INCENTIVES TO EMIT IN UPSTREAM OIL AND GAS: THEORY, EVIDENCE, AND POLICY IMPLICATIONS

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Summary

Identifying effective policy levers for reducing emissions of methane, a potent greenhouse gas, is a policy priority. This study examines the effect of market incentives and infrastructure constraints on methane emissions from oil and gas production in the Permian Basin of the United States. Using new methods that leverage satellite observations of atmospheric methane concentrations to quantify emissions from oil and gas operations in the Permian, the authors develop a model that relates emissions to variations in oil and gas prices and pipeline transport costs. Applying this model to potential policy interventions, the authors estimate that a $1,500 per metric ton methane tax could reduce upstream methane emissions from oil and gas production in the Permian by as much as 7 percent, though the tax's emissions benefits are attenuated when pipeline networks are congested, and are also smaller under less favorable assumptions about the efficacy of flaring as an abatement technique. Expanding gas pipeline infrastructure also reduces emissions and generates social returns that substantially exceed pipeline construction costs. Importantly, the two policies are complementary: implementing a methane tax in combination with pipeline expansion achieves greater emission reductions than the sum of reductions from either policy implemented alone.

Background & context

Methane, the main component of natural gas, is the second-most important anthropogenic greenhouse gas and a major driver of near-term climate change, with an estimated social cost more than ten times that of carbon dioxide on a per-ton basis. The oil and gas industry is a significant source of this pollutant, accounting for roughly one quarter of anthropogenic methane emissions in the United States.

Intentional and unintentional releases of methane occur at multiple points in the oil and natural gas supply chains: producers sometimes vent gas for safety reasons or to maintain proper equipment pressure and leaks can occur in pipelines and downstream distribution systems. Producers may also dispose of excess natural gas by flaring it. This practice, while environmentally preferable to simple venting (because the combustion process converts most of the methane to carbon dioxide and water before it enters the atmosphere), is still socially costly. Flaring not only generates carbon dioxide missions without providing useful energy, it also releases significant amounts of methane due to

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inefficient combustion or unlit flares. According to one recent study, flaring efficacy in the Permian can be as low as 87–91 percent, meaning that 9–13 percent of the methane in flared natural gas may still be escaping to the atmosphere (Plant *et al*. 2022).

Despite the scale and importance of the oil and gas industry as a source of methane emissions, and despite the fact that the industry has private incentives to avoid emissions (since every unit of natural gas flared or leaked to the atmosphere represents unsold product and lost revenue), tracking emissions and designing effective mitigation policies for this industry has been a challenge. With recent advances in atmospheric modeling and satellite methane observations, however, researchers have access to new tools and datasets that allow for a more sophisticated exploration of how market conditions and infrastructure constraints influence producer decisions and affect resulting emissions.

This study focuses on the Permian Basin, a large shale formation in the southwestern United States that stands out, both as a leading region for oil and gas production and as a major source of associated methane emissions. Oil and gas extraction in the Permian was responsible for an estimated 4 teragrams (Tg) of methane emissions in 2019 (Varon *et al*. 2026); industry operations there are also more methane intensive, per unit production, than in any other major oil and gas region of the United States (Lu *et al*. 2023).

Most of the natural gas produced in the Permian is "associated gas," meaning that it is captured as a byproduct of oil extraction, which is generally far more profitable. Thus, even the largest gas producers in the Basin are primarily motivated by oil production. When associated gas cannot be economically delivered to market, taking into account prevailing natural gas prices and costs for transport, producers may choose to dispose of it at the wellsite by venting or flaring, rather than curtailing their oil operations.

Model design and data sources

To provide a unified framework for analyzing upstream oil and gas sector methane emissions and mitigation opportunities, the authors develop a model of producer behavior in which firms make decisions about drilling and gas disposal in response to changes in natural gas prices and pipeline transport costs. Specifically, oil and gas producers make choices in each period about (1) how many wells to drill and (2) what share of produced gas to market rather than flare. Drilling decisions are dynamic, reflecting expectations about future prices and production, while decisions about whether to market or dispose of gas are static, responding only to contemporaneous gas prices and marketing costs. Because producers cannot adjust output from existing wells, production is exogenous in each period; flaring decisions concern only what share of gas produced to sell versus emit.

In the model, methane emissions arise from three distinct sources: well drilling, baseline leakage from well equipment, and venting or flaring to dispose of gas at the wellsite. A central feature of the model is that costs to market gas are endogenously determined and rise with increasing pipeline utilization. In other words, as pipelines become more congested, the marginal cost of transporting gas away from the wellsite increases, which in turn reduces producers' expected profit from selling the gas. This generates a feedback mechanism: individual producers' flaring choices affect aggregate pipeline flows, which influence the marketing costs faced by producers.

To test their model, the authors draw on three complementary sources of information about methane emissions and oil and gas operations in the Permian Basin. First, they use weekly emissions estimates for the Permian Basin from Varon *et al*. (2026), which combine atmospheric transport modeling with data collected by the satellite-borne Tropospheric Monitoring Instrument (TROPOMI) to infer the source of methane emissions.

At the lease-level, the authors use data on drilling, venting, and flaring that oil and gas producers self-report to the Texas Railroad Commission. They validate flaring trends with nighttime light intensity data from the satellite-mounted VIIRS instrument, using the brightness of gas flares as a proxy for flaring volume. Together, these sources provide a detailed, ground-based record of operator activity, allowing researchers to relate firm-level decisions that lead to emissions (i.e., drilling, flaring) to the aggregate impacts of these decisions on total emissions (as estimated from the TROPOMI observations). This approach balances the granularity of self-reported data on producer activity with the objectivity of remote sensing data on resulting emissions.

Findings & discussion

Analyzing data on emissions, flaring and drilling activity, and oil and gas prices in the Permian over the period from January 2019 through December 2023, the authors find support for several key model predictions. When natural gas prices rise nationally, making it more profitable to market gas from the Permian, flaring activity and methane emissions in the basin fall.[1] Higher costs to transport gas cause flaring activity and methane emissions to increase, because they reduce producers' expected profits from marketing the gas versus disposing of it. Overall, the authors find that a $1 increase in natural gas prices reduces flaring by about 4.5 percent; conversely, a $1 increase in pipeline transport costs is associated with a 10 percent increase in flaring.

Higher oil prices also correlate with an increase in methane emissions in the Permian, since higher oil prices create an incentive to drill new wells. Specifically, a 10 percent increase in expected oil prices leads to a roughly 15 percent increase in well drilling. The authors estimate that drilling responses to gas prices and methane-targeting policies are likely to be relatively small, which is consistent with producer behavior being primarily motivated by the economics of the oil market.

The authors next use their model to evaluate policy options. They find that a methane tax of $1,500 per metric ton (mt), modeled after the Waste Emissions Charge authorized by the Inflation Reduction Act, would reduce flaring in the Permian by as much as 13 percent and methane emissions in the region by up to 7 percent. Importantly, these results assume that the pipeline system is congestion-free. Under observed pipeline congestion conditions, costs to transport gas are higher, which dampens the response to a methane tax and results in somewhat lower reductions in both flaring and emissions. For example, when the pipeline system operates at 99.5 percent of its maximum capacity, the reduction in venting and flaring attributable to a methane tax is 25 to 35 percent smaller than it would be under uncongested conditions. Even so, the authors estimate that a $1,500/mt methane tax would generate social cost savings between $570 million and $4.8 billion annually in the Permian Basin alone,

1 Outside the Permian, it should be noted, the emissions impacts of higher gas prices could be more ambiguous: high gas prices could stimulate drilling for new gas wells, which would tend to increase emissions, even as flaring or venting of emissions at existing wells would be expected to fall. Within the Permian, however, oil tends to drive drilling decisions and the authors estimate a relatively small drilling response to changes in gas price.

depending on the specific factors used to calculate the social cost of greenhouse gas emissions[2] and on assumptions about the efficacy of flaring as a methane abatement measure.[3]

Finally, the authors evaluate the emissions impacts of alleviating pipeline congestion. They find that reduced congestion also reduces methane emissions as producers find it more profitable to transport gas to market rather than flaring or venting it at the well site.[4] Specifically, the model predicts that fully eliminating pipeline congestion in the Permian would have reduced flaring by 4.7 percent on average during the study period, and by as much as 25 percent during periods of high congestion. Adding a single large pipeline with 2 billion cubic feet (Bcf) per day capacity would achieve most of this potential emissions benefit, cutting flaring by 4.3 percent on average. The authors further estimate that the social benefits of such a pipeline would exceed construction costs in just a few years, even under conservative assumptions about the social cost of greenhouse gas emissions.

Importantly, the study results show that policies to alleviate pipeline congestion and tax methane emissions are complementary. This reflects the fact that when pipelines are congested, producers' ability to respond to a methane tax is constrained: if they flare less gas, they have to move more of it to market, which further exacerbates congestion, raises transmission costs, and reduces expected profits. By explicitly capturing this feedback, the authors show that combining a methane tax with pipeline expansion yields superadditive benefits: in other words, resulting emission reductions are greater than the sum of reductions from each of these policies alone.

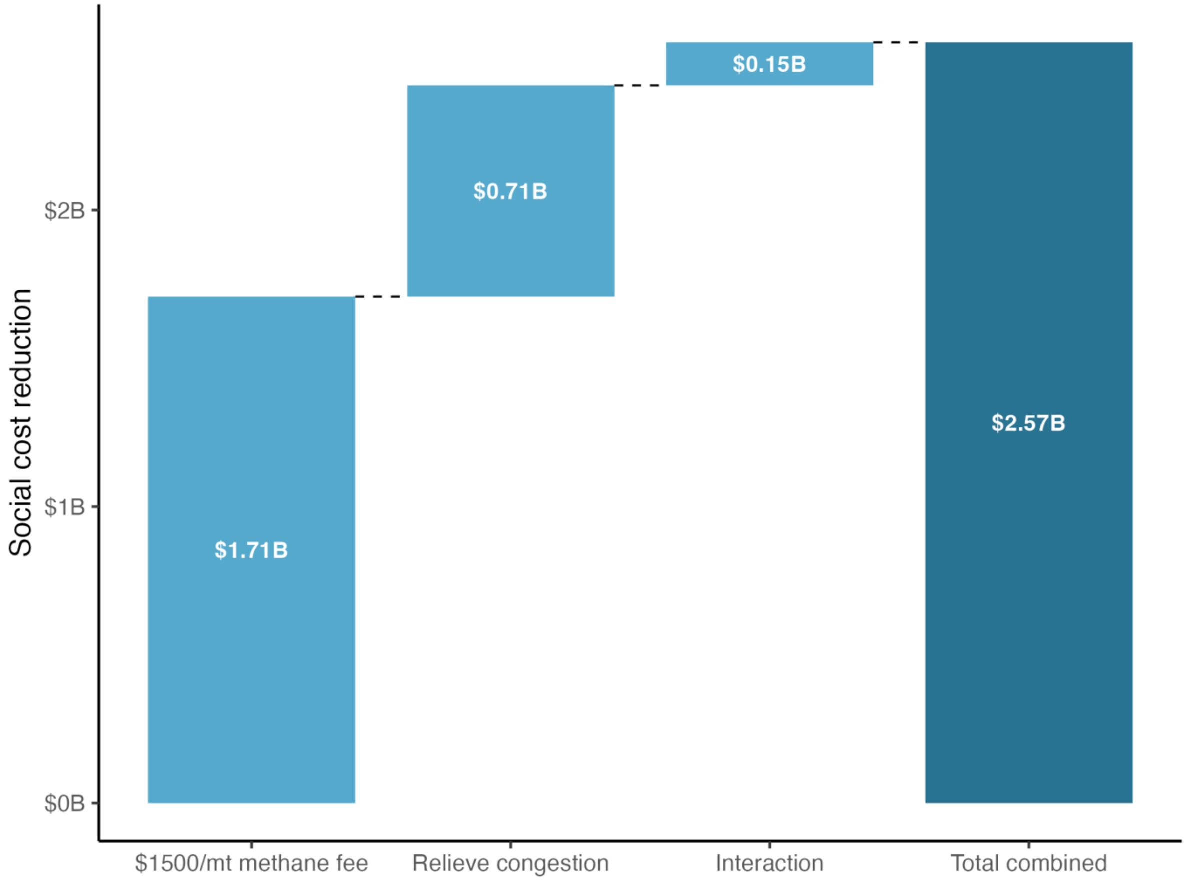
Figure 1 illustrates this complementarity, in terms of the social cost reductions achieved by the two policies separately and in combination. Using social costs from the Interagency Working Group (IWG) for methane and carbon dioxide, and assuming a $1,500/mt tax and 91 percent flaring efficacy, the tax alone reduces social costs by $1.71 billion annually, while congestion relief alone reduces social costs by $0.71 billion annually. Together, however, the two policies reduce social costs by $2.57 billion annually, which is modestly greater than the sum of their individual effects ($2.32 billion). This pattern holds across all tax levels and flaring efficacy assumptions. In the sample period for which these effects are computed, 58 percent of months exhibited binding congestion (defined as utilization exceeding 90 percent), while only one-quarter of months experienced utilization above 95 percent. If pipeline congestion increases in the future, the additional benefits achieved by expanding capacity in tandem with a methane tax would be expected to grow.

2 This study considers social cost factors from two sources: The Interagency Working Group on the Social Cost of Greenhouse Gases (2021), which gives factors of $67/mt and $2,024/mt for carbon dioxide and methane, respectively, and Azar *et al*. (2023), which proposes significantly higher factors of $293/mt and $6,880/mt for carbon dioxide and methane, respectively, expressed in 2024 dollars.

3 An important finding from this study is that the impacts of a methane tax are sensitive to the assumed efficacy of flaring. The authors consider two assumptions for flaring efficacy: 98 percent, consistent with the U.S. Environmental Protection Agency's November 2024 proposed rule for implementing the Waste Emissions Charge in the Inflation Reduction Act, and 91 percent, which is closer to observed flaring efficacy in the Permian Basin (Plant *et al*. 2022). In this study, changing assumed flaring efficacy from 98 percent to 91 percent increases the expected impacts of a $1,500/mt methane tax by roughly a factor of three.

4 As with higher gas prices (see footnote 1), expanded pipeline capacity could have an ambiguous effect on methane emissions in other regions if lower gas transmission costs change producers' calculus for drilling new wells. In the Permian, as already noted, drilling decisions are driven mainly by oil market considerations, so new drilling in response to increased gas pipeline capacity is unlikely to significantly impact emissions.

Figure 1. Decomposition of the impact of combining methane fee and pipeline congestion relief



Notes: This figure decomposes the annual social cost reductions (in 2024 dollars) resulting from a $1,500/mt methane tax and full pipeline congestion relief. Estimates assume the Interagency Working Group on the Social Cost of Greenhouse Gases (2021) social cost valuations for carbon dioxide and methane and that the tax is implemented with an assumed flaring efficacy of 91 percent. The first two bars display the reductions from each policy implemented in isolation. The "Interaction" bar captures the superadditive effect of combining the policies, which arises because congestion relief eliminates the countervailing transmission cost response to the tax. The "Total combined" bar represents the simultaneous implementation of both policies.

Conclusion

A central conclusion from this study is that policies to reduce upstream methane emissions from the oil and gas sector will be more effective if they are designed with an understanding of producer incentives and infrastructure constraints. In the Permian Basin, pipeline constraints create network externalities that affect oil and gas producers' ability to respond to an emissions tax. Thus, combining a methane tax with midstream infrastructure improvements can be expected to deliver larger emission reductions than either a tax or pipeline investments alone. Such policy interactions, it is worth noting, are not unique to the oil and gas industry. In other key sectors, such as electricity production, the effectiveness of carbon pricing or regulatory interventions can similarly hinge on the characteristics of the networks to which producers are connected.

The Permian Basin is by no means representative of other major hydrocarbon producing regions in the United States or across the world. However, findings from this study are globally important, not only because of the scale and intensity of emissions from oil and gas operations in the Permian, but also because pipeline congestion is a major issue in other regions too. Several other U.S. basins (e.g., Appalachia, the Bakken shale) have faced limits on natural gas takeaway capacity, and some are projected to encounter increasing bottlenecks in the near future. The modeling framework developed for this study is flexible enough to be applied even in regions with very different infrastructure and production dynamics, enabling the evaluation of producer responses to policies in a range of contexts.

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About the Program

The Harvard Methane Initiative seeks meaningful and sustained progress in reducing global emissions of this very important greenhouse gas — through research and effective engagement with policymakers and key stakeholders. This Initiative is supported by the Salata Institute for Climate and Sustainability at Harvard University. The Harvard Methane Initiative and other Research Clusters supported by the Salata Institute comprise interdisciplinary teams of researchers from across Harvard's schools, whose varied expertise is required to address the complexity of the climate-related problems that they seek to solve. Robert N. Stavins, A.J. Meyer Professor of Energy and Economic Development at Harvard Kennedy School, directs the Harvard Methane Initiative. The findings, views, and conclusions in this publication are those of the authors alone.