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WHITEPAPER

What is the Best Indicator of Pneumatic Venting:

Device count or production data?

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TITLE

What is the Best Indicator of Pneumatic Venting: Device count or production data?

LOCATION

Scope limited to Alberta and British Columbia, Canada

SITE TYPE

Executive Summary

Pneumatic devices powered by instrument gas are among the most prevalent sources of routine methane venting at upstream oil and gas facilities. However, the relatively small and intermittent nature of these releases makes them difficult to measure on a continuous basis, with regulatory and industry practice relying primarily on emission factor approaches that may not accurately reflect changes in production activity and actual vent volumes.

This paper presents findings from a statistical analysis of 1847 pneumatic devices operating at 116 upstream oil and gas facilities in Alberta and British Columbia, drawing on 12 months of continuous nitrogen consumption data (May 2025 – April 2026). Nitrogen consumption provides a direct and accurate proxy for pneumatic methane venting, enabling facility-level analysis at a scale and resolution not previously available.

Three variables were assessed as potential predictors of facility-level pneumatic venting: 1) total pneumatic device count, 2) actual 12-month production volume (BOE), and 3) average well age.

The findings are significant and consistent across all seven model specifications tested:

- Device count explains 75.1% of variation in facility-level pneumatic venting across 116 facilities (R^2 = 0.751).
- Production volume explains only 16.7% of variation in isolation (R^2 = 0.167) and adds no independent explanatory power once device count is known (p = 0.607 in combined model).
- Well age is negatively correlated with venting (r = -0.499) but also loses explanatory power once device count is included.
- Each additional pneumatic device is associated with approximately 1,262 m^3 of additional methane vented per year.

1. INTRODUCTION

Pneumatic devices are a cornerstone of upstream oil and gas operations. Process controllers and pumps are installed across production facilities to automate the management of pressure, flow, and liquid levels. In conventional configurations, these devices are powered by the same natural gas flowing through the production system ("instrument gas"). During normal operation, that gas is vented to atmosphere, making pneumatic devices one of the most common and widespread sources of routine methane emissions at the wellsite.

The challenge of accurately quantifying pneumatic venting has been well documented. Two approaches dominate current practice. The first applies manufacturer-specified bleed rates (emission factors) to device inventories, multiplied by operating hours. The second uses point-in-time optical gas imaging (OGI) to visually detect and estimate venting events. Both have significant limitations: manufacturer specifications assume continuous operation at rated capacity and do not account for variability in wellsite activity, device maintenance condition, or equipment condition; OGI captures a snapshot and cannot reflect how vent rates vary seasonally or with changes in production activity.

A third approach — novel but highly accurate — involves the direct measurement of the instrument gas within the pneumatic control system. Where nitrogen-based methane mitigation systems are deployed, nitrogen consumption data provides a continuous, facility-level record of instrument gas usage that can be converted to methane equivalent with high precision. This dataset is the foundation of the analysis presented here.

The central question this paper addresses is straightforward but consequential: of the variables that are commonly considered as influencing pneumatic venting (device count, production volume, and well age) which is the most reliable predictor of the volume of methane vented from pneumatics? The answer has direct implications for emission inventory methodology, regulatory reporting requirements, and the allocation of monitoring and mitigation resources.

2. BACKGROUND AND PREVIOUS RESEARCH

2.1 The Measurement Challenge

The difficulty of measuring pneumatic emissions stems from several characteristics that distinguish them from other industrial emission sources. Individual release events are small in volume, intermittent in timing, and numerous across a typical facility. Seasonal temperature variation may affect actuation frequency and methanol pump usage. Equipment age and maintenance condition introduce substantial variability that is not captured by manufacturer specifications.

Allen et al. (2015), in one of the most comprehensive measurement studies to date, directly measured emissions from 377 pneumatic controllers at natural gas production sites across the United States1. They find that emission rates vary substantially by device type and operating application. Specifically, that controllers on separators and in compressor applications showed average rates well above the dataset mean and that a small amount of high-emitting devices can account for a majority of the emissions.

These findings complement the analysis presented here. Allen et al. measured 377 individual devices using point-in-time high-volume samplers. In contrast, the dataset underlying this paper covers 1,847 devices across 116 facilities on a continuous 12-month basis; roughly five times the device count, with the additional dimension of temporal continuity. The two studies are methodologically complementary: Allen et al. establishwhat individual devices emit; this analysis establishes how facility-level venting is tied to inventory and site characteristics at scale.

2.2 The Production-Venting Relationship
The intuition that higher-producing sites should vent more methane is not unreasonable: more production activity generally implies more equipment and more actuation events. However, the relationship between production and venting is neither straightforward nor linear. As Toothman (2020), presenting on behalf of EQT Corporation, demonstrated, intermittent bleed device emissions are fundamentally action-based rather than time-based2. For liquid level controllers in particular, the emission rate is driven by dump cycle frequency, which is in turn driven by water production per well. Water production follows a hyperbolic decline curve: new wells produce water at high rates, driving frequent actuation and elevated venting; as wells mature and water production declines, actuation frequency falls and so do vent rates. This means the production-venting relationship is influenced by well age and with the ratio of water to hydrocarbon production, neither of which is captured by a simple production volume figure.

EQT's modelling suggested that actual GHG emissions from intermittent bleed devices can be substantially below current EPA guidance once production decline is accounted for, with an initial evaluation yielding an average emissions rate 49% lower than the 13.5 scf/hr EPA benchmark (0.4 m^3/h).

2.3 The Role of Device Count
If production volume is an unreliable proxy, device count offers an alternative that is more directly tied to the physical source of emissions. Every venting pneumatic device represents a source of methane release; more devices mean more sources. The total device count at a facility reflects its operational complexity and the number of automated control points that require instrument gas — a more direct representation of venting potential than throughput volumes.

The limitation of device count as a metric has historically been the difficulty of maintaining accurate inventories of this ubiquitous piece of equipment. Devices are added, replaced, and decommissioned over time, and different operators and regulatory bodies may differ in their inventory management and reporting practices. Where inventories are well-maintained and verified, however, device count provides an operationally grounded basis for emission factor application.

3. DATA AND METHODOLOGY

3.1 The Nitrogen Measurement System
The dataset underlying this analysis is generated by nitrogen-based methane mitigation systems deployed at upstream oil and gas facilities. Nitrogen, which is a clean, dry, and inert gas, is used as an instrument gas replacement in pneumatic control systems. Liquid nitrogen is stored on site in a specialized tank and dispensed in gaseous form to power existing pneumatic controllers and pumps, replacing the natural gas that would otherwise serve as instrument gas. The methane line is turned off, eliminating routine venting entirely. As such, the nitrogen system is primarily a mitigation technology.

However, the nitrogen systems have important measurement benefits as well. Because the nitrogen system operates in a closed loop (a fixed volume of nitrogen enters the pneumatic circuit and is consumed by the devices), the volume of nitrogen used directly reflects the volume of natural gas that would otherwise have been consumed and vented3. Every nitrogen tank is equipped with level sensors and a telemetry system that transmits hourly readings to a cloud-based portal. This produces a continuous, facility-level record of instrument gas consumption throughout the year, capturing seasonal variation, changes in wellsite activity, and anomalous events such as device malfunctions.

Methane equivalent is derived from nitrogen consumption via a two-step conversion. Nitrogen mass (kg) is first converted to volume using the standard density conversion factor for nitrogen gas at standard conditions

M(1 kg N_2 = 0.843642 m^3). The resulting nitrogen volume is then multiplied by a validated gas equivalency ratio between nitrogen and methane (GER = 1.2764)4:

$$CH_4 \text{ Avoided } (m^3) = N_2 \text{ (kg)} \times 0.8436 \times 1.2764$$

For every kilogram of nitrogen consumed, approximately 1.076 m^3 of methane would otherwise have been vented. (Assumes 100% methane composition of fuel gas.)

This approach is more accurate than any existing alternative for continuous facility-level measurement. OGI cameras can detect pneumatic emissions but provide only point-in-time snapshots and cannot reliably quantify small or intermittent releases. Manufacturer emission factors cannot account for actual operating conditions in real-time. The nitrogen consumption method provides a verified, auditable, and continuous record that enables longitudinal statistical analysis.

3.2 Dataset

The analysis draws on data from 116 upstream oil and gas facilities in Alberta (n=96) and British Columbia (n=20), covering the 12-month period from May 1, 2025 to April 30, 2026. Only facilities with a complete 12-month record of nitrogen consumption are included; sites where nitrogen systems were added or removed during the study period were excluded to ensure full-year comparability.

Pneumatic device inventories were sourced from verified records maintained by the nitrogen system operator at each site. Recognizing that multiple wells may be producing at a given facility, production volumes and average well age were both determined by analyzing individual well data and aggregating at the facility level. The authors aggregated publicly-available data to determine production volumes (12-month BOE production from May 2025 through April 2026) at each surface hole location level. Average well age was calculated by averaging the years in production of each well at a facility (April 30, 2026 minus first production date, divided by 365.25).

Table 1 – Dataset parameters

Parameter	Value
Total facilities	116
Alberta	96 (82.8%)
British Columbia	20 (17.2%)
Study period	May 1, 2025 – April 30, 2026
Total pneumatic devices (incl. pumps)	1,847
Non-pump devices	1,373
Pumps	474 (25.7% of total)
Sites with pumps installed	102 of 116 (87.9%)
Mean devices per site	15.9
Mean well age	16.7 years

3.3 Variables

The dependent variable is **total 12-month CH_4 avoided (m^3),** derived from nitrogen consumption via the two-step conversion described in Section 3.1. This represents the volume of methane that would have been vented from pneumatic devices over the study period had natural gas been used as instrument gas.

Three independent variables were assessed as predictors:

Total device count (incl. pumps): The sum of all pneumatic devices at the site, including liquid level controllers, transducers, positioners, pressure controllers, pneumatic switches, and pumps, from verified facility records.

12-month production volume (BOE): Barrels of oil equivalent produced across all wells at the surface hole location during the study period.

Average well age (years): Mean years in production across all wells at the site, calculated from first production date to April 30, 2026. Included as a proxy for production maturity and its associated effects on actuation frequency and vent rates.

3.4 Analytical Approach

Ordinary least squares (OLS) regression was used to assess the relationship between each predictor variable and the dependent variable. Seven models were estimated, including single-predictor models for each variable and all combinations. This structure allows direct comparison of each variable's individual explanatory power as well as their combined effect.

Outliers were identified as any site where a variable fell more than three standard deviations from the mean was flagged. Seven sites were identified; models were run on both the full dataset (n=116) and the outlier-removed dataset (n=109). All site and company identifiers are anonymized.

Four metrics evaluate model performance: R^2 (proportion of variation in venting explained), Adjusted R^2 (R^2 corrected for the number of predictors to prevent artificial inflation when adding variables), RMSE (average size of prediction errors in m^3, the same units as the outcome), and p-values (probability that a result is due to chance rather than a real underlying relationship).

4. RESULTS

4.1 Descriptive Statistics

The dataset reflects the diversity typical of upstream production portfolios. Facility-level venting ranges from 1,529 m^3 to 117,409 m^3 per year, with a mean of 22,034 m^3 and a median of 11,420 m^3. The divergence between mean and median signals a right-skewed distribution: most facilities have modest venting profiles, while a smaller number of larger, more complex sites drive the average upward.

Table 2 – Descriptive statistics

Variable	Mean	Median	Std. Dev.	Range	Skewness
CH_4 Avoided (m^3) (Dependent)	22,034	11,420	24,919	1,529–117,409	1.87
Total Devices (incl. pumps)	15.9	9.5	17.1	1–90	2.02
12-Month BOE Production	151,855	19,169	308,545	30–1,929,922	3.22
Avg. Years in Production	16.7	14.1	11.7	0.6–48.1	0.77

4.2 Correlations

Correlations confirm that device count has by far the strongest linear relationship with facility-level venting ($r = 0.867$). Production volume shows a moderate positive correlation ($r = 0.408$), while well age shows a moderate negative correlation ($r = -0.499$), indicating that older sites tend to vent less (as further explored in Section 5.3.)

Table 3 – Correlations of independent variables with facility venting

Predictor Variable	r	p-value	Interpretation
Total Devices (incl. pumps)	0.867	< 0.001	Strong positive (more devices, more venting)
12-Month BOE Production	0.408	< 0.001	Moderate positive (larger producers vent more)
Avg. Years in Production	−0.499	< 0.001	Moderate negative (older sites vent less)

4.3 Regression Models

Table 4 summarises the performance of all seven regression models investigating the impact of predictors (independent variables) on pneumatic vent volumes. The results are unambiguous: device count is the dominant predictor of pneumatic venting across all model specifications.

Table 4 – Regression results

Model	Predictors	R^2	Adj. R^2	RMSE (m^3)	p (model)
Model 1	Device Count	0.751	0.749	12,490	< 0.001
Model 2	12-Month BOE	0.167	0.159	22,849	< 0.001
Model 3	Avg. Years in Production	0.249	0.242	21,687	< 0.001
Model 4	Device Count + BOE	0.752	0.745	12,534	< 0.001
Model 5	Device Count + Years	0.754	0.748	12,497	< 0.001
Model 6*	BOE + Avg. Years	0.290	0.278	21,182	< 0.001
Model 7	All Three Combined	0.756	0.749	12,471	< 0.001

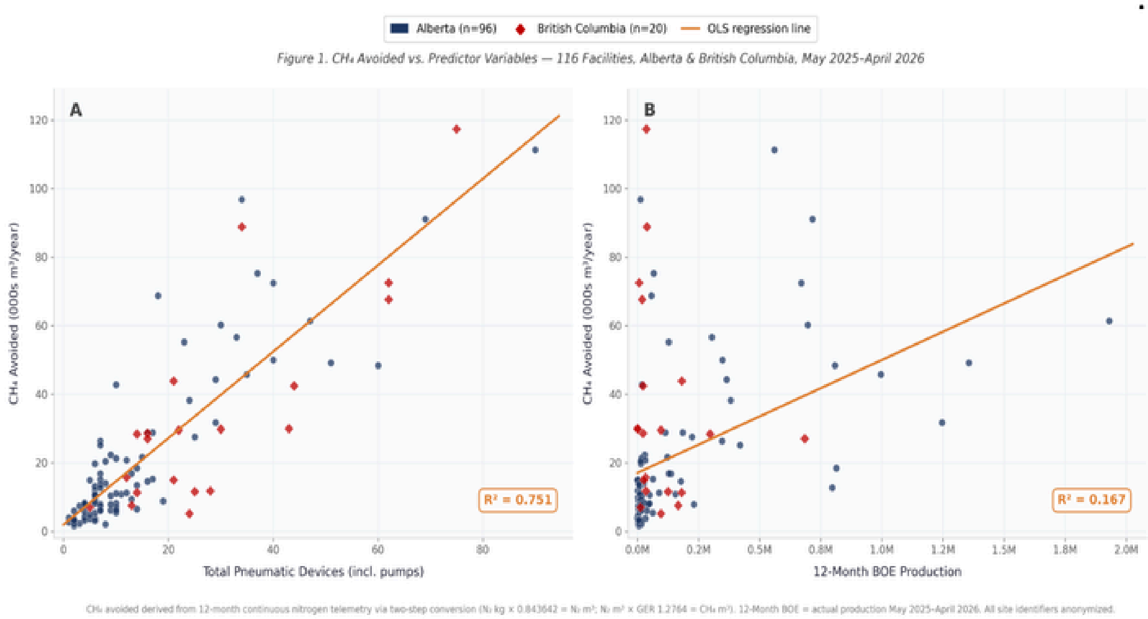
Model 1: Device count alone explains 75.1% of variation ($R^2 = 0.751$, RMSE = 12,490 m^3). Each additional pneumatic device is associated with approximately 1,262 m^3 of additional methane vented annually ($\beta = 1{,}262$, $p < 0.001$).

Model 2: Production volume alone explains only 16.7% of variation ($R^2 = 0.167$). The RMSE of 22,849 m^3 is nearly double that of Model 1, meaning production-based predictions are on average roughly twice as far from observed venting.

Model 3: Well age alone performs somewhat better than production ($R^2 = 0.249$), confirming that site maturity carries information about venting behaviour, though far short of device count.

Model 7: All three predictors combined produce an R^2 of 0.756, virtually identical to Model 1. The BOE coefficient is $\beta = -0.002$ ($p = 0.607$) and well age $\beta = -184$ ($p = 0.129$), indicating that neither variable is statistically significant once device count is in the model. Production volume and well age add nothing beyond what device count already captures.

Figure 1 – Vent volumes vs. total device count (left) and 12-month BOE production (right)



Navy circles = Alberta; red diamonds = British Columbia. Orange line = OLS regression fit. Across 116 facilities, May 2025–April 2026.

The above graphs provide visual confirmation of the core findings: the device count graph (left) demonstrates a much tighter, more consistent relationship than the production volume graph (right).

4.4 Device Disaggregation: Pumps vs. Non-Pump Devices

An additional analysis examined whether differentiating between pumps and non-pump devices improves model accuracy. After all, pumps are typically much higher emitters than other pneumatic devices5, suggesting that we may want to account for how many pumps are operating at a given facility. As such, we performed additional analyses, separating out non-pump pneumatic devices from pumps.

Table 5 – Differentiating device type – regression results

Model	Predictors	R^2	Adj. R^2	RMSE (m^3)
Device count only (no pumps)	Devices excl. pumps	0.763	0.761	12,174
Pumps only	Pumps	0.365	0.359	19,951
Device count + Pumps	Both, separately	0.767	0.763	12,131
Total devices (incl. pumps)	Combined count	0.751	0.749	12,490

Non-pump devices (controllers, transducers, positioners, switches) alone explain a marginally higher proportion of variation (R^2 = 0.763) than total devices combined (R^2 = 0.751). Pumps alone explain 36.5% of variation. When both are entered as separate predictors, the predictive value of the model increases modestly (adjusted R^2 rises to 0.763) compared to just looking at the total number of devices (adjusted R^2 of 0.749).

When both device types are entered into a combined model, the pump coefficient drops sharply and becomes non-significant (β = 416, $p = 0.182$). These findings ultimately underscore a multicollinearity effect: sites with more non-pump devices also tend to have more pumps. As such, knowing the number of total pneumatics operating is much more important than the breakdown of these pneumatics (by type) – the number of pumps is likely to be relative to the number of non-pump devices.

Unfortunately, we are unable to identify emission factors and cleanly attribute venting to each pneumatic device type from this dataset alone. Differentiating between device types would require separate metering of pump circuits and controller/switch circuits (a direction identified as a priority for future work in Section 7).

5. DISCUSSION

5.1 Device Count Dominates

The strong performance of device count as a predictor ($R^2 = 0.751$) reflects a direct physical relationship: unsurprisingly, every pneumatic device at a facility is a source of methane venting. More devices mean more sources. Device count (the number of automated control points that require instrument gas) reflect a facility's design and complexity, and is a more reliable indicator of total venting potential than how much oil and gas the facility produces.

This finding is consistent with Allen et al. (2015) in demonstrating that pneumatic device characteristics can have significant impact on overall venting. The present study confirms this relationship at the facility level at substantially larger scale, across a geographically diverse sample with continuous rather than point-in-time measurement.

5.2 Production Volume as a Weak(er) Predictor of Venting

The results of this study show that production volume is a relatively weak predictor compared to device count ($R^2 = 0.167$). Production volume and device count are correlated (given that larger producing sites tend to have more equipment) but this correlation is imperfect. A high-producing site with efficient control systems may have fewer pneumatic devices than a lower-producing site with older, more complex equipment. A 60-inch separator and a 30-inch separator at the same facility may each have three or four pneumatic devices despite very different throughput capacities.

Field experience from nitrogen system deployment and sizing provides a practical illustration. Attempts by operators to track nitrogen consumption on a per-barrel-of-fluid basis have yielded ranges from under 0.03m^3/BBL to over 0.40 m^3/BBL. This variability is reflected in the R^2 of 0.167: production volume captures a general tendency but leaves the vast majority of the variation in venting unexplained.

5.3 The Well Age Effect and Its Interpretation

The negative correlation between well age and venting ($r = -0.499$) demonstrates that methane venting decreases the longer a facility has been in production. This is consistent with Toothman's (2020) findings on intermittent bleed device emission rates: as wells mature and fluid production declines, dump cycle frequency decreases and so does per-device venting. On a dataset where the mean well age is 16.7 years, the majority of sites are well into the flat tail of the production decline curve, where actuation rates have stabilised at relatively low levels.

This interpretation suggests that the well age effect would be substantially stronger in a dataset of newer wells. Sites in the first 12–18 months of production (when water production is at its highest and actuation frequency is greatest) would be expected to show considerably higher per-device vent rates than the dataset average.

It is important to emphasise that the negative well age coefficient does not mean older wells are inconsequential from an emissions standpoint. The median annual venting in this dataset (11,420 m^3/year) represents a meaningful methane release even at the typical older site. Older wells vent less per device than newer ones, but they are numerous and collectively constitute a large share of total industry pneumatic emissions. A well that has been producing for 20 years may vent at a lower per-device rate than a new well, but it still vents. The case for addressing pneumatic emissions across the full age spectrum of producing assets remainsstrong.

5.4 Geographic Considerations: Canada, the United States, and Climate Effects
This study draws on data generated from facilities in Alberta and British Columbia (Canada) which may impact the representativeness and replicability of the findings more broadly. Canada's colder climate means that pneumatic pump activity is likely higher than in warmer producing regions of the United States. Methanol and diaphragm pumps are used extensively in colder climates to manage increased fluid viscosity, freeze protection, and the operational challenges of winter production. This is reflected in the dataset: 87.9% of sites have at least one pump installed, and pumps represent about a quarter of all pneumatic devices (474 of 1,847).

Other major US producing basins, including Haynesville, Permian and Anadarko Basin, are warmer with lower pump prevalence. This has two implications for applying these findings in a US context. First, the absolute per-device venting rate may differ, since pump-heavy facilities appear to have higher per-unit venting. Second, the finding that non-pump devices are a marginally stronger predictor than total devices may be more pronounced in warmer climates where pump counts are lower and non-pump devices represent a larger share of the total inventory.

Despite these differences, the fundamental conclusion is expected to hold across geographies: namely, that device count outperforms production volume as a predictor of facility-level venting.

5.5 The Value of Continuous Measurement
Beyond the specific findings on device count and production, this analysis illustrates a broader point about the value of continuous, measurement-based pneumatic vent data. The nitrogen consumption dataset enables rigorous statistical analysis at a scale and resolution that OGI surveys and manufacturer-specification approaches cannot support. 12 months of data across 116 facilities allows for the assessment of seasonal patterns, detection of anomalous consumption events (indicative of device malfunctions), and longitudinal tracking of how venting profiles change over time.

The dataset also supports measurement-informed inventory methodology: where operators deploy nitrogen systems across a significant proportion of their pneumatic assets, the resulting consumption data can serve as the empirical foundation for company-specific emission factors that may be more accurate and accessible than other estimation techniques.

6. IMPLICATIONS

6.1 For Emissions Quantification
The most direct implication of these findings is that device-count-based emission factor frameworks are empirically well-founded. An R^2 of 0.751 represents a strong and consistent relationship between device count and actual venting across a diverse sample of 116 facilities. This finding supports the use of per-device emission factors with reasonable confidence, provided the device inventory is accurate.

These findings also carry implications for what generic emission factors from pneumatic devices should be. The regression coefficient from Model 1 (β = 1,262 m^3/device/year for total devices including pumps)represents the average marginal contribution of each additional device to facility-level venting. We are unable to differentiate emission factors between pumps and non-pump devices with the data provided; the coefficient above (Model 1) reflects average behaviour across a heterogeneous sample. Nevertheless, these results provide a useful empirical anchor; a device-level emission factor substantially above or below these values should prompt scrutiny.

Conversely, production-based proxies for pneumatic venting carry substantial uncertainty. With an R^2 of 0.167, a production-based approach leaves approximately 83% of the variation in facility-level venting unexplained. For any given facility, a production-based estimate could be materially off in either direction.

6.2 For Methane Reduction Priorities

Device count provides a practical basis for prioritising methane reduction activities: facilities with large device inventories are more likely to be high emitters, and facilities that show anomalous nitrogen consumption (elevated relative to device count) should be checked for leaks. This kind of data-driven prioritization is most impactful when inventories are well maintained.

6.2.a. Marginal Wells

A related question of current policy interest concerns marginal wells, which are low-producing or older assets that may be nearing the end of their productive life. Some stakeholders have argued that such wells should be subject to less stringent methane requirements given their lower production values. We caution against that conclusion. Production volume is a weak predictor of pneumatic venting (R^2 = 0.167), suggesting that a low-producing well can still have a substantial pneumatic venting profile if it has multiple devices installed. The number of devices, not the production level, is what drives emissions. A marginal well with ten pneumatic controllers may vent as much methane as a high-producing well with the same device count.

Applying differential regulatory treatment based on production thresholds, without accounting for device count, risks systematically exempting facilities that are material emitters.

6.2.b. Aging Assets

Installing non-emitting process controls are standard practice on new wells in many jurisdictions. This paper's findings reinforce the rationale for extending that focus to existing sites. Device count at established facilities can be as high as new ones (oftentimes higher), and the large aggregate number of existing pneumatic devices in operation is much larger than those at new facilities. Most of the industry's pneumatic devices are on wells that have been producing for years or decades. As such, mitigating pneumatic venting on existing, older sites still yields material emissions reductions.

6.3 For Policy and Regulatory Design

These findings suggest several considerations for regulators developing or refining methane reporting and reduction frameworks:

- Verified pneumatic inventories are the foundation of accurate emission accounting. Policies that encourage or require operators to maintain up-to-date pneumatic device inventories will produce better emission data than those that rely on production-based proxies. The investment required to develop and maintain a device inventory is modest relative to the improvement in inventory accuracy it enables.

- Even low-producing and older facilities can still generate meaningful methane emissions. Device count should be the determining factor for assessing methane vent volumes and potential exemptions from zero-bleed pneumatic requirements.

- Measurement-based approaches create incentives for mitigation as well as accurate reporting. Where nitrogen systems are deployed, operators simultaneously eliminate venting, generate accurate emission data, and create an auditable record that supports regulatory compliance. Frameworks that recognize and reward measurement-based reporting can accelerate both accuracy and mitigation.

6.4 For Industry

For oil and gas operators, the practical message is that device inventory management is critical for accurate emissions quantification, credible reporting, and effective mitigation planning. Operators who maintainverified inventories and understand the configuration of their pneumatic assets are better positioned to identify high-emitting sites, prioritise mitigation investments, and demonstrate emissions performance to regulators and stakeholders.

7. LIMITATIONS AND FUTURE RESEARCH

These findings should be interpreted with the following limitations in mind, each of which also points toward future lines of research:

- Geographic scope and replicability: All 116 facilities are in Alberta or British Columbia. While the fundamental relationship between device count and venting is expected to hold broadly, absolute emission rates and device configurations may differ in other producing regions. Applying this methodology to nitrogen system data from other oil and gas basins would enable direct comparison across geographies and producing environments, allowing us to test whether the prevalence of pumps observed in Canada results in measurable emission differences in warmer climates.

- Longitudinal analysis: The analysis covers one 12-month period. Longitudinal analysis across multiple years would enable assessment of how venting profiles evolve with well age, production decline, and changes in equipment configuration. Expanding the dataset to include recently drilled wells with ages below two years would also test the EQT (Toothman 2020) hyperbolic decline hypothesis directly with measurement data, providing one of the first empirical validations of that model at scale.

- Seasonality: The analysis uses annual totals for nitrogen consumption and BOE. However, monthly data is available. Isolating monthly changes in nitrogen consumption could help inform the relative impact of seasonality, including the impact of methanol pumps (which are typically only used in winter months) on total emissions.

- Device type disaggregation and emission factor development: Nitrogen consumption is measured at the facility level, not at a single device (unless it's a one-device facility). Device-level disaggregation would require separate metering of pump circuits and controller circuits. If the nitrogen flowing to pumps and non-pump devices were metered separately, it would be possible to derive defensible per-device emission factors for pumps and non-pump devices. The same exercise could be done by non-pump pneumatic devices: liquid level controllers, transducers, positoners, etc., which are currently bucketed into a single group. Better understanding the vent rates of specific device types may be material for emission inventory accuracy and validating emission factors.

8. CONCLUSIONS

This paper set out to answer a practical question: of the variables most commonly thought to influence pneumatic vent rates, which is the most reliable predictor of pneumatic venting? The answer, supported by continuous 12-month measurement data from 116 facilities and 1,847 devices, is device count.

Device count explains 75.1% of the variation in facility-level pneumatic venting across the study sample. Production volume explains 16.7% in isolation and nothing additional once device count is known. Well age provides some explanatory value in isolation but is similarly redundant in the combined model.

These findings do not suggest that production volume and well age are irrelevant to understanding pneumatic emissions. The mechanisms connecting these variables to methane venting are statistically significant. But as predictors for pneumatic emissions, they are poor substitutes for accurate device count data. Having accurate pneumatic inventories are the best way for producers to understand their total methane emissions from pneumatics and devise impactful mitigation plans accordingly.

The broader finding is that nitrogen-based methane elimination systems produce continuous, measurement-based pneumatic vent data, enabling statistical analysis and improving our understanding of pneumatic venting with a precision and at a scale that was previously unattainable. The dataset underlying this analysis sets the stage for future emission factor research, methane intensity tracking and policy development.