Measured or assumed? Regulatory defaults, ownership, and the measurement content of the U.S. greenhouse gas inventory

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Abstract

Municipal solid waste landfills are the third-largest anthropogenic source of methane in the United States, and the national inventory for this source is assembled almost entirely from facility self-reports filed under Subpart HH of the Greenhouse Gas Reporting Program (GHGRP). Airborne and satellite surveys estimate actual emissions at 1.4 to 2.7 times reported levels, but remote sensing alone cannot identify how individual filings or reporting methods contribute to this gap. We examine the construction of reported emissions under Subpart HH and distinguish facility-years according to the regulatory equation used. The analysis covers the full universe of Subpart HH filings—16,319 facility-years for 1,331 landfills from 2010 to 2023—linked to the GHGRP parent-company register and the EPA Landfill Methane Outreach Program database.

Use of the unmeasured branch varies systematically with ownership. It accounts for 13.7% of facility-years at landfills owned and operated by publicly listed waste firms, compared with 27.5% at municipally owned sites operated by a listed firm, 31.3% at private firms, and 33.2% at municipally owned and operated sites. We then use the staggered installation of gas collection systems at 119 landfills to estimate changes associated with crossing the equation boundary. Pre-treatment coefficients are generally indistinguishable from zero, and the two-way fixed-effects and Callaway-Sant'Anna estimates are similar (0.350 and 0.373). Installation is associated with a 34- to 38-percentage-point increase in implied mitigation and an approximately 45% decline in reported methane. Because installation changes both physical capture and the applicable reporting equation, public data do not permit those components to be separated. In contrast, switching from the regulatory default methane fraction to a site-specific value produces no detectable within-facility change. The 23-percentage-point cross-sectional difference between measured and default reporters therefore reflects selection. About one third of facilities also reverse their reporting of durable attributes such as truck scales at least once, whereas the gas-collection indicator is much more stable.

The regulatory partition is strongly reflected in the data. Under 40 CFR 98.343(c)(2), emissions for landfills without gas collection equal modeled generation adjusted by a table-based oxidation factor; 96.9% of facility-years in this branch correspond exactly to a permitted default value. The branch represents 25.0% of facility-years and 23.4% of reported methane tonnage. Prior research documents reliance on default oxidation factors among landfills without collection systems. We extend that evidence by quantifying the branch in tonnage, showing that the partition is nearly exhaustive, and documenting its stability over fourteen years. An extension to Subpart C stationary combustion, based on 274,858 fuel-year records at 7,479 facilities, indicates that the broader mechanism is not limited to landfills. Default-factor methods account for 92.9% of combustion facility-years and 64.2% of reported carbon dioxide; the tonnage share increased from 57.9% to 67.4% during the sample period, and tier downgrades outnumber upgrades by 1,488 to 974. Together, the findings show that regulatory equation assignment materially affects reported inventory totals and that reliance on default methods varies across ownership types and has increased in stationary combustion.

Keywords: greenhouse gas reporting; landfill methane; measurement, reporting and verification; regulatory default parameters; environmental inventory quality; ownership and environmental performance

1. Introduction

Methane from municipal solid waste (MSW) landfills is the third-largest anthropogenic methane source in the United States. Policy attention has increased alongside evidence that reported emissions systematically understate observed emissions. Cusworth et al. (2024), in the largest airborne survey of U.S. landfills to date, estimated emission rates averaging 1.4 times the values reported by the same facilities to the GHGRP. Much of the discrepancy was concentrated at sites with active work-face emissions, which are not represented in GHGRP methods. Satellite studies reach similar conclusions: annual monitoring estimates U.S. landfill emissions at about 51% above reported values (Balasus et al., 2025), a high-resolution survey documents large site-level plumes at 60 North American landfills (Krause et al., 2025), and a global analysis highlights continued uncertainty in bottom-up estimates (Dogniaux et al., 2025). At four large landfills in the southeastern United States, satellite estimates were six times the reported values.

These studies establish the presence and approximate magnitude of a reporting gap, but remote sensing cannot determine how reporting methods contribute to it. Addressing that question requires examining the regulatory equations and the facility-level information used to construct reported emissions.

Under 40 CFR 98.343, a landfill's reported methane depends on whether it operates a gas collection system. With one, reported emissions are built from metered gas recovery. Without one, paragraph (c)(2) sets emissions equal to modeled generation adjusted only for oxidation, and the oxidation fraction is, by the text of the rule, a value looked up in Table HH-4 rather than anything measured on site. A landfill without gas collection therefore reports a number that is arithmetically its own first-order-decay model output multiplied by a regulatory constant. Nothing about the methane leaving that landfill enters the national inventory.

We use this regulatory structure to partition the inventory and examine the characteristics of facilities in each branch. Earlier work shows that landfills without gas collection rely on default oxidation factors; Section 5 verifies that pattern in our data. Our analysis builds on this foundation in four ways.

We first link each facility-year to the GHGRP parent-company register and to an independent ownership classification from the EPA Landfill Methane Outreach Program (LMOP). The linked data reveal a monotonic association between ownership and use of the formulaic branch, including differences between municipal ownership and private operation that previous studies of the program could not observe without ownership data.

We then treat gas-collection-system installation as a staggered treatment and estimate the associated change in the reported inventory using pre-trend tests and a staggered-adoption estimator. The estimated effect combines physical capture with the change in reporting equation; Section 7 explains the interpretation and policy relevance of this composite.

The analysis also tests whether voluntary use of a site-specific methane fraction changes reported outcomes. Once facility selection is accounted for, we find no effect. In addition, roughly one third of facilities report inconsistent values over time for physically durable attributes.

Finally, we extend the analysis to Subpart C stationary combustion. This comparison shows that permissive use of regulatory defaults is not unique to landfills and that the relationship between facility size and measurement intensity differs across the two regimes.

Section 5 also quantifies the formulaic branch by reported tonnage and documents that its share is nearly exhaustive and stable over fourteen years. These results establish the empirical scale of the reporting structure used in the subsequent analyses.

Relation to Stark et al. (2024). Using the same public database, Stark, Tian and Krause (2024, *Waste Management* 186:86–93) analyze the two calculation pathways available to landfills with gas collection: the first-order-decay approach in Equation HH-6 and the collection-efficiency approach in Equations HH-7 and HH-8. They show that movement toward the latter pathway produced diverging modeled-generation trends and that national emissions would have been 1.3 to 1.7 times higher if all facilities had used the former. They also report an increase in the average assumed oxidation fraction among landfills without gas collection, from 10% to 17%. Our mean implied mitigation of 0.149 in the formulaic branch reproduces that result and provides a validation check for our data construction. Whereas their analysis focuses on how pathway choice affects the national total, ours examines the ownership of facilities in each branch and the reported changes associated with moving between branches. Section 7 uses their evidence to clarify the interpretation of our main estimate.

2. Related literature

This study draws on four related areas of research: remote sensing of landfill methane, self-reporting under environmental regulation, ownership and contracting, and engineering estimates of gas-collection efficiency. Together, these literatures motivate the distinction between observed emissions and the measurement content of regulatory filings.

2.1 Reported against observed landfill methane

A now-substantial body of measurement work establishes that reported US landfill methane is too low, and by how much. Cusworth et al. (2024), the largest airborne survey of US landfills conducted to date, found aerial emission rates averaging 1.4 times the values the same facilities reported to the GHGRP, and traced much of the discrepancy to active work-face emissions, a source category the Subpart HH methods do not represent at all. Satellite work points the same way and sometimes further: annual satellite monitoring places US landfill emissions roughly 51% above reported values (Balasus et al., 2025), a high-resolution survey of 60 North American landfills documents large and persistent per-site plumes (Krause et al., 2025), and a global satellite survey emphasises how much uncertainty remains in bottom-up estimates generally (Dogniaux et al., 2025). Top-down inventory benchmarking finds regional discrepancies in activity-based estimates across the United States (Worden et al., 2026). For four large landfills in the southeastern United States, satellite estimates exceeded reported values sixfold.

Remote-sensing research identifies the existence and approximate size of the gap but does not show how it is distributed across reporters. Atmospheric observations can reveal that a facility emits more than reported, but they do not indicate whether its filing incorporated site-specific measurement, which regulatory equation generated the value, or whether reporting methods vary systematically with ownership. We address these questions using facility-level regulatory filings.

2.2 Self-reporting, auditing, and misreporting under regulation

The economics of self-reported environmental compliance is well developed. Livernois and McKenna (1999) set out the enforcement problem formally: when a regulator must rely on firm self-reports and can audit only at a cost, the penalty and audit structure determines whether truthful reporting is an equilibrium. Empirically, Duflo, Greenstone, Pande and Ryan (2013) provide the sharpest evidence that reporting institutions are decisive rather than incidental. In a two-year field experiment in Gujarat, they found the status quo third-party audit system was largely corrupted, with auditors systematically reporting plant emissions just below the regulatory standard while true emissions were typically higher; randomising auditor assignment and payment caused auditors to report more truthfully, and treated plants then actually reduced emissions.

Recent work shows the problem is not confined to developing-country enforcement. A study of major US corporations finds that 58% of public firms' self-reported emissions were subsequently revised, that firms are more likely to understate than overstate, and that the volume of understated emissions exceeds overstated emissions by more than a factor of two (Cohen, Rouen and Sachdeva, 2026). Related accounting work finds firms underreport carbon emissions after firm-specific climate controversies, particularly where reporting discretion is greater (Gipper, Sampson and Shi, working paper).

Most of this literature concerns misreporting, in which a firm possesses or could obtain a measurement but reports a different value. The setting studied here differs because a landfill without gas collection complies with Subpart HH by reporting modeled generation adjusted by a table-based oxidation factor. The filing contains no site-specific emissions measurement because the regulation does not require one. Additional auditing would therefore not resolve the underlying issue. The relevant dimension is measurement content rather than reporting honesty, a distinction that has not, to our knowledge, been quantified for a major national inventory.

2.3 Ownership, contracting, and non-contractible quality

Our central descriptive finding is that occupancy of the unmeasured branch tracks ownership. The natural theoretical reference is Hart, Shleifer and Vishny (1997), who show that when contracts are incomplete, private providers have stronger incentives than public employees to reduce costs, but that those incentives are often too strong because private contractors do not internalise the effect of cost reduction on quality dimensions that cannot be written into a contract.

Measurement quality in a self-reported inventory has features of non-contractible quality. Metering is costly, the regulation does not require it in the branch examined here, and outside parties may not readily observe its absence. The Hart-Shleifer-Vishny framework could therefore imply less investment in measurement by private operators than by public entities. Our descriptive pattern is the reverse: facilities owned and operated by publicly listed waste firms are least likely to use the unmeasured branch, whereas municipally owned and operated sites are most likely to do so. This pattern is not a test of the theory, and scale or sector composition may account for it, as discussed in Section 12. Possible explanations include capital-market and reputational scrutiny of listed firms and their greater ability to absorb the fixed cost of measurement infrastructure.

2.4 Gas collection efficiency and the construction of the inventory

The waste-engineering literature has documented for two decades that the parameters at issue here are uncertain. EPA's AP-42 default collection efficiency of 75%, drawn from a range of 60% to 85%, was derived from a literature review and compiled engineering estimates rather than from measurement at the facilities to which it is applied. The cover-type-dependent defaults that replaced the single value rest on a 2007 industry report using flux-chamber data from six studies covering eleven landfills. In-situ measurements find enormous spread around these values, with reported collection efficiencies of 14% to 95% for intermediate covers and 53% to 100% for final covers, and recent syntheses argue that the effective collection efficiency may be closer to 50% than to the 75% default (Reinhart, 2012; Giordano et al., 2024; Saul et al., 2026).

Stark, Tian and Krause (2024) provide the closest analysis of the reporting system. They examine the two calculation pathways available to landfills with gas collection and show that movement between them has contributed to divergence in modeled-generation trends. Section 5 distinguishes the findings already established in their study from the additional evidence reported here.

Engineering studies indicate that default parameters are uncertain and may be biased, while research on reporting methods shows that the choice among permitted equations can materially affect national totals. The remaining questions are how much of the inventory is based on defaults rather than measurement, which facilities produce those reports, and how reported outcomes change when a facility moves between regimes. Sections 5 through 10 address these issues.

3. Institutional background

Subpart HH requires every MSW landfill with modeled emissions above the reporting threshold to file annually. The calculation proceeds in stages, and each stage embeds default parameters that matter for what follows.

Modeled generation (Equation HH-1). Annual modeled methane generation G_CH4 comes from a first-order-decay model over the landfill's disposal history. Its parameters are largely fixed by rule: the methane correction factor MCF takes a default of 1 unless waste is actively aerated; the dissimilated fraction DOC_F takes a default of 0.5; and F, the methane fraction by volume of landfill gas, takes a default of 0.5 unless the facility has current-year measurement data. Degradable organic carbon and the decay constant k come from Table HH-1.

Oxidation adjustment (Equation HH-5). MG = G_CH4 × (1 − OX), where OX is "the appropriate oxidation fraction default value from Table HH-4." The rule provides no site-specific measurement option for OX; the facility selects among tabulated values (0.10, 0.25, 0.35) according to cover type and methane flux.

Emissions without gas collection (§98.343(c)(2)). Emissions equal MG. This is the formulaic branch, and it is the analytical foundation of this paper: the facility's reported emissions are its own model output times a lookup constant.

Emissions with gas collection (§98.343(c)(3)). Facilities compute emissions from metered recovery R (Equation HH-4) via Equation HH-6, which nets recovery against generation, and via Equations HH-7 and HH-8, which infer generation from recovery and an estimated collection efficiency CE with a default of 0.75 where cover-area detail is unavailable. Equation HH-6 contains a clause that proves important below: G_CH4 is taken as the modeled generation rate **or the metered recovery, whichever is greater**.

Two implications organise our empirical design. Reported emissions in the no-collection branch are a deterministic function of the model and a constant, so the implied mitigation rate defined below must equal a tabulated OX value. And the "whichever is greater" clause means that reported emissions can exceed the published modeled-generation field, which will explain the left tail of our outcome variable rather than requiring us to discard it.

4. Data

GHGRP Subpart HH. We draw the complete Subpart HH record from the EPA Envirofacts REST service: `hh_landfill_info` for facility-year landfill characteristics and reporting choices, and `hh_subpart_level_information` for reported methane. Paging by row range alone fails on the final partial block, so the extraction slices by reporting year first. The result is 16,444 facility-years for 1,335 landfills over 2010–2023. After restricting to observations with positive modeled generation and positive reported methane we retain 16,319 facility-years at 1,331 landfills.

Ownership. The GHGRP parent-company workbook gives facility-to-parent mappings with percent ownership, by reporting year. We keep the majority owner and classify parent names into publicly listed waste and environmental-services operators, municipal entities (city, county, town, district, authority, sanitation district, and related forms), and other private firms. Every facility-year matches. Publicly listed operators account for 7,344 facility-years, municipal entities 6,828, and private firms 2,147; Waste Management (4,066), Republic Services (2,710) and Waste Connections (701) are the largest listed operators in the data.

LMOP. The EPA Landfill Methane Outreach Program landfill and project databases carry a `GHGRP ID` field, so the link is exact rather than fuzzy: 1,313 of our 1,331 facilities match (98.6%). LMOP supplies waste in place (99.5% coverage), gas-collection well counts and blower capacity (79%), landfill area (91%), an independent government-versus-private ownership label (99.8%), and dated LFG energy projects. The independent label validates our classification: municipal parents map to LMOP "Public" in 6,722 facility-years against 100 "Private," and listed-operator parents map to LMOP "Private" in 6,290 against 1,042 "Public." Those 1,042 are not errors but a distinct arrangement — municipally owned sites operated under contract by a listed firm — which we exploit in Section 6.

Outcome variable. We define the implied mitigation rate as

$$mitigation = 1 - \text{reported } CH_4 / \text{modeled } CH_4 \text{ generation}$$

the share of a facility's own modeled generation that it reports as not emitted, whether through metered recovery, destruction, or the oxidation credit. In the no-collection branch this quantity must equal OX by construction.

Measurement-discretion variables. `is_mcf_value_default_indicator` is unusable: it takes the value "Y" in 4 of 16,444 rows. `annual_mcf_value` is equally uninformative, equal to 1.00 in 12,686 of 12,689 non-missing rows, which is exactly what the Equation HH-1 default predicts. We therefore build the discretion measure mechanically from the reported methane fraction: `methane_frac_deter_annual_valu` equals the regulatory default of 0.50 in 11,504 rows and takes a site-specific value in 1,185. This indicator agrees with the self-described `methane_fraction_deter_method` field in all but 29 rows.

5. Empirical validation and scale of the formulaic branch

We first verify that the regulatory partition described in Section 3 is evident in the facility-level data and then quantify its scale. The initial validation reproduces a pattern documented by Stark et al. (2024), while the subsequent analysis provides additional evidence on the completeness, tonnage, and stability of the branch.

Comparison with Stark et al. (2024). Using the same database, Stark et al. report that the average assumed oxidation fraction among landfills without gas collection increased from 10% to 17% between 2010 and 2022. The mean implied mitigation rate in our no-collection sample is 0.149, closely matching their estimate. We use this agreement as a validation of the extraction and construction procedures; reliance on default oxidation factors in this branch is not presented as a new contribution.

Completeness of the partition. Among 4,162 facility-years without a gas collection system, 4,031 (96.9%) report an implied mitigation rate equal to one of the permitted values—0.10, 0.25, or 0.35. A further 91 report exactly zero; treating zero as an additional lookup outcome raises the formulaic share to 99.0%. In comparison, only 45 of 12,157 facility-years with gas collection lie on a default value. Thus, the regulation almost fully determines reported mitigation in the no-collection branch.

Tonnage represented by the branch. The formulaic branch accounts for **25.0% of facility-years and 23.4% of reported methane tonnage**, equivalent to 767,000–917,000 metric tons of CH_4 per year. The similarity of the facility and tonnage shares contrasts with stationary combustion, where facility size strongly predicts the reporting branch (Section 10). No comparable size relationship appears among landfills.

Stability over time. Across the fourteen-year sample, the formulaic branch ranges from 22.7% to 25.9% of reporters and from 21.5% to 25.0% of reported tonnage (Figure 2). Despite changes in landfill regulation and operating practices, its share of the inventory remained broadly stable.

Figure 1 shows the shape of the partition. The no-collection distribution is three spikes. The with-collection distribution is broad and continuous, with a median of 0.769 and an interquartile range from 0.523 to 0.891, because metered recovery varies continuously across sites and years.

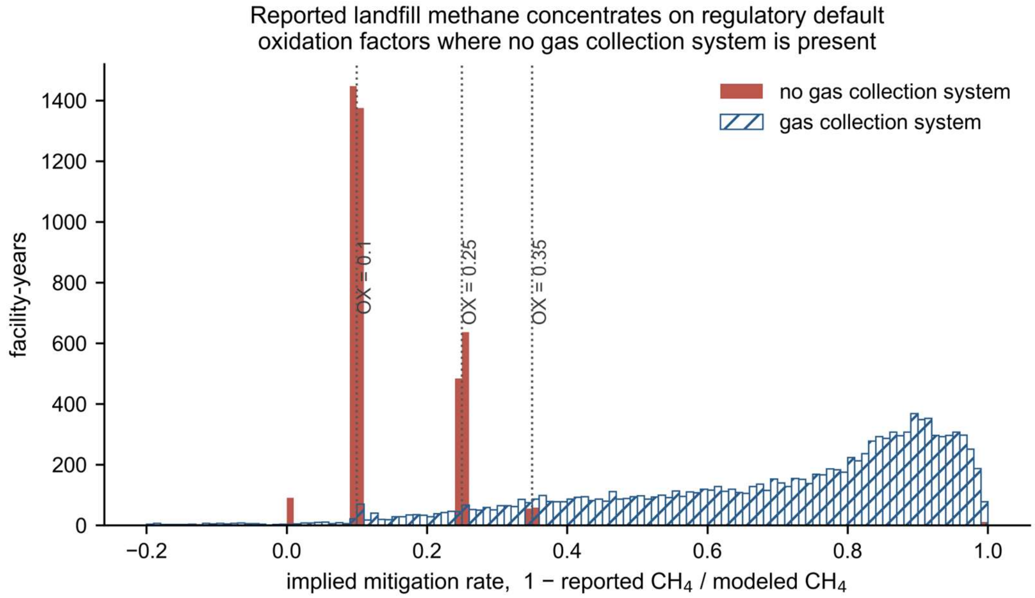

Figure 1. Distribution of the implied mitigation rate, by gas-collection status. Facility-years, 2010-2023. Dotted lines mark the oxidation factors permitted by Table HH-4. Landfills without a gas collection system (solid) pile up exactly on those values because 40 CFR 98.343(c)(2) makes their reported emissions modeled generation times a default; landfills with one (hatched) spread continuously because their figure is anchored to metered recovery.

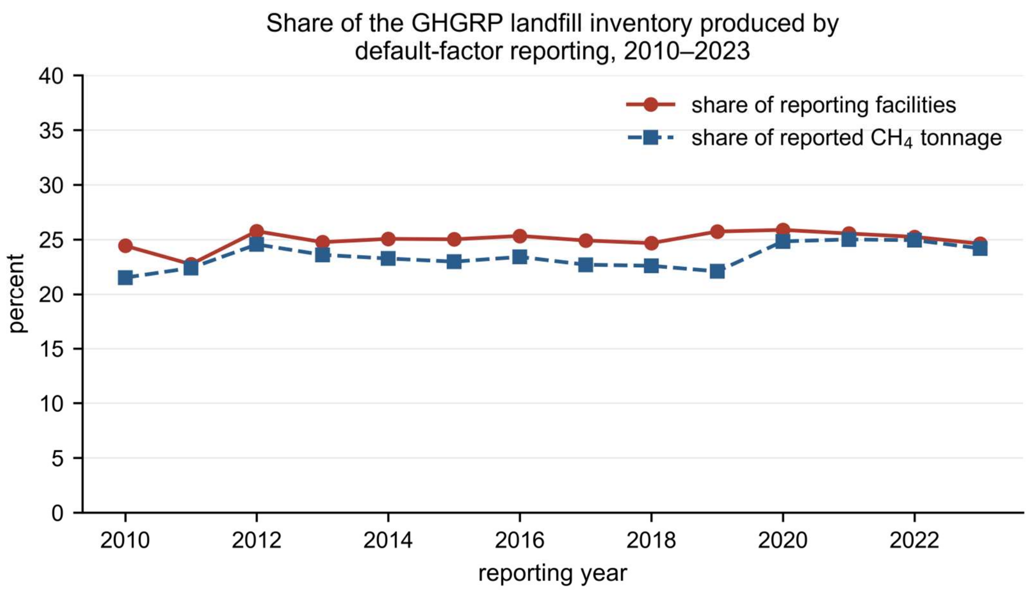

Figure 2. Share of the GHGRP landfill inventory produced by default-factor reporting, 2010-2023. The two series move together because landfill size does not predict which branch a site occupies. Section 10 shows this is not true of stationary combustion.

The left tail of the outcome variable is a regulatory artefact rather than a data problem, exactly as Section 3 predicts. 259 facility-years report more methane than the published modeled-generation figure, and 255 of them (98.5%) have a gas collection system, which is the only branch where the "whichever is greater" clause of Equation HH-6 can bind. Section 8 shows every result is insensitive to how this tail is handled.

Sections 6 and 7 turn to the paper's main analyses: the characteristics of facilities in each branch and the reported changes associated with moving between branches.

6. Who reports under which branch

Occupancy of the formulaic branch is strongly structured by ownership (Table 2). Municipal landfills fall in it in 33.1% of facility-years and private firms in 31.3%, against 15.6% for facilities whose GHGRP parent is a publicly listed waste operator. Conditional on being in the metered branch, the ownership gradient persists in level and in dispersion: median implied mitigation is 0.846 at listed operators (standard deviation 0.240), 0.682 at private firms (0.486) and 0.599 at municipal sites (0.441). The gap is stable across the panel and is not an artefact of any single year (Figure 3).

Separating ownership from operation sharpens this into a monotone gradient (Table 3). Ordering arrangements by their formulaic share:

Arrangement	Facilities	Facility-years	Formulaic share	Median mitigation
Listed firm owns and operates	532	6,290	13.7%	0.825
Municipally owned, listed operator	121	1,042	27.5%	0.647
Private firm	276	2,147	31.3%	0.473
Municipally owned and operated	612	6,722	33.2%	0.380

Municipally owned sites handed to a listed operator sit between the two poles. We do not read this as a causal effect of contracting — operators are not assigned at random, and larger municipal sites are the ones likely to be contracted out — but the ordering is consistent with organisational capability and reporting infrastructure travelling with the operator.

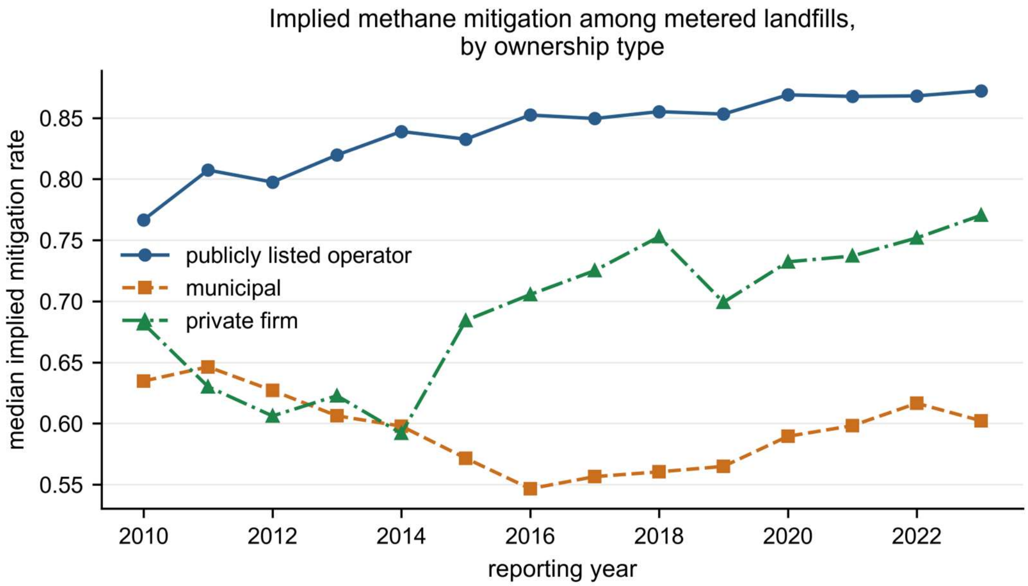

Figure 3. Implied methane mitigation among metered landfills, by ownership type. Medians by reporting year, restricted to the metered branch, so the gradient is not mechanically driven by differing rates of default-factor reporting across ownership types.

California provides a useful descriptive comparison. Its Landfill Methane Regulation took effect on 17 June 2010, with surface-emission standards beginning on 1 January 2011, before the start of our panel. We therefore do not estimate a difference-in-differences effect. Across the sample, 4.0% of California facility-years are in the formulaic branch, compared with 27.0% elsewhere; 95.9% have gas collection, compared with 72.5% outside California (Table 4). These differences are consistent with the state rule substantially reducing the use of the formulaic branch, although the research design does not identify a causal effect.

7. Crossing the equation boundary

Installing a gas collection system moves a facility from the formulaic branch to the recovery-based one. We estimate what this does to the reported inventory using facility and year fixed effects with standard errors clustered by facility, controlling for log modeled generation:

$$y_{it} = \beta \cdot GCS_{it} + \gamma' X_{it} + \alpha_i + \delta_t + \varepsilon_{it}$$

The coefficient is 0.285 (s.e. 0.021) on the implied mitigation rate and −0.570 (s.e. 0.071) on log reported methane, a reduction of 43.5%. With state-by-year fixed effects absorbing every state policy change and state-level shock we have not enumerated, the estimate is 0.286 (s.e. 0.020), essentially unchanged.

Event study. Of 1,331 facilities, 292 are never observed with a collection system, 911 already have one in their first observed year and so have no pre-period, and 127 adopt within the panel; dropping 36 facilities that report a reversal, which an absorbing-treatment design cannot accommodate, leaves 119 adopters in 13 annual cohorts of 3 to 21 facilities. Relative-time coefficients on implied mitigation are −0.001, 0.010, 0.016 and 0.007 at four to two years before adoption, all with confidence intervals covering zero, then 0.140 at adoption and 0.340 one year on, settling at 0.31 to 0.35 (Figure 4). Reported methane falls by 0.60 log points and stays down (Figure 5).

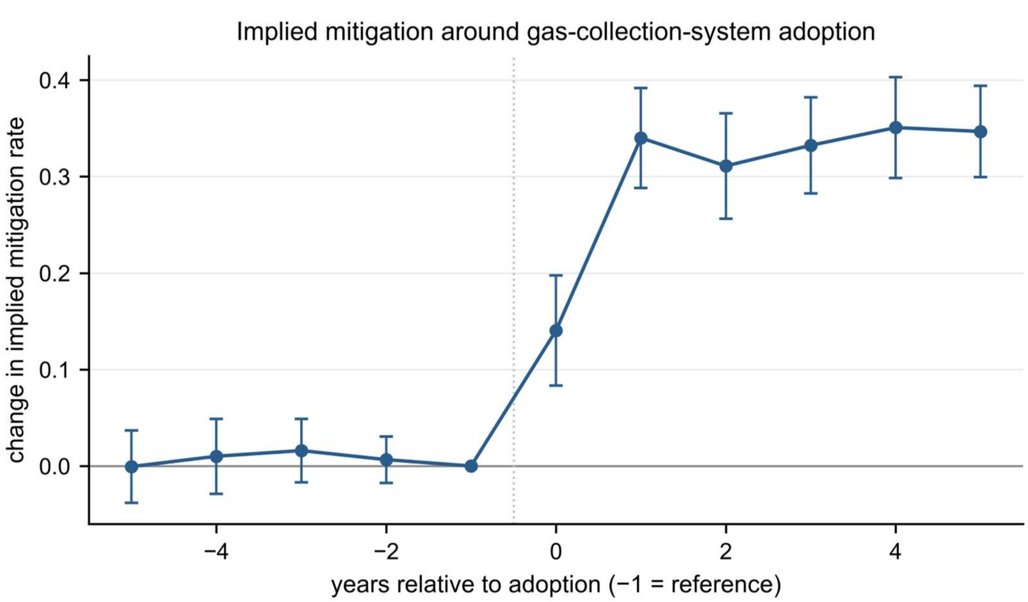

Figure 4. Implied mitigation around gas-collection-system adoption. Facility and year fixed effects, 119 staggered adopters in thirteen annual cohorts; bars are 95% confidence intervals from standard errors clustered by facility. Period -1 is the omitted reference.

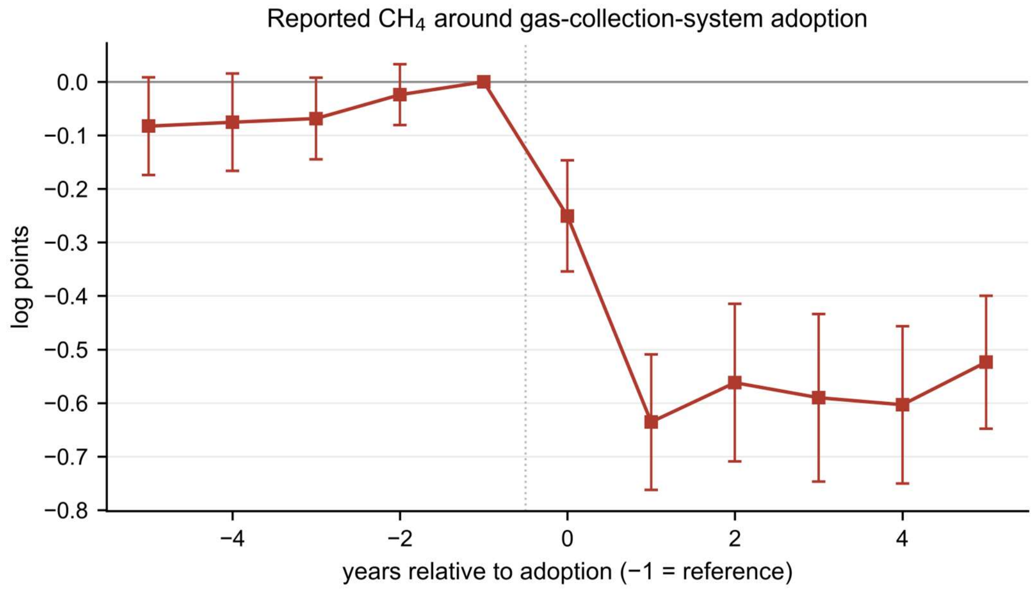

Figure 5. Reported methane around gas-collection-system adoption. As Figure 4, with log reported CH4 as the dependent variable and log modeled generation as a control.

Staggered-adoption estimator. Because two-way fixed effects can place negative weights on treated cohort-period cells under staggered timing (Goodman-Bacon, 2021; de Chaisemartin and D'Haultfoeuille, 2020), we re-estimate with Callaway and Sant'Anna (2021). On the identical restricted sample, pre-period estimates are flat back twelve periods (the largest, −0.032 at −12, is the only one distinguishable from zero) and post-period estimates run 0.159 at adoption to 0.41–0.45 by five to twelve years out, with an overall ATT of **0.373 (s.e. 0.020)** using never-treated controls and **0.375 (s.e. 0.020)** using not-yet-treated controls. Cohort-specific effects range from 0.265 to 0.440 and are individually significant in all thirteen cohorts. If anything the two-way estimate is conservative (Figure 8).

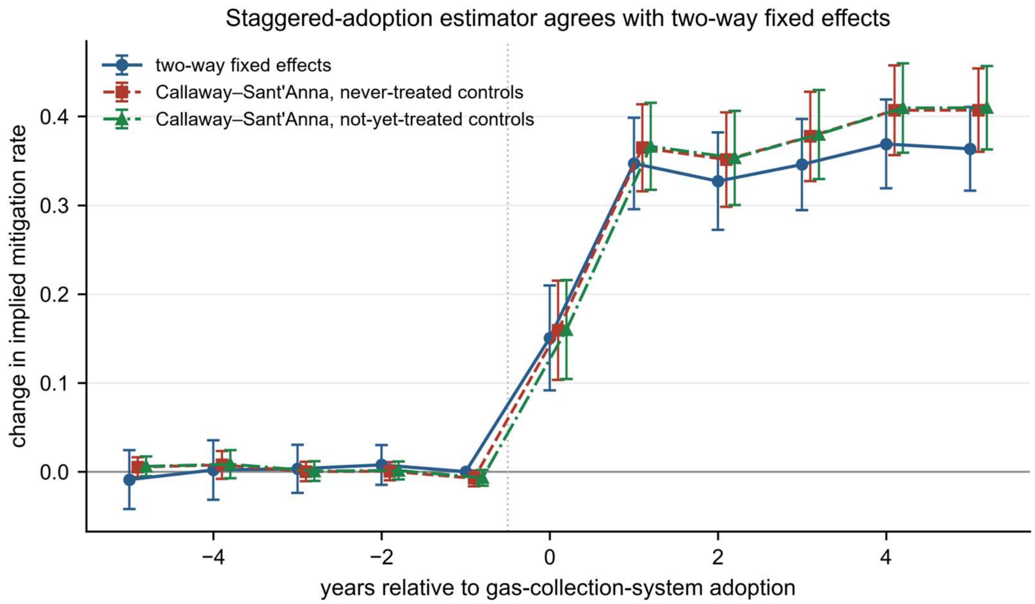

Figure 8. Two-way fixed effects against the Callaway-Sant'Anna estimator. Estimated on the identical restricted sample, after dropping the 36 facilities whose gas-collection flag reverses, since an absorbing treatment design cannot accommodate them. Series are offset horizontally for legibility.

Interpretation of the treatment effect. The estimates describe changes in the reported inventory rather than changes measured directly in atmospheric emissions. One feature of the reporting system is particularly important for interpreting the coefficient.

A facility that installs gas collection changes two things at once: what it physically does, and which regulatory equation governs its filing. It leaves Equation HH-5, where emissions are modeled generation times a default oxidation factor, and enters the recovery-based branch. But that branch is itself two equations, and Stark et al. (2024) show that the choice between them moved substantially over exactly our sample period. They document that roughly two of every three operators came to prefer the collection-efficiency route of Equations HH-7 and HH-8 over the first-order-decay route of Equation HH-6, that the two routes imply opposite trends in modeled generation (+19% against -8.9% from 2010 to 2022), and that universal use of HH-6 would place national emissions 1.3 to 1.7 times higher. The public emissions field does not record which equation produced a given figure.

The estimated effect therefore combines three components that cannot be separated with the public data: physical methane capture, the move from a default-factor equation to a recovery-based equation, and subsequent changes in the recovery-based equation selected by the facility. Only the first component is a physical environmental outcome; the other two are accounting changes. Accordingly, the 34-percentage-point estimate should not be interpreted as a measured improvement in physical capture.

The coefficient identifies the change recorded in the inventory when a facility moves across the regulatory boundary. This quantity is well defined regardless of which recovery equation is used because reported emissions in the new branch are anchored to metered recovery rather than a table value. The result also shows that equation assignment can account for part of a large change in reported emissions. This supports the policy conclusion in Section 11 that reporting equations are an important determinant of inventory totals.

A second treatment. LFG energy projects offer independent variation. Once a collection system is in place, starting an energy project does essentially nothing to reported mitigation: post-period coefficients average 0.008, with a pre-trend of −0.065 at four years out that we flag rather than explain (Table 18, Figure 9). Energy recovery is downstream of collection, and it is collection that the inventory registers.

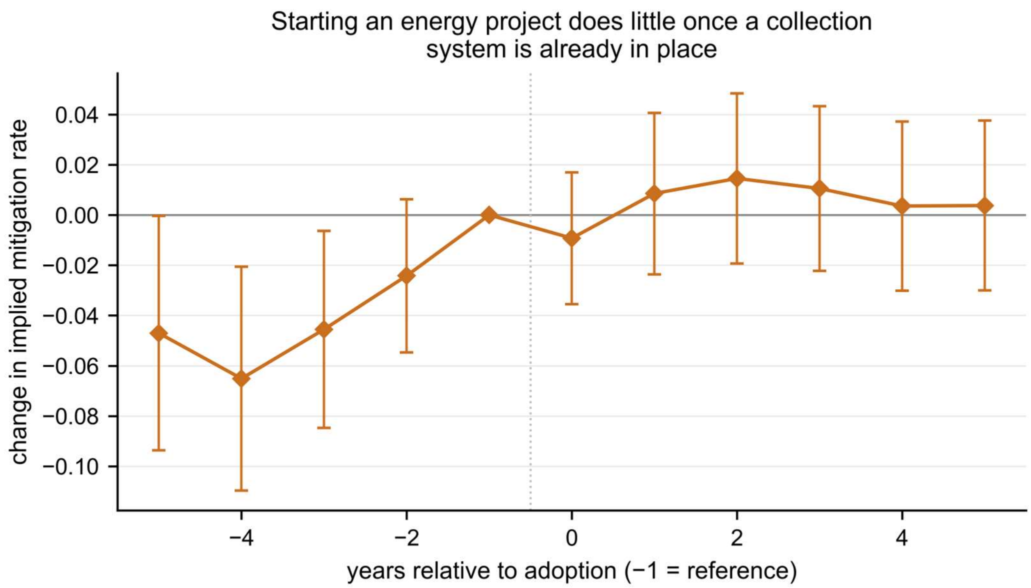

Figure 9. Implied mitigation around the start of a landfill-gas energy project. A second staggered treatment, distinct from installing the collection system itself. The pre-trend at four years out is flagged in the text rather than explained.

8. Site-specific methane fractions and facility selection

Facilities may elect to report a site-specific methane fraction instead of the 0.50 default. Cross-sectionally this looks consequential: among metered facilities, those reporting a measured fraction have median implied mitigation of 0.576 against 0.807 for those on the default, a gap of 23 percentage points that invites the reading that measurement exposes weaker performance.

The association disappears after facility fixed effects are included. With facility and year effects, the coefficient on the measured-fraction indicator is −0.013 (s.e. 0.013, $p = 0.32$); clustering by state gives −0.013 (s.e. 0.016), and restricting the sample to metered facilities gives −0.009 (s.e. 0.014). Event-study estimates for all nine relative periods from −4 to +4 are statistically indistinguishable from zero, with a maximum point estimate of 0.023 (Figure 6). These results indicate that the cross-sectional gap reflects selection: facilities with lower implied mitigation are more likely to adopt site-specific measurement.

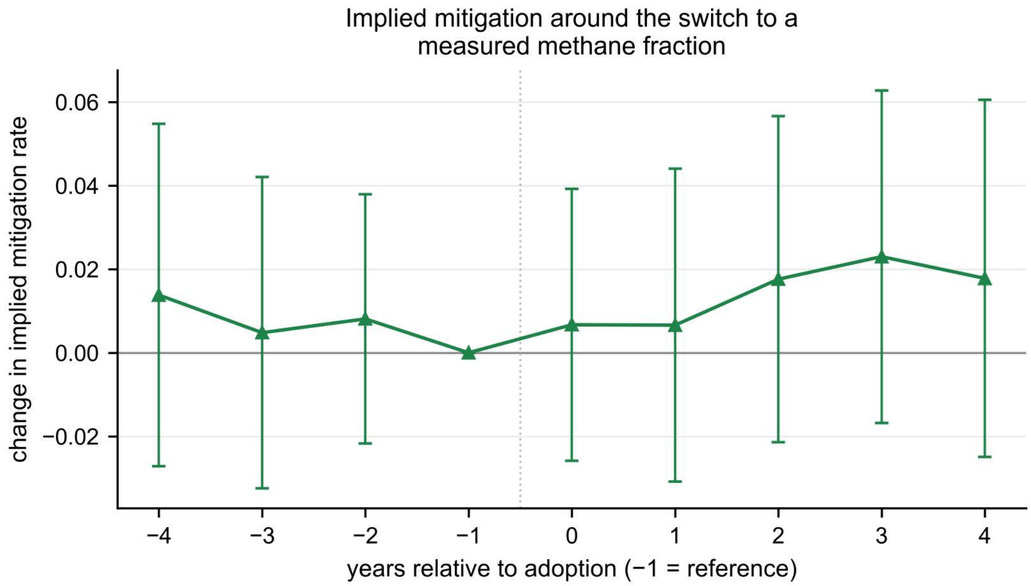

Figure 6. Implied mitigation around the switch to a measured methane fraction. All nine relative periods are statistically indistinguishable from zero, which is why the large cross-sectional gap between measured and default reporters is read as selection.

This distinction affects the interpretation of voluntary measurement. The lower mitigation reported by facilities using site-specific values could be taken as evidence that default parameters overstate performance. The within-facility estimates instead show that switching to measurement does not produce a detectable change in reported outcomes; the difference arises primarily from which facilities choose to measure.

Robustness to the tail. Table 11 reports the gas-collection coefficient under five treatments of the negative tail — untouched, clipped to [−0.5, 1], winsorized at the 1st and 99th percentiles, dropping negative facility-years, and dropping every facility ever negative — giving 0.262, 0.285, 0.293, 0.327 and 0.339, all with t-statistics above 11. Maximum absolute pre-trends stay below 0.025 throughout (Figure 7). The ratio-free specification in log reported methane gives the same conclusion. We note that log(reported/modeled) is not independent evidence: with log modeled generation as a regressor it is a linear reparameterisation and returns the identical coefficient.

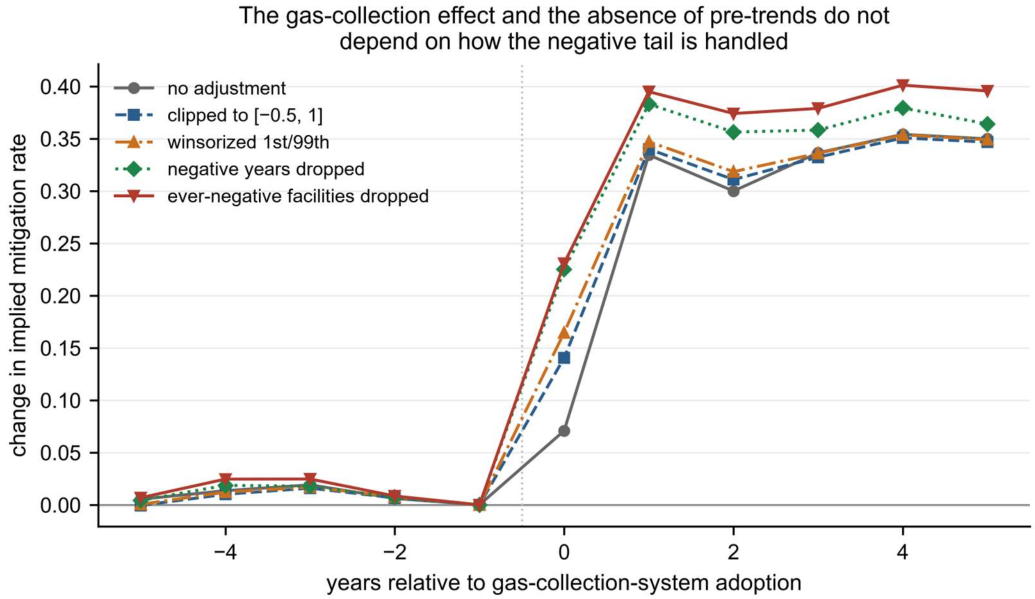

Figure 7. The gas-collection event study under five treatments of the negative tail. 259 facility-years report more methane than their published modeled generation, a mechanical consequence of the "whichever is greater" clause in Equation HH-6. Neither the post-adoption effect nor the absence of pre-trends depends on how those observations are handled.

9. Reporting consistency

Some Subpart HH attributes describe durable physical facts. A truck scale is not routinely uninstalled, and passive vents are not removed and replaced. Transitions in these fields are therefore informative about reporting quality rather than about the landfill (Table 6).

Attribute	Mean	On-transitions	Off-transitions	Facilities ever changing
Gas collection system	0.745	137	39	157 of 1,331 (11.8%)
Scales present	0.781	417	446	387 (29.1%)
Leachate recirculation	0.219	411	515	437 (32.8%)
Passive vents or flares	0.193	438	449	460 (34.6%)
Site-specific methane fraction	0.093	193	208	208 (15.6%)

The gas-collection indicator, which corresponds to a substantial capital asset, reverses 39 times. The other attributes reverse 446, 515, and 449 times, approximately symmetrically with transitions in the opposite direction and across about one third of facilities. These inconsistencies do not establish misreporting of emissions; the truck-scale indicator is not used in the main estimates and is statistically insignificant throughout. They do, however, indicate substantial instability in reported values for durable facility characteristics over the fourteen-year period.

10. Extension to stationary combustion under Subpart C

The mechanism identified above is not peculiar to landfills. It is a general feature of how the Greenhouse Gas Reporting Program is built: where the rule permits a default parameter, the reported number can be produced without measuring anything. Subpart C, which covers stationary fuel combustion at essentially every industrial facility in the program, lets a reporter choose among four tiers that differ precisely in how much measurement they demand. Tier 1 multiplies fuel quantity by a default emission factor. Tier 2 adds a periodically measured heat content but keeps the default carbon factor. Tier 3 requires the fuel's carbon content to be measured. Tier 4 requires continuous emission monitoring. Tiers 1 and 2 are therefore default-factor methods in exactly the sense of Section 5: the facility's reported carbon dioxide is its own fuel throughput times a number supplied by the regulation.

To assess whether the mechanism extends beyond landfills, we assembled the complete Subpart C fuel-level record from Envirofacts: 274,858 fuel-year observations covering 7,479 facilities from 2010 to 2023. Each facility-year is classified according to the highest reporting tier used. The results provide evidence on the prevalence, distribution, and movement of default-factor reporting in a larger source category.

The default-factor branch dominates by facility count and remains large by tonnage. 92.9% of Subpart C facility-years never rise above Tier 2. Weighting by reported carbon dioxide rather than by facility cuts that share substantially, to **64.2%** — Tier 1 accounts for 24.7% of reported tonnage and Tier 2 for 39.4%, against 35.8% for the measured-carbon Tier 3. The gap between the two shares is informative in itself (Figure 10a): mean reported emissions per fuel row rise monotonically across tiers, from 15.0 kt at Tier 1 to 32.1 kt at Tier 2 to 92.1 kt at Tier 3, so the combustion regime does concentrate measurement where the tonnage is. This is a genuine contrast with landfills, where the formulaic share is nearly identical whether facilities (25.0%) or tonnage (23.4%) are counted, because landfill size does not predict which branch a site occupies. Two regulatory regimes, built on the same permissive-default logic, distribute measurement effort quite differently.

Trends in reliance on default-factor methods. The default-factor share of reported combustion tonnage increased from 57.9% in 2010 to 67.4% in 2023 (Figure 10b). This change was not mandated by the rule and reflects greater use of the less measurement-intensive tiers over time.

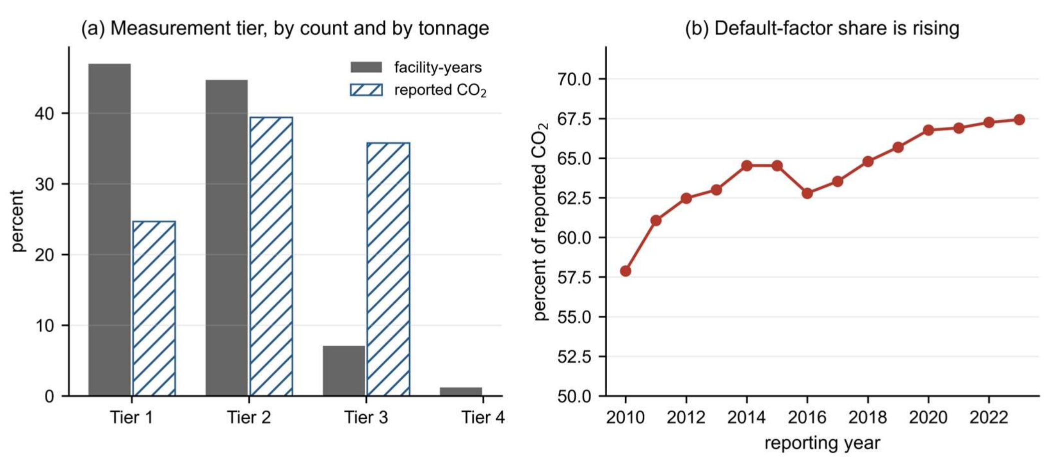

Figure 10. Measurement tier under Subpart C stationary combustion, 2010-2023. Panel (a) contrasts the share of facility-years at each tier with the share of reported carbon dioxide; Tier 4 has no tonnage bar because Part 75 carbon dioxide is not carried in the fuel-level tier columns, which is why the 64.2% default-factor share is an upper bound. Panel (b) plots the default-factor share of reported tonnage by year.

Transitions across tiers. We observe 974 tier upgrades and 1,488 downgrades within facilities. The greater frequency of downward moves resembles the reporting reversals documented in Section 9: the gas-collection indicator reverses only 39 times, whereas less durable reported attributes reverse hundreds of times and about one third of landfills report at least one inconsistency. In both settings, reported measurement intensity can move in either direction over time.

These estimates require two qualifications. First, Tier 4 and Part 75 carbon dioxide is generally reported under Subpart D rather than in the fuel-level tier fields. The 64.2% tonnage share is therefore an upper bound on the default-factor share, and the true measured share is higher. Second, the tier shares are descriptive rather than causal. Unlike gas-collection adoption in Section 7, tier transitions are not absorbing and do not support the same research design; we therefore do not estimate the effect of moving a facility to a higher tier.

The Subpart C analysis indicates that default-based reporting is not unique to the landfill provisions. In the program's largest source category, most reporting facilities and approximately two thirds of reported combustion tonnage rely on regulatory parameters rather than facility-measured carbon content, and this reliance increased over the fourteen-year sample.

11. Policy implications

Targeting independent monitoring. Airborne and satellite campaigns are costly and necessarily selective. The facility-level classification identifies the quarter of the landfill inventory that contains no site-specific methane information and therefore cannot be internally validated against a measured quantity. Municipally owned and operated landfills without gas collection are potential priorities because they are most likely to use the formulaic branch and least likely to report a metered quantity.

Role of the oxidation factor. In the formulaic branch, the full difference between modeled generation and reported emissions is determined by a lookup among three oxidation values. Because the branch has not previously been quantified in tonnage terms, the results raise a regulatory design question: whether Table HH-4 should remain the only permitted approach for facilities without gas collection.

Inventory effects of equation assignment. A landfill's contribution to the reported inventory depends substantially on the equation that applies to it. This design is defensible to the extent that the equations yield accurate estimates, but it becomes consequential when independent observations indicate systematic differences between reported and actual emissions.

Evidence from state rules. California's regulation predates the panel, so the available evidence is descriptive: the state's formulaic share is 4.0%, compared with 27.0% elsewhere. Oregon's rule took effect in October 2021, leaving only twelve facilities and two post-treatment years; the estimated effect is 0.056 with a 95% confidence interval of [−0.031, 0.143], which is too imprecise to support a conclusion. Maryland finalized its rule in 2023, and Washington published its rule in May 2024, leaving no usable post-period in a panel ending in 2023. The effects of these state policies can be evaluated as filings for 2025–2028 become available.

12. Limitations

All dependent variables are reported quantities rather than direct measurements of atmospheric methane. The estimates describe how reported inventory values vary with reporting arrangements, but they do not identify changes in physical emissions and should not be interpreted as mitigation effects.

For facilities with gas collection, the public emissions field does not identify which recovery-based equation produced it, and Stark et al. (2024) document substantial migration between them during our sample. Our partition-and-share results rest only on the no-collection branch, where the formula is unique and empirically confirmed at 96.9–99.0%, but the magnitude of the gas-collection effect is a composite of physical and accounting change.

Identification of the gas-collection effect rests on 119 adopters, because 911 facilities already had a system in the first panel year. The estimate is therefore local to landfills that adopted between 2011 and 2023 and may not generalise to the earlier adopters that dominate the sample.

Ownership is measured from the GHGRP reporting parent and cross-checked against LMOP, but contracting arrangements are observed only crudely, and the ownership gradient is descriptive throughout. LMOP's well counts, blower capacity and waste in place are current-snapshot values without a time dimension, so they support cross-sectional heterogeneity but are absorbed by facility effects in the panel estimates.

13. Conclusion

Our results show that the U.S. landfill methane inventory combines two substantially different reporting regimes. For approximately three quarters of reporters, emissions are anchored to metered gas recovery. For the remaining quarter—23.4% of reported tonnage and roughly 0.8 million metric tons of CH_4 per year—emissions are calculated from a decay model and a table-based oxidation factor. The share of facilities in this formulaic branch remained stable throughout the program's history and varies systematically with ownership and operation, from 13.7% among landfills owned and operated by listed waste firms to 33.2% among municipally owned and operated sites. Installation of gas collection is associated with a 34- to 38-percentage-point increase in reported implied mitigation and an approximately 45% decline in reported methane. These estimates exhibit no systematic pre-trends and are similar across staggered-adoption and two-way fixed-effects methods. By contrast, a facility's switch to a site-specific methane fraction produces no detectable change in reported outcomes.

The extension to Subpart C stationary combustion yields a similar distinction between default-based and measurement-intensive methods. Default-factor approaches account for 92.9% of facility-years and 64.2% of reported carbon dioxide. Unlike the landfill regime, however, combustion reporting concentrates measurement among larger emitters. Reliance on default methods increased from 57.9% to 67.4% of reported tonnage between 2010 and 2023. Reporting choices also move in both directions: tier downgrades exceed upgrades by 1,488 to 974, and about one third of landfills report at least one inconsistent value for a durable physical attribute.

Independent observations consistently place actual landfill emissions above reported values. Identifying facilities whose filings contain no site-specific methane measurement is therefore important for designing verification and monitoring efforts. The evidence also indicates that permissive use of regulatory defaults affects reporting well beyond the landfill sector and should be considered when interpreting national greenhouse gas inventory totals.

Figures and tables

Figures 1 to 10 are placed inline at first reference. Vector (PDF) versions of every figure, suitable for production, are in `output/figures/`, alongside the 600 dpi rasters embedded here. Tables 1 to 20 and the full regression output are in `output/tables/`, and every number in the text is reproduced by `code/10_manuscript_numbers.py`.

Data and code availability

Every input to this study is public and free of charge, and the full analysis is reproducible end to end from the raw sources.

Primary sources. GHGRP Subpart HH and Subpart C are retrieved programmatically from the EPA Envirofacts REST service (`https://data.epa.gov/efservice`). The GHGRP parent-company register and the Landfill Methane Outreach Program landfill and project databases are downloaded from epa.gov. Nothing is behind a subscription and no proprietary database is used, so any reader can rebuild the panel from scratch.

Derived data. The constructed facility-year panels, the ownership classification, and the data dictionary are deposited at Zenodo under [DOI to be inserted on posting], released under CC BY 4.0. The deposit includes the 16,319 facility-year Subpart HH analysis panel with parent-company and LMOP links, and the 76,697 facility-year Subpart C measurement-tier panel used in Section 10.

Code. Extraction, construction, estimation and figure scripts are included in the same deposit under the MIT licence, numbered in execution order. `code/10_manuscript_numbers.py` recomputes every figure quoted in the text on a single consistent sample and is the intended way to audit the numbers.

Author contributions (CRediT)

Song, S.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. **Wang, Y.:** Conceptualization, Methodology, Supervision, Writing – review & editing.

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Competing interests

Song is employed as a data engineer by Republic Services, a publicly listed solid-waste operator whose facilities appear in the sample. The company provided no funding, data or editorial input, and all data used here are publicly available from the U.S. Environmental Protection Agency. The analysis treats Republic Services facilities identically to all others, and no firm-specific result is reported. The remaining authors declare no competing interests.

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