerial and/or satellite measurements would ensure that, while emissions estimates for individual firms may be imprecise, the total fee liabilities from each basin would be accurate.

Firms would have an incentive to take mitigation actions in their facilities that lower their component-based emissions factors (with the limitations discussed above), some incentive to reduce their own actual emissions rate (with the size of the incentive depending on the share of the emissions they can control) and an incentive to support collective action to reduce emissions rates at the basin level. A signal to reduce gas use from the basin, based on accurate emissions estimates, would be passed on through the supply chain. A methane price that is levied according to relative shares of total basin emissions would, however, still provide imperfectly targeted incentives. The regulatory burdens it imposes would still not be perfectly correlated with actual emissions. A facility that, in reality, has low emissions would not necessarily face a lower burden than a higher-emitting facility.

Low-emitting firms could therefore be allowed to further distinguish themselves from their higher-emitting neighbors by providing improved measurement estimates at the facility level. A well-designed emissions pricing policy should be crafted to allow both firms and regulators to take advantage of the advances made in measurement technology over time. The next section discusses how this could be done.

6. A methane pricing design to incentivize firms to measure methane

A well-designed methane pricing policy for the oil and gas sector could not only internalize the cost of methane to society and incentivize the collective of firms in a basin to reduce emissions, but it could also incentivize firms to create and adopt new measurement technologies and robust MRV practices. This would improve firms' own private information about their methane emissions, give them targeted incentives to reduce their emissions and make those data available to the regulator.[15]

[15] Such a policy designed to address negative externalities from production in settings in which aggregate emissions are known, but individual contributions are unobserved, is discussed in Cicala et al. (2020).

As an example of an MRV protocol, since 2014 the Oil and Gas Methane Partnership has offered companies a voluntary framework for achieving emissions reductions. The partnership's updated methane reporting framework was published in 2020 (OGMP2.0) and outlines current best practices for methane MRV (CCAC, 2020). The framework underscores the importance of conducting site-level measurements and provides guidelines to firms around various issues. These include the scope of emissions, practices to ensure high-quality data, and transparent reporting and systematic verification.

If a methane price policy were to allow firms to provide an empirical estimate of their emissions that is more detailed than the methodology required by the regulators (either by adopting an MRV protocol that is already approved — for example, one similar to OGMP2.0 — or by creating and getting approval for a new MRV protocol), then those that are emitting less than the regulator's methodology suggests will have an incentive to do so and thereby reduce their liability under the price. As an example, let's look at the approach discussed above, in which both basin-level measurements and component-based emissions factors are used as a basis to determine emissions price liabilities for each firm in the basin. Suppose that policy makers also include an option for firms to measure, report and verify using more granular methods. Firms could submit a third-party certified MRV protocol for empirically determining their facility-level methane emissions. If the regulator approves the protocol submitted,[16] it would be used to assess the methane price liability for the firm. Once an MRV protocol is approved, it would become available to other firms.

If one company in the basin were to show that its emissions are lower than the default method suggests and thus reduces its methane price burden, the liabilities for all other companies should, in principle, be revised upward. Total basin-level emissions have not changed, so the sum of liabilities should not change. The remaining companies still reporting using default factors would then, through this upwards revision of their liability, also have stronger incentives to mitigate emissions and to adopt more accurate measurement protocols themselves. If other companies' liabilities were to be reassessed, two issues would need consideration. First that total emissions measured "bottom up" through facility certified emissions may not match total basin emissions measured using a different technology; and second, that the firms that do not opt into

[16] The regulator could, for example, require that the protocol be peer-reviewed by independent scientists, be available to the public in its entirety and include the regular collection of data, and that all underlying data collected under it are made available to the public.

the more accurate measurement might not necessarily have a higher emissions intensity, but might simply be smaller and hence less able to bear the fixed cost of the more expensive monitoring. This could generate serious inequitable burdens.

Stochastic high-emission events, which satellites are increasingly able to detect,[17] may not, however, be captured even with the improved measurement and reporting methodologies discussed above, as these will still rely on sampling and not continuous measurement. To account for these, the methane policy design could estimate additional emissions from such stochastic emissions events that are missed in the standard monitoring on top of the emissions determined with the regular MRV system. When large leaks are identified by remote sensing, facilities could be notified and required to carry out site-level measurements immediately. They would then pay for these stochastic emissions, as well as those estimated through their standard MRV approach, until the leak is resolved. The targeting approach taken for identifying methane leaks from these rarer stochastic process failures can make a big difference. And an approach based on targeting using aerial measurements such as satellite data would significantly increase effectiveness in capturing emissions due to stochastic events.[18]

Regardless of methane price policy design — be it based on default emissions factors or more granular MRV protocols — the regulator will always have a key role in designing and enforcing a robust MRV system. The regulator can audit a selection of firms and impose a hefty fine in the case of underreporting — if the fine is high enough, the threat alone will disincentivize purposeful underreporting (Malik, 1993).

7. A methane price as a complement to direct regulations and other non-price policies

Policy makers need to consider how a price on methane complements existing and potential future non-price policies for addressing methane and its co-pollutants. In fact, policy makers should always consider a combination of policies.

[17] See Olczak et al. (2020), pp. 8–9 for an overview of how the Canadian satellite company GHGSat informed a field operator in Turkmenistan of three sources of a large methane plume in 2019.
[18] See Dunkle Werner and Qiu (2020) for a discussion of auditing approaches based on remote sensing.

A well-designed emissions price can facilitate cost-effective reductions, spur innovation and the adoption of new technologies and practices, generate public revenue and create a long-term price signal to drive further emissions reductions. However, it is unlikely to be efficient on its own, even if a high emissions price were politically possible.

Complementary or companion policies will not only have value individually by serving their own policy objectives, but can also make emissions pricing policies more effective. They can address market failures other than externalities.

Government support for innovation, and particularly the high-risk research that underlies innovation, can provide new technologies and practices that firms can use as they pursue cost-effective abatement opportunities under a methane price. Providing information on emissions and mitigation opportunities can facilitate efficient responses to an emissions price — or to other pressures to reduce emissions, such as those from consumers and the investor community. In some cases, directly mandating certain mitigation activities is more cost-effective than relying on price incentives because, for behavioral reasons or because of lack of information, companies may not respond efficiently. Non-price policies may also serve other important public policy goals, such as protecting vulnerable people and communities from co-pollutants.

This section provides a qualitative overview of some of the key considerations regarding how a methane emissions price would complement non-price regulations. Specifically, we explore how a price would complement the two main categories of existing U.S. regulatory approaches: LDAR regulations and technology standards.

7.1 Methane pricing as a complement to LDAR regulations

LDAR regulations require firms to detect, document and repair leaks at a certain frequency. They do not provide direct incentives to reduce emissions beyond the reductions achieved with the specific repair requirements. In particular, LDAR programs do not target purposeful emissions, such as normal venting or flaring operations. Moreover, firms are not incentivized to monitor for large leaks that occur in the intervals between the inspections required under the LDAR regulation. As a result, even if firms comply with the regulation and address their leaks, their overall emissions may still be inefficiently high. Introducing a methane emissions price therefore supplements LDAR requirements by directly targeting emissions.

Conversely, LDAR programs can enhance the effectiveness of a pricing policy as they require firms to overcome a common obstacle to effective mitigation: the information barrier (Jaffe, 2017). LDAR inspection requirements ensure firms actively search for emissions at the component level, which is a crucial part of MRV best practice (EDF, 2020). Firms that have information regarding their emissions profile will be better equipped to identify their cheapest opportunities for reduction. Behavioral barriers might otherwise lead firms to underinvest in understanding their emissions even when they face a price. A well-designed methane pricing policy for the oil and gas sector could encourage firms to conduct LDAR inspections if such programs are not already in place, or encourage them to carry them out more regularly.

Repairing leaks and taking advantage of the low-cost reduction opportunities identified with LDAR would reduce firms' payment obligations under a methane emissions pricing policy based on methane measurement data. The higher the price, the more methane leaks they would be incentivized to address and the more frequently they would choose to search for leaks and work to reduce their risk of high-emission stochastic events. Responses to one policy would contribute to their obligations under the other.

7.2 Methane pricing as a complement to technology standards

In the U.S., technology standards already exist to address methane emissions from the oil and gas sector. As discussed above, these standards may introduce inefficiencies if they force firms to incur costs for technologies that provide fewer emissions reductions than other mitigation options could achieve at the same or lower cost. However, technology standards can fulfill policy objectives that extend beyond cost-effectively limiting methane as a GHG. An effective methane price would not necessarily replace technology standards. Policy objectives for technology standards could include curbing local air pollution or addressing safety concerns from malfunctioning components.

Technology standards can improve local air quality by forcing firms to stop certain operations, including those that purposefully release methane and other pollutants through venting. Altering these operations can be expensive, because they sometimes require firms to install additional components or to retire existing components or equipment early.[19] Even with emissions pricing, the cost savings from avoiding such emissions may not be enough to convince firms to undertake the investments, or behavioral barriers may inhibit response to the price even if it would be cost-effective for the firm. However, policy makers may still want these technologies installed because, in addition to emitting methane, oil and gas production also emits health-harming pollutants such as VOCs and various HAPs (Lattanzio, 2020). Technology standards can therefore help to limit community exposure to health hazards associated with oil and gas production.

A methane price would complement technology standards by incentivizing cost-effective GHG emissions reductions beyond those mandated through a technology standard, including carbon dioxide emissions from reductions in gas use by gas consumers.

8. Conclusions

In this brief, we explored how to effectively design a methane emissions price on oil and gas production that could either stand alone or act as a complement to the type of technology standards and LDAR requirements that already exist in some regions today. Recent advances in measurement technologies and practices have improved our understanding of the scale of methane emissions from the oil and gas sector. In addition to underscoring the need for effective action, the new methane emissions data provided by these advances provide an opportunity for policy innovation.

Methane emissions meet most of the key criteria for effectively pricing a pollutant, and a methane emissions price — even if based on imprecise data — can achieve emissions reductions. Moreover, a well-designed methane emissions price mechanism can encourage firms to take advantage of new measurement methods. This could improve understanding among both companies and the regulators of methane emissions, help companies identify additional emissions-reduction opportunities, and improve the set of methane monitoring methods available to regulators in the future.

[19] For example, pneumatic pumps — a common piece of equipment at extraction sites — are designed to vent natural gas to the atmosphere. For many types of production, they are relatively expensive to swap out with zero-bleed electric or solar pumps.

A methane emissions price would complement direct regulations, such as technology standards and mandated LDAR programs. LDAR can improve the abilities of firms to respond to a methane price signal, while at the same time a price based on new measurement data means LDAR inspections are likely to achieve greater emissions reductions. Technology standards can play an important role in achieving policy objectives beyond cost-effective GHG reductions, such as by improving local air quality.

Policy makers around the world are taking an increasing interest in methane emissions from the oil and gas sector, including in the European Union, where upstream methane emissions from imported fossil fuels is becoming a concern (e.g., Lefebvre [2020]). Pricing methane emissions from domestic oil and gas production in a way that also generates more granular data on methane emissions could be one way for policy makers in oil- and gas-producing regions to help their industry stay internationally competitive in a world with increasing climate ambitions.

Additional research could clarify the potential benefits from applying a methane pricing mechanism in the oil and gas sector. A deeper understanding of the behavior of oil and gas companies could identify non-price barriers that may limit their responses to a methane price. Better estimates of the emissions-reduction potential and cost of the wide range of mitigation options would help estimate the potential efficiency gains from pricing. Better information on the cost of acquiring improved methane emissions data with different measurement technologies would inform decisions on whether to require the use of these technologies, as well as predict levels of voluntary uptake of them if the methane price approach outlined here were used. Evaluations of the emissions reductions achieved and the distributional and local air-quality impacts of existing methane price- and non-price-based policies in jurisdictions across the world would shed further light on the value of introducing a price on methane emissions in oil- and gas-producing regions.

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