The Role of Continuous Monitoring Systems in Methane Emissions Inventories: Insights from 2 Years of Data on 35 Production Sites in the Appalachian Basin

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1. Introduction

- Most methane emissions inventories for the oil and gas sector are built at the basin-level because it is hard to obtain enough measurements to accurately characterize emissions at smaller scales.
- However, regulatory (e.g., EU import rules) and voluntary (e.g., OGMP 2.0) programs increasingly want granular, site-level estimates of methane emissions that account for temporal intermittency.
- Continuous monitoring systems (CMS) provide high-frequency measurements of methane concentrations on individual oil and gas sites, making them well positioned to complement existing basin-level emissions inventories.
- **Here we synthesize over three years of methodological developments to produce 27 site-level, measurement-based emissions inventories in the Appalachian basin using CMS.**

2. Data

- CMS data were collected on 35 production sites in the Appalachian basin. Due to data quality issues (e.g., faulty sensors), we only analyze 27 of these sites.
- All 27 production sites are instrumented with point-in-space CMS, where sensors are mounted at specific locations around the perimeter of the site.
- Sensors record methane concentrations, wind speed, and wind direction every minute. Each site has between 3 and 9 sensors.
- Between 12 and 52 months of data were collected on each site. Across all sites, a total of 57 years of data were collected!

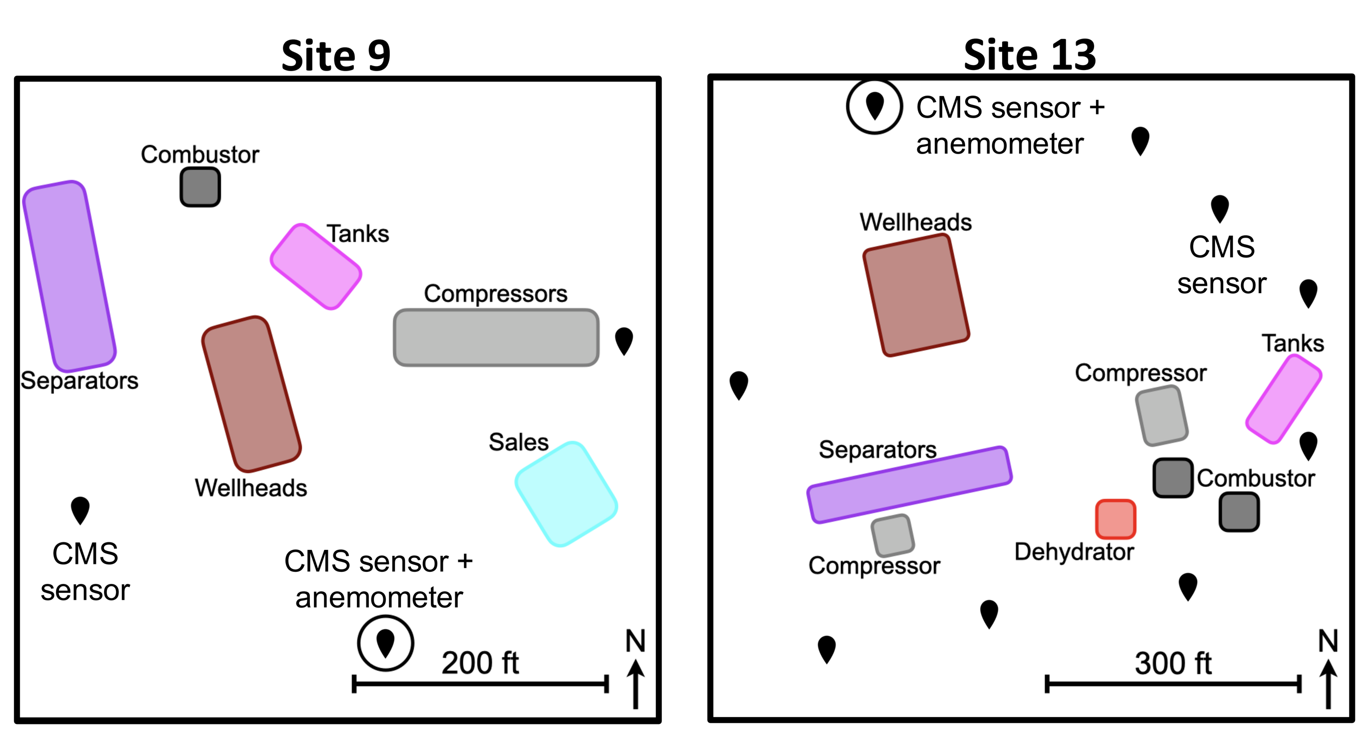


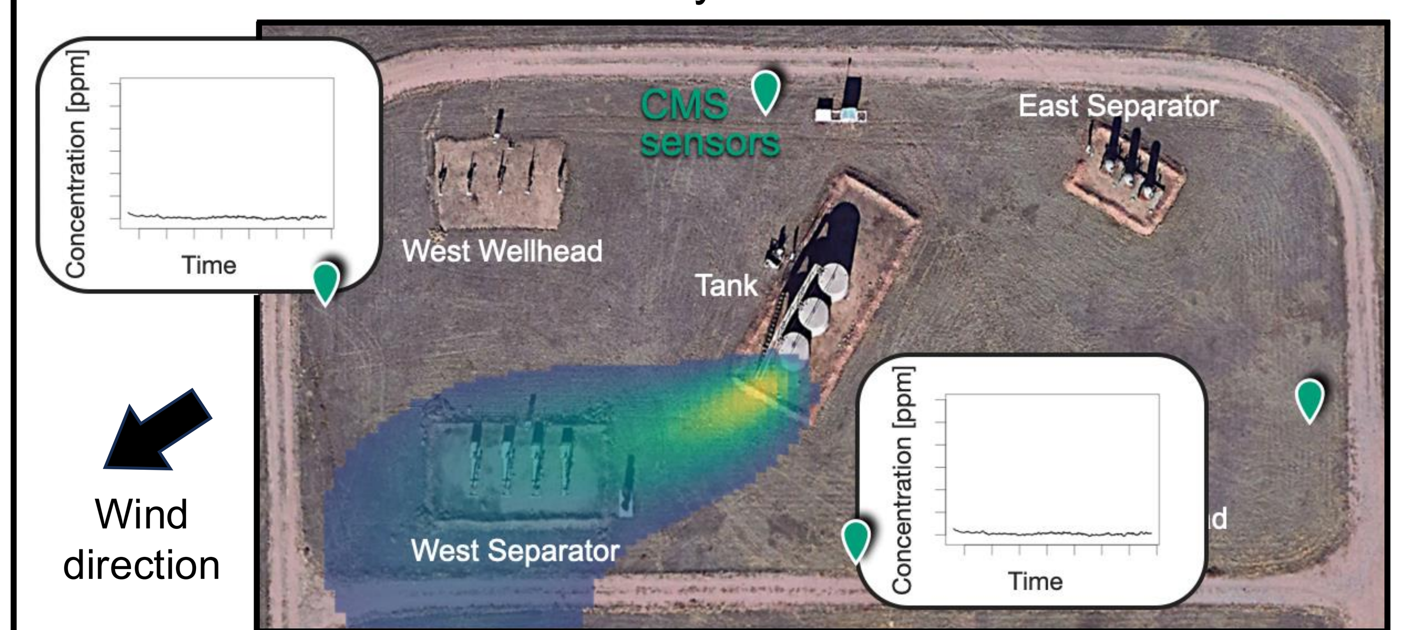
Figure 1: Schematic of two production sites analyzed in this study. Equipment groups are marked with color-coded rectangles. CMS sensor locations are shown with teardrop-shaped pins. All CMS sensors measure methane concentrations, and the circled sensor also measures wind speed and direction.

References

1. Daniels, Jia, and Hammerling (2024). Estimating methane emission durations using continuous monitoring systems. *Environmental Science and Technology Letters.* DOI: 10.1021/acs.estlett.4c00687
2. Daniels, Nychka, and Hammerling (2025). A Bayesian hierarchical model for methane emission source apportionment. *arXiv.* DOI: 10.48550/arXiv.2506.03395

3. Methods

Step 1: For each source, identify periods of "no information" where the wind does not blow towards any of the CMS sensors.



This situation cannot be interpreted as 0 kg/hr!

Paper on CMS information masking

Figure 2: Illustrative example of a "no information" period. During periods of no information, it naively appears as if no emissions are occurring. In this example, the CMS sensors only record background concentrations despite a tank emission.

Step 2: Run an inverse model during periods of information. Without an extremely dense sensor network, it is hard to parse out individual emission "events." Instead, run the inversion on fixed, independent intervals.

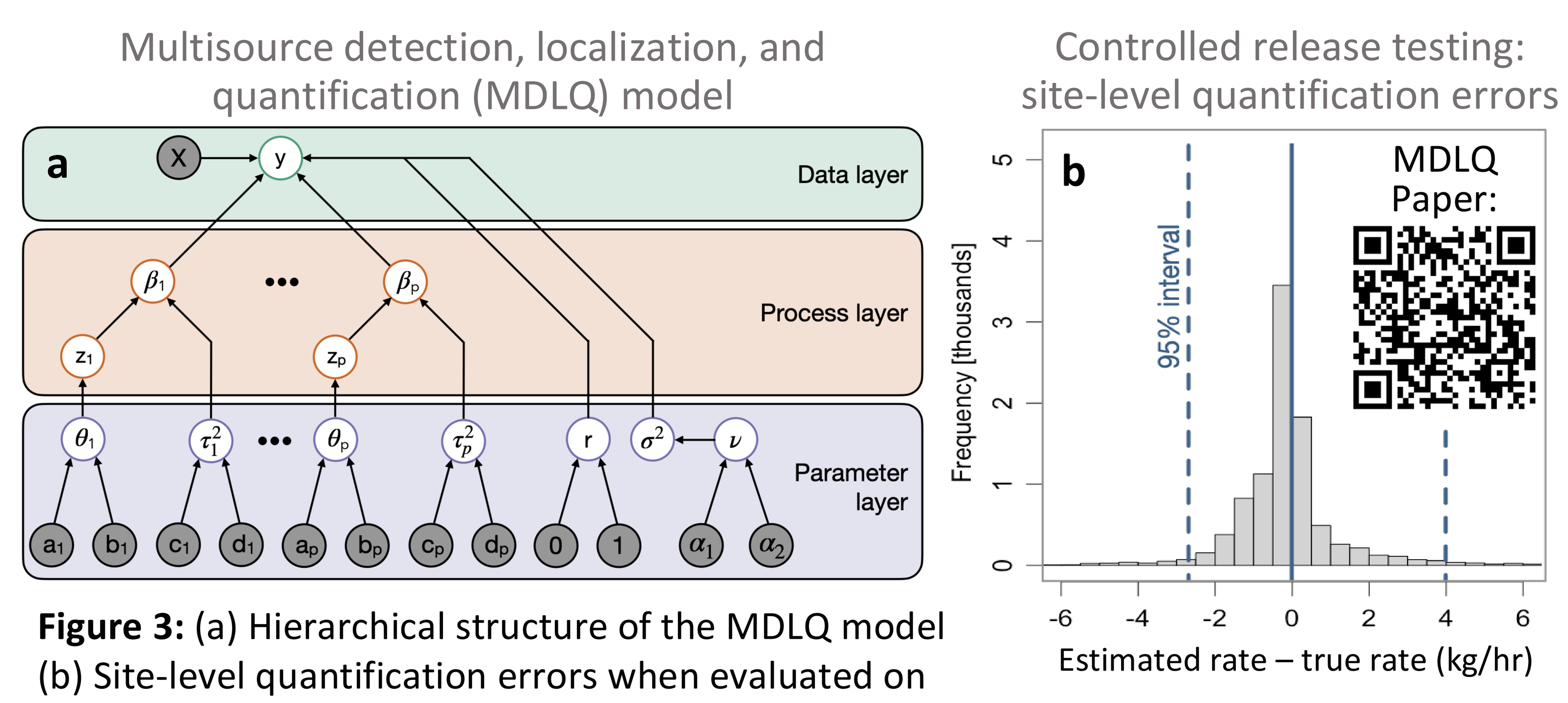


Figure 3: (a) Hierarchical structure of the MDLQ model (b) Site-level quantification errors when evaluated on multisource controlled releases at METEC.

Step 3: Calculate source-level average emission rates across periods of information. Averages must be taken over sufficiently long time periods to accurately characterize the true emission distribution. Averages can then be extrapolated over periods of no information and summed to the site-level to create an emissions inventory. For easier comparisons, we show average emission rates in the results section, not the extrapolated inventories.

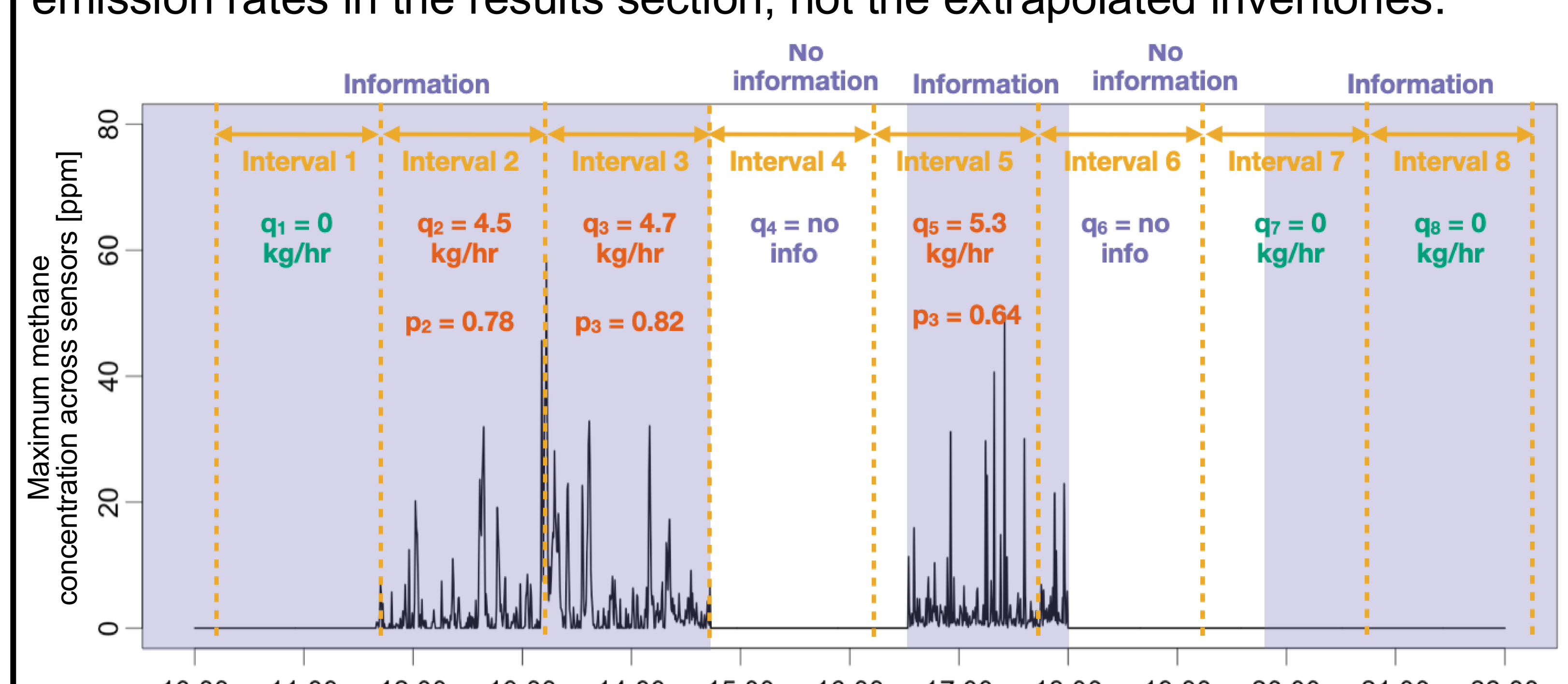


Figure 4: 12-hour example demonstrating periods of no information, no emissions, and non-zero emissions. Fixed intervals are overlaid on the CMS concentration observations.

4. Results

- Site-level monthly averages reveal seasonal trends and dominant sources.

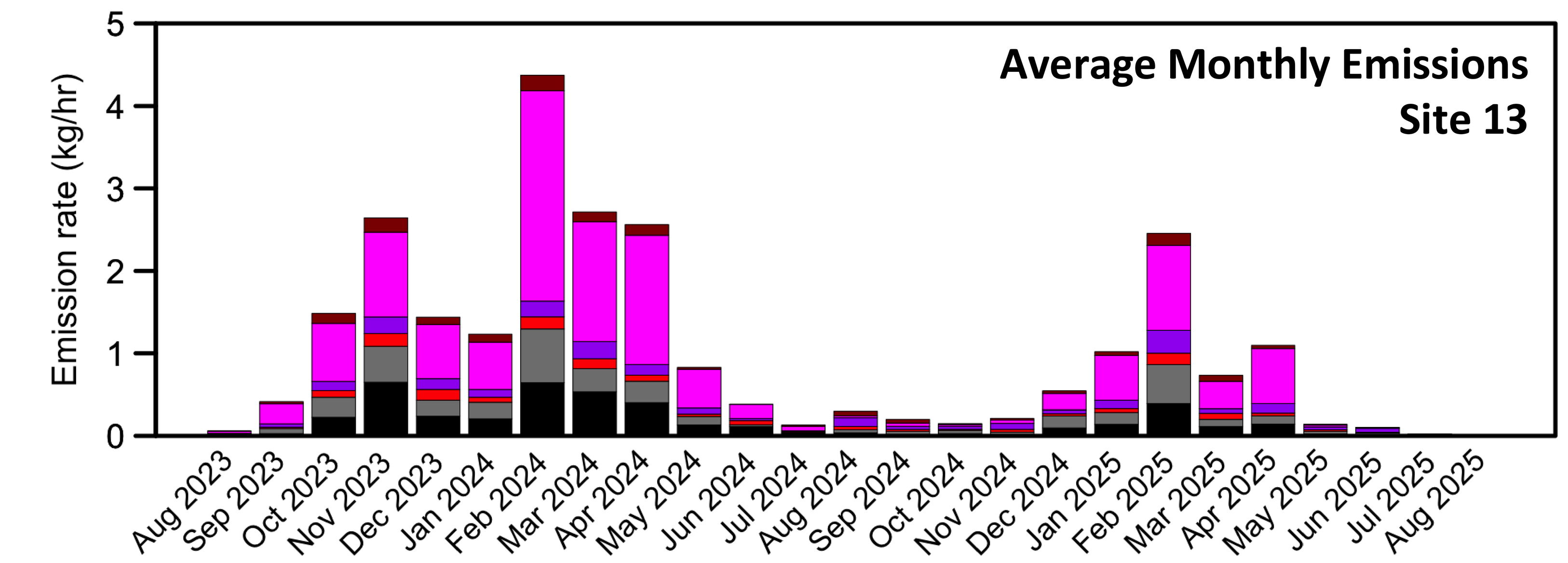


Figure 5: Average monthly emissions at a single oil and gas production site. Color corresponds to emission source (see Figure 6 legend for the key).

- Overall site-level averages reveal notable variation between sites.

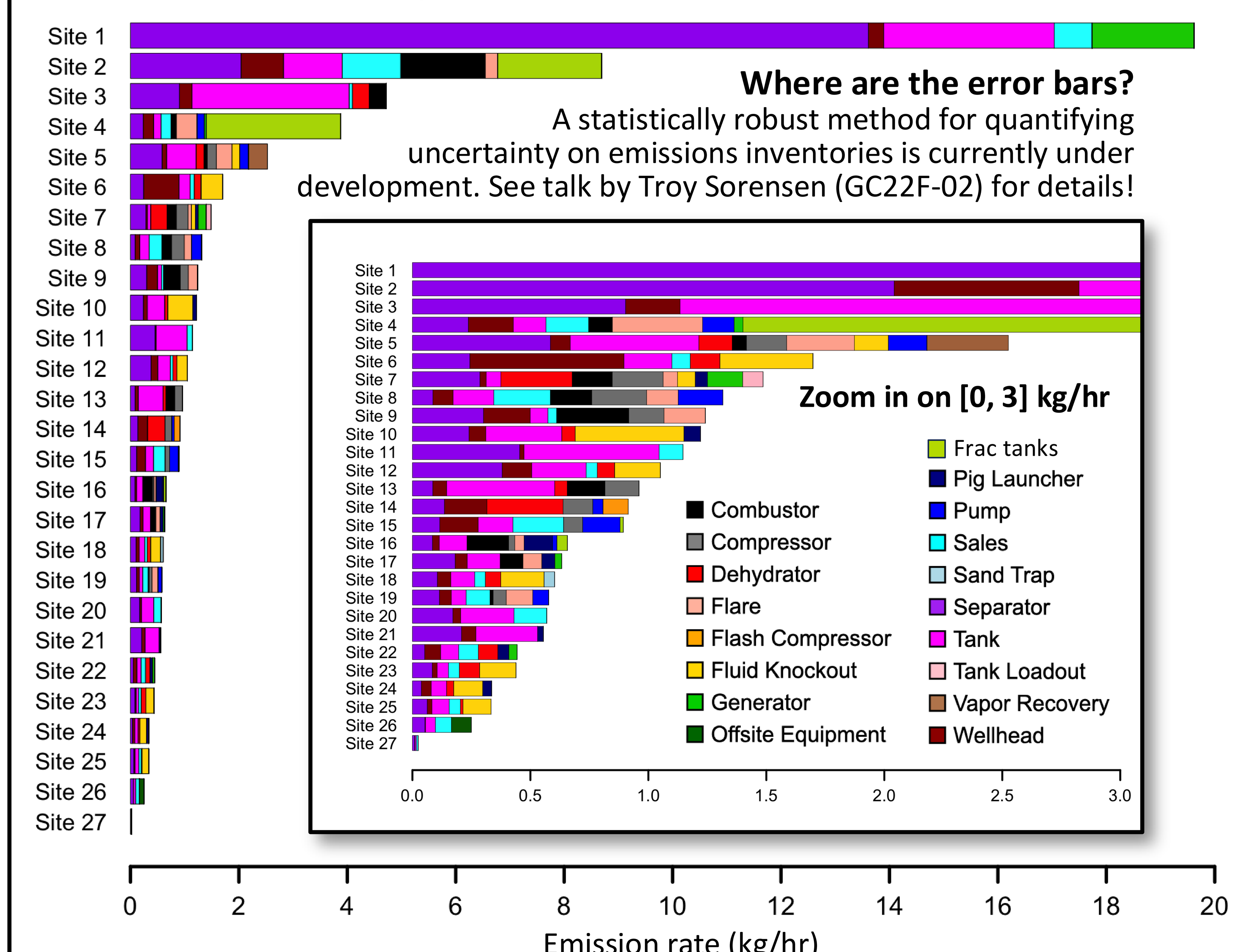


Figure 6: Average source-level emission rates for 27 oil and gas production sites. Average is taken across the full data record for each site, which ranges from 1 to 4 years.

Key Implications

1. *Continuous monitoring systems (CMS) can be used to create site-level methane emissions inventories that account for temporal variability.*
2. *Regulators can use long-term CMS inventories to revise emission factors for specific source types (e.g., tanks and separators), improving inventories on all sites, not just those with CMS.*
3. *Even a relatively small CMS deployment can identify high-emission seasons and site-types, enabling targeted deployment of other, more scalable, measurement technologies.*