Reducing Emissions of Methane: Abatement Cost in the Oil & Gas Sector

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"Abatement of Methane Emissions in the Oil & Gas Sector: Costs & Opportunities"

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Harvard Initiative on Reducing Global Methane Emissions

- **In 2023, we launched the Harvard-wide "Initiative on Reducing Global Methane Emissions," … which I direct**
  - It's one of five research clusters of the Salata Institute on Climate and Sustainability at Harvard
- **Goal is to achieve *meaningful and sustained* progress in methane emissions reductions** …
  - … through *research* ***and*** *effective engagement* with key stakeholders …
  - … to deliver information that facilitates *design & implementation* of emission-reduction *policies & programs*

- **This initiative is now more important than ever …**
  - … *because* of the U.S. government's rescinding climate policies, and cuts of support for climate research!

Harvard Initiative on Reducing Global Methane Emissions (continued)

- **Brings together two dozen researchers, including Harvard faculty, fellows, and doctoral students from across the university (plus external collaborators)**
  - *7 departments* in Faculty of Arts & Sciences
  - *5 professional schools*: Business, Engineering, Government, Law, and Public Health
  - *Disciplines*: physics, chemistry, biology, engineering, economics, political science, law, business, and history
  - By collaborating across research teams, *the whole is greater than sum of its parts*
- **Overall theme: seeking to *translate* science into *action***
  - Engaging in *two-way communication* with government, business, NGOs, and international organizations
  - This includes governments and stakeholders at the *international*, *regional*, *national*, *and sub-national levels*
- **23 Research/Outreach Projects across 3 Sectors**
  - Oil and Gas
  - Agriculture (Livestock and Paddy Rice)
  - Waste/Landfills
  - Projects That Cut Across Sources and Sectors
- **Next: 1 of 8 projects of economic analysis of O&G sector …**

Methane Abatement Costs in the Oil and Gas Sector

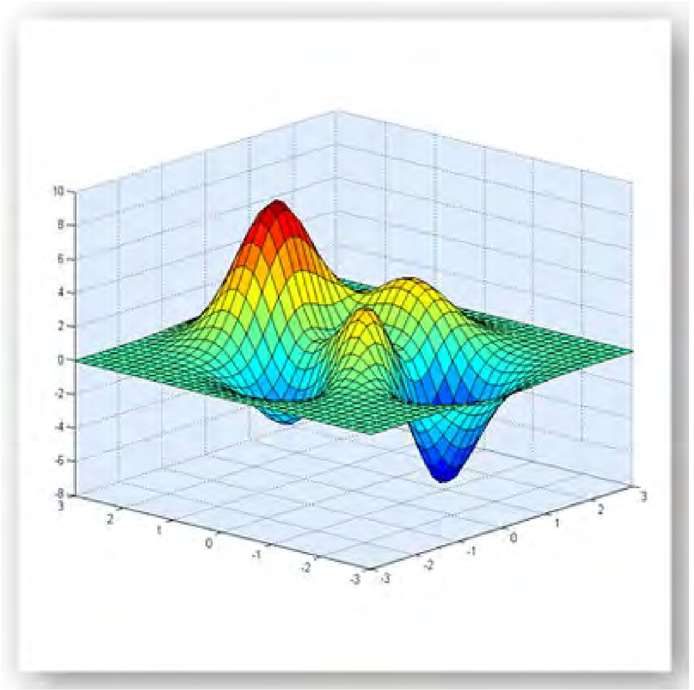
- **Survey and Synthesis**

- **New Analysis of Factors Affecting Methane Emission**

Methane Abatement Costs in the Oil and Gas Industry: Survey and Synthesis[1]

Joseph E. Aldy[a], *Forest L. Reinhardt*[b], *and Robert N. Stavins*[a]

Economics of Energy & Environmental Policy, Vol. 14, No.1.



Survey and Synthesis

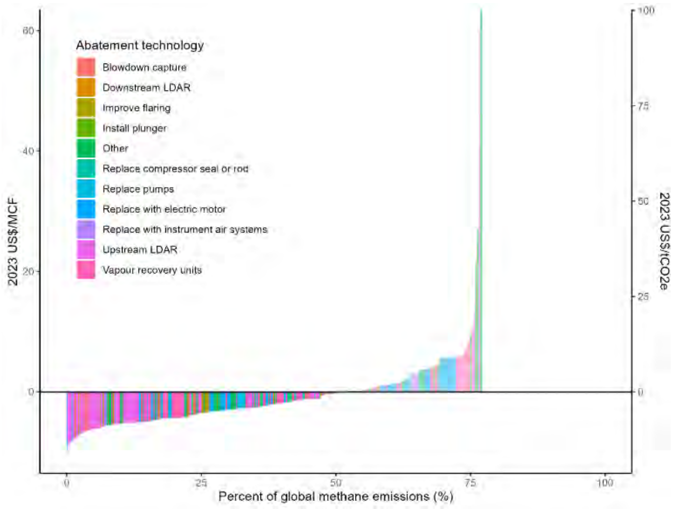
Prospective Analysis – Engineering Cost Models

Prospective Analysis (Engineering Cost Models)

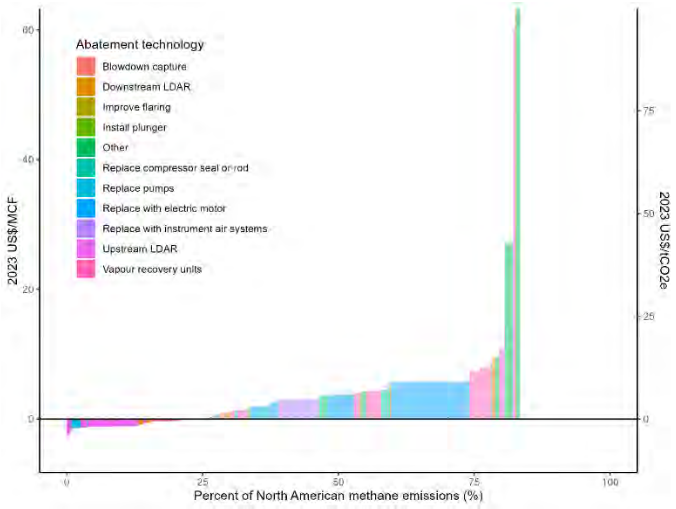
- **Specify Equipment and Actions for a "Model Plant"**
  - Specified Abatement Technologies (such as cost for new pump or pipeline)
  - Specified Abatement Procedures (such as cost for repairing pump or patching pipeline)
- **Estimate Bottom-Up Cost and Emissions Reductions**
  - Investment Cost + Operating Cost – Revenues
  - Revenues are from marketing captured methane
- **Examples**
  - Used by International Energy Agency (IEA) to Develop Marginal Abatement Cost Curves for:
    - ➢ Methane emissions from coal mines, and from oil & gas (O&G) operations
  - Used by U.S. Environmental Protection Agency (EPA) for:
    - ➢ Prospective analysis of impacts of methane regulations on O&G sector

Results from Engineering Cost Models: IEA Analysis (2024)

- **Estimated that *more than half* of 77 million tons …**
  - … of methane produced globally by O&G sector in 2023 …
  - … could be captured at ***no net cost***, after accounting for value of methane sold into natural gas markets.
  - Looks like the (in)famous McKinsey cost curves for reducing CO_2 emissions



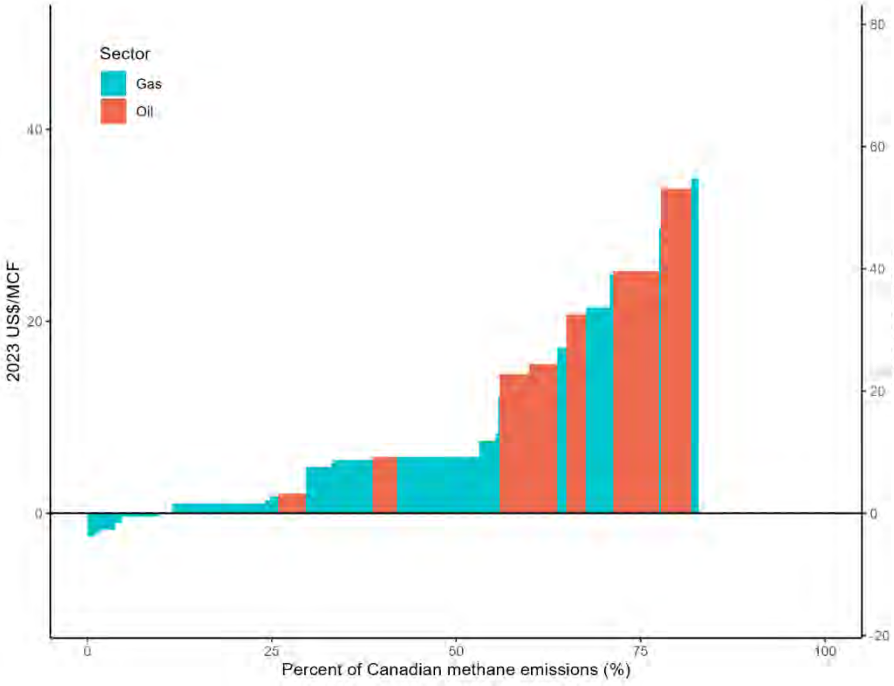
- **Estimated that 25% of North American O&G methane emissions …**
  - … could be eliminated at *no net cost*
  - … and 74% could be reduced at \$10 per ton of CO_2e or less.



More Results from Engineering Cost Models

- **U.S. EPA Regulatory Impact Analysis (RIA) of 2023 methane rule found that …**
  - … 80% of U.S. O&G methane emissions from 2024 to 2038
  - … could be reduced at *average net cost* of \$12/tCO_2e after accounting for value of recovered product.

- **Dunsky Climate & Energy Advisors (2023) estimated that …**
  - … 80% of Canadian O&G methane emissions
  - …could be reduced at *average net cost* of \$17/tCO_2e, after accounting for value of recovered product.



Limitations of Engineering Cost Models

- **Assume sales of captured methane (natural gas) can *offset* abatement costs**
  - But delivering captured methane to potential buyers is *not* necessarily possible, nor cost-effective
  - For example, oil wells may lack gas pipelines; or gas pipelines may be at capacity
- **Ignore costs of detecting (locating) methane leaks**
- **Ignore management time/opportunity costs**
- **Average estimates mask firm-level heterogeneity**
- **Most models build on a single (ICF) data set!**

Retrospective Analysis – Econometric Models

Retrospective Analysis (Econometric Models)

- **Statistical Analyses of Market Behavior**
  - Implicitly account for the factors that pose limitations for Engineering Cost Models
  - All of the *prospective (engineering cost) estimates rest on assumptions* about:
    - Technologies
    - Their costs
    - Their efficacy in cutting emissions
    - Their adoption
    - Their maintenance after adoption
    - And broader economics informing the investment, production, and returns from upstream O&G development
  - So, econometric approaches provide *potentially* valuable alternative (or complement) to engineering cost models

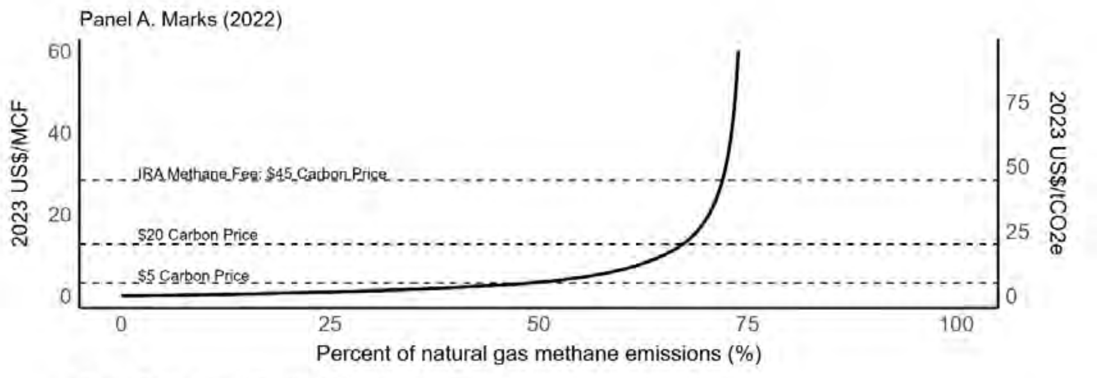
- **Statistical Models Seek to Explain How Methane Emissions Have Varied …**
  - … with Prices and/or Policies
  - I will review the methodology, results, and problems for ***just one*** of these econometric models …

Econometric Model: Levi Marks (2022)

- **Exploits variation in *natural gas prices* at 96 U.S. trading hubs over 6 years, and U.S. Greenhouse Gas Reporting Program (GHGRP) *methane emissions* data**
  - Annual facility-level reports (but excludes Colorado & North Dakota -- because of state regulations)
  - GHGRP data at “facility” level, defined as all wells operated by a single operator (company) in a given sub-basin
- **Thought experiment: as natural gas prices increase, O&G operator has greater incentive to capture fugitive methane in order to sell into natural gas market**
  - Panel Regression finds that methane emissions fall in response to higher natural gas prices
    - Does not need to identify how operators cut their emissions
    - Rather, model posits that profit-maximizing operators search over all available options
- **To produce marginal abatement cost function, fitted values of estimated equation simulate response to a price (tax or fee) on emissions**

Key Results from Econometric Analysis (Marks 2022)

- **A marginal methane price of $5/t$CO_2$e would induce emissions reductions of 50%.**
  - Methane Waste Emission Charge in Inflation Reduction Act began at $900/t$CH_4$, i.e., $26/t$CO_2$e
  - The proposed (since cancelled) fee in 2034 ($45/t$CO_2$e) estimated to result in 75% methane emissions reduction.
  - Marginal costs rise non-linearly beyond 50% reduction, and dramatically beyond 75% reduction



- **Total Costs for 60% reduction = $60 million, …**
  - … achieving ¾ of reductions predicted for EPA regulation at only 4% of EPA's estimated $1.5 billion annual compliance cost.

Issues/Limitations of Econometric Analysis (Marks 2022)

- **Estimated methane emissions data are *self-reported* (GHGRP)**
  - Reflect modeling emissions based on various types of activity and equipment
  - During period of study, GHGRP known to have yielded underestimates compared with direct measurements
  - GHGRP reporting required only for operators with basin-wide annual emissions > 25,000 tons of CO_2e; omits smaller operators, who may face higher abatement costs
- **Static model: Operator observes current price, and takes action accordingly**
  - But, in practice, operator's decision is dynamic
    - Cost of abatement in each period depends on investments made in earlier periods
    - And operator needs to consider not just current price but expectations of prices over life of the investment
- **Gas prices affect *both* operation of existing wells *and* development of new wells**
  - Whereas higher natural gas prices may cause operators to cut methane emissions from existing wells, …
  - … higher natural gas prices (expectations) causes more drilling of new wells, and so increased emissions
- **Emission fee associated with 70% reduction would result in natural gas prices …**
  - … well *beyond the range* of prices used to estimate the statistical model; this extrapolation may yield marginal abatement cost function that is either more or less steep than true function

New Econometric Analysis of Factors Affecting Methane Emissions in the Oil & Gas Sector

Addressing Previous Issues & Limitations

- **Improving on Engineering Cost Models**
  - Assume sales of all natural gas can offset abatement costs
    - We distinguish between "associated gas" from oil wells versus "dry gas" wells
  - Employ constructed estimates of methane emissions based upon modeled technologies
    - We instead use geographically & temporally precise *remote-sensing (satellite) data of methane emissions*
  - Ignore costs of detecting (locating) methane leaks and costs of management time
    - We (and Marks) implicitly include these
- **Improving on Previous Econometric Models (such as Marks 2022)**
  - Estimated methane emissions data were *self-reported* (GHGRP)
    - We instead use geographically & temporally precise *remote-sensing (satellite) data of methane emissions*
  - Operator's decision was modeled as *static*
    - We allow for lagged effects of *previous investment*
    - We employ contemporaneous and *expected future* natural gas prices
  - Gas prices affect *both* operation of existing wells *and* development of new wells
    - We *separate* the impacts on emissions from existing wells from impacts on development of new wells

Multiple Ways Natural Gas Prices Can Affect Methane Emissions

- **Higher prices encourage more production and throughput**
  - More drilling, processing, and pipeline flow create more opportunities for leaks (or intentional venting/flaring)
  - Marginal wells and infrastructure that were previously uneconomic may come back into service
- **Higher prices may increase value of captured methane → *potential* sale of natural gas**
  - When gas prices rise, firms may have a stronger financial incentive to:
    - Detect and repair leaks (replace faulty valves and seals)
    - Improve compressor maintenance
    - Install vapor recovery systems.
    - Reduce venting/flaring
- **So, emissions intensity (methane per unit of gas produced) may decline when prices rise because operators may work harder to conserve saleable gas, …**
  - … but total emissions may still increase if total production expands enough (growth dominates efficiency gains)
- **The outcome also depends heavily on:**
  - Regulation, monitoring technology, whether operators are large firms or small independents, age of infrastructure, and whether the gas is "associated gas" from oil production (where incentives can differ substantially) …

The Case of "Associated Gas"

- **This is natural gas dissolved in crude oil reservoirs, or present as gas cap above oil**
  - When oil is produced, gas comes up with it
  - Creates a very different set of incentives than "dry gas" production
- **The oil decision drives gas production**
  - The firm decides how much oil to produce; gas output is largely a byproduct of that decision.
  - Oil price↑ → oil production↑ → associated gas production↑
- **Flare vs capture choice**
  - Sometimes associated gas cannot be economically transported, especially in remote or offshore fields
  - Producers choose among: capturing & selling gas; flaring it ($CH_4 \rightarrow CO_2$); and venting (increasingly regulated)
- **In any event, greater activity can raise total emissions**
  - Scale effect can dominate efficiency effect
- **Bottom line for associated gas**
  - Oil prices↑ → oil production↑ → associated gas production↑ → methane handling activity↑
  - Gas prices ↑ → incentive to capture gas instead of flaring/venting ↑ → methane intensity↓; net effect?
  - Also, note empirical reality of *negative* natural gas prices (in Permian Basin) can be incentive to flare

Data for Econometric Analysis

- **Five Texas Basins (Anadarko, Barnett, Eagle Ford, Haynesville, Permian) over Six Years (2018-2023)**

- **Methane Emissions:** Integrated Methane Inversion (IMI) Estimates at *cluster x month* level (25 km grid cells)
    - Emissions estimated statistically from satellite measurements of concentrations plus ground-level information by research teams of atmospheric chemists at Harvard (Daniel Jacob, *et al.*) and MIT (Daniel Varon)

- **Oil and Gas Production:** Enverus well-level monthly O&G production, spatially assigned to clusters via well coordinates, then aggregated to cluster x month (includes well count, operator identification, drill type, dates of spud, completion, & start of production)

- **Oil and Gas Prices:** Monthly hub prices mapped to clusters, and expected future prices

Basic Preliminary Econometric Specification

- **For initial exploration, let:**

$$R_{ct} = \alpha P_{gct} + \beta P_{oct} + \eta EP_{gct} + \theta EP_{oct} + \gamma \boldsymbol{X}_{ct} + \lambda_c + \delta_t + \mu_m + \varepsilon_{ct}$$

$$R_{ct} = \frac{CH_4\ Posterior\left(\frac{tons}{month}\right)_c}{Gas\ Production\frac{(Mcf)_c}{53.68}}$$

where: R_{ct} = methane emission rate for cluster *c* in month *t*

P_{gct} = monthly natural gas price at hub serving cluster *c*'s basin

P_{oct} = monthly oil price *index* (market oil price interacted with location identifier) for cluster *c*'s basin

EP_{gct} = monthly expected natural gas price at hub serving cluster *c*'s basin

EP_{oct} = monthly expected oil price *index* (market price interacted with location identifier) for cluster *c*'s basin

λ_c = cluster fixed effects

δ_t = year fixed effects

μ_m = month-of-year fixed effects (to allow for seasonal emission patterns)

$\boldsymbol{X}_{ct}$ = control variables, including oil & gas output, well count, operator identification, drill type, spud, completion & production start dates, number of wells completed in previous 12 months, etc.

Findings & Policy Implications

Findings and Implications from Survey & Synthesis

- **There appears to be significant potential for low-cost methane abatement …**
  - … in the Oil & Gas sector in the USA and elsewhere
- **Claims of widespread negative abatement cost opportunities are not well founded**
  - This may change over time as new satellite and other remote-sensing technologies become available, …
    - … and thereby reduce costs of searching for and identifying precise location of methane emissions
    - So, in some cases marginal abatement costs may indeed become negative
  - But lack of pipelines/capacity may continue to mean that some natural gas cannot be sold at a positive price
- **In the short term at least, potential for low-cost abatement is not without limit**
  - Whereas in some cases, cutting methane emissions to some degree may be relatively inexpensive, …
    - … costs escalate sharply beyond 50-60% reductions.
- **Considerable variation across firms in USA, & among O&G producing countries**
  - Abatement opportunities vary by sources, ownership, and available pipeline capacity
  - Together with reality of sharp cost increases beyond 60% reductions, implications are clear for stringency of emission targets, and for potential use of market-based policy instruments

Thank You!

For More Information

Harvard Project on Climate Agreements
https://www.belfercenter.org/programs/harvard-project-climate-agreements

Harvard Environmental Economics Program
https://heep.hks.harvard.edu/

Salata Institute Initiative on Reducing Global Methane Emissions
https://salatainstitute.harvard.edu/projects/methane/

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