Satellite analysis identifies 40% more methane from Australian coal mines

A collaborative satellite-comparison of Australia's coal mine methane emissions reveals higher greenhouse gases than officially reported.

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About

This report outlines the preliminary findings of a collaborative satellite analysis to estimate Australia's coal mine emissions for the 2020 and 2021 financial years. It utilised wind-rotation methods using TROPOMI satellite data across six clustered coal mining regions. These regions accounted for 79% of Australia's black coal production, and more than 90% of Australia's metallurgical coal production. The estimates are compared against state-level and national coal mine methane emissions from National Greenhouse Accounts.

Highlights

40%	2x	4-6x
Satellite estimates of Australia's black coal identified 40% more methane	Fugitive emissions in NSW were twice as high as official reporting, covering only half the coal	Emissions estimates from open-cut mines in NSW reduced by 4-6x following site-specific estimation shift

Executive summary

Satellite data shows 40% more emissions than national reports

Satellite examination of mines responsible for less than four-fifths of Australia's coal production found that these mines emit 40% more than Australia's reported total.

Australia's coal mine methane emissions reporting remains under a cloud of international scrutiny. Building on a body of nationally reported data, peer-reviewed satellite assessments, and independent estimates from Kayrros, Ember assessed coal mine methane emissions across six key coal mining clusters.

The preliminary results of this study, which cover approximately four-fifths of Australia's black coal production, indicate fugitive methane levels at least 40% higher than officially reported for the country as a whole. In New South Wales (NSW), which has largely shifted emissions reporting of open-cut mining towards company-led estimates, this study found fugitive emissions levels twice as high as officially reported, whilst only covering two-thirds of total coal production.

Critically, this study's areas included more than 90% of Australia's metallurgical coal production, indicating significant potential for emissions uncertainty within the key steelmaking coal supply chains.

> Australia’s coal mine methane emissions remain under a cloud of international scrutiny. These findings highlight that if we don’t improve reporting, not only could our own emissions accounting be inaccurate, but our international customers can’t know for certain what the scale of emissions lie embedded in their supply chains.

Christopher Wright
Climate Strategy Advisor, Ember

> Satellite estimates, including the one generated for this report, all point to the same finding: there is a significant gap between reported emissions and satellite-based estimates. It is crucial to close this knowledge gap to better understand where emission reductions can be made. Given methane's high global warming potential, improving reporting is essential for identifying and implementing effective mitigation strategies.

Sarah Shannon
Satellite Analyst - Coal Mine Methane, Ember

Key takeaways

01 **40% higher fugitive methane**

Satellite estimates, covering only 79% of Australia's black coal production, identified 40% more fugitive methane than officially reported in 2020.

02 **Twice NSW fugitive estimate**

State-based estimates of coal fugitives, covering 60 to 64% of the state's coal output, indicated methane levels 90% higher in 2020 and 106% higher in 2021.

03 **Metallurgical coal uncertainty**

These satellite estimates incorporate more than 90% of Australia's metallurgical coal production, indicating significant levels of emissions uncertainty could be embedded within international steel supply chains.

These preliminary findings come after a year-long national inquiry into methane measurement approaches, during which the government appointed an Expert Panel to provide advice on atmospheric measurement of fugitive methane emissions in Australia and has now initiated a departmental review of the impact of company-led emissions reporting.

This study highlights the critical nature of both reviews. It finds that without significant changes to Australia's existing coal mine methane reporting inventory, Australia's policymakers and international steel-making supply chains will remain in the dark about the total scale of Australia's coal mine methane emissions.

Satellite estimates indicate significant methane underestimate

Australia's coal mine fugitive emissions have come under intense international scrutiny over the past couple of years. A diverse array of international and peer-reviewed satellite estimates have identified considerably higher emissions from a range of underground and open-cut coal mines.

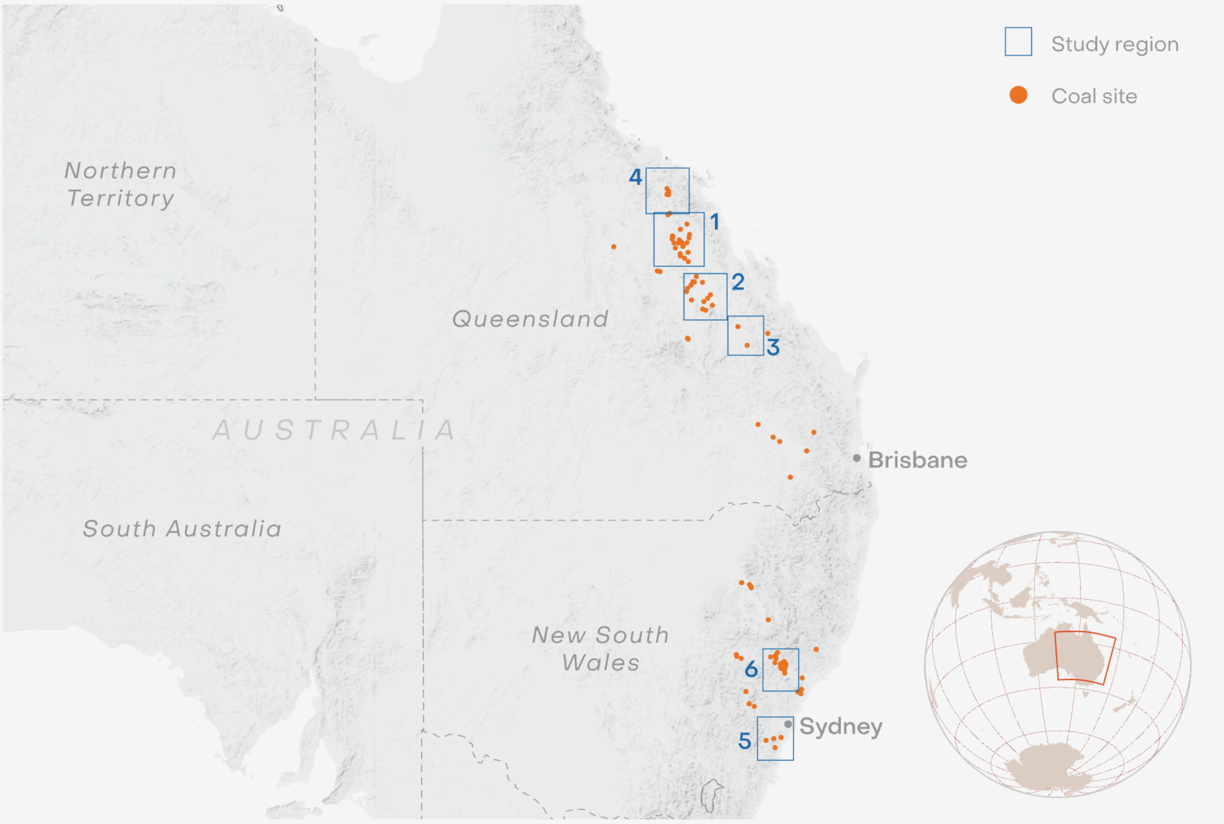
Following widely publicised research, the Australian government responded to these concerns through a year-long review of the national emissions reporting system. In its conclusion, the Climate Change Authority recommended a series of changes required to improve transparency, review measurement approaches, and integrate top-down emissions verification at coal mines across Australia.

Since then, preliminary findings from Open Methane utilising a combination of atmospheric modelling and satellite measurements have estimated that Australia's coal mines and gas fields may be emitting twice as much methane as currently reported. More recently, a numerical modelling re-evaluation of current approaches for estimating fugitive emissions at open-cut coal mines found that existing company-led approaches may be underestimating fugitive scope-1 emissions by a factor of 3.6 to 4.2.

Australia's coal mine methane emissions may be higher than official estimates

In this report, we contribute to the growing body of evidence through a satellite assessment of fugitive methane emissions from coal mines across New South Wales (NSW) and Queensland. The collaborative study with energy intelligence firm [Kayrros,](#) utilised TROPOMI satellite observations across six coal mining clusters while controlling for wind effects and non-fossil methane sources. The locations of the coal mining clusters are shown below.

Locations of study areas in Queensland and New South Wales

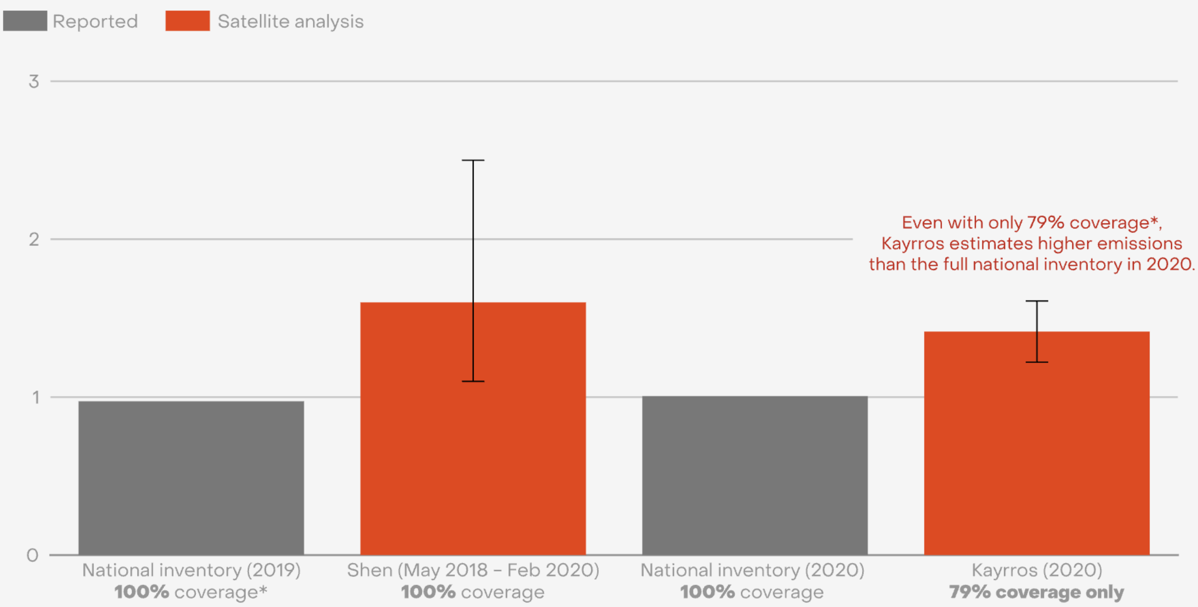


Source: Ember, Global Energy Monitor
The locations of operational coal mines are from the Global Energy Monitor, Coal Mine Tracker, release 2024

The study area covers 79% of Australia's total black coal production in 2020, and more than 90% of its metallurgical coal production that year. Of the six clusters, four were located in Queensland, incorporating 79% of the state's total black coal production and 97% of its metallurgical coal production. Queensland is the world's largest seaborne exporter of metallurgical coal, with significant exports into Asian and European markets.

Satellite estimates reveal that methane emissions from coal mines in Australia are higher than reported

Coal mine methane emissions (million tonnes CH4)



Source: National Greenhouse Accounts, Shen (2023), Kayrros estimates for Ember based on 6 coal mining clusters
*Australia's total coal production

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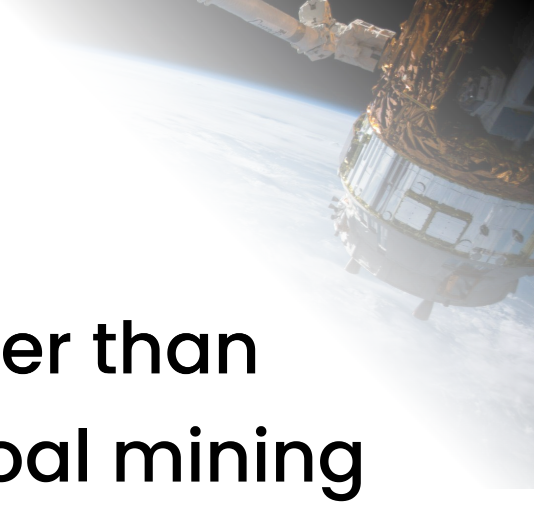
An additional two clusters were located in New South Wales across the Hunter Valley and Illawarra coal fields, covering 60 to 64% of the state's coal output and more than 70% of its metallurgical coal sales. As such, we expect that our results for both national and state-based emissions comparisons should be considered to be highly conservative. An in-depth description of the methods used to develop these estimates is in the supporting material.

Our satellite study has identified significantly higher coal mine methane emissions than reported nationally

According to preliminary findings from our study, satellite estimates across these six clusters identified a total of 1.42 ± 0.19 million tonnes of methane released from coal mines in 2020. This is significantly higher than the 1.01 million tonnes of methane that was officially reported by the National Greenhouse Accounts that year.

This estimate aligns with satellite results from Shen estimated that Australian coal mine methane emissions from May 2018 to February 2020 could be closer to 1.6 million tonnes annually. This was nearly 60% higher than the officially reported estimate of 0.974 million tonnes of methane in 2019. Despite slight differences in the study's time periods, this remains a significant discrepancy.

The study also seeks to compare these cluster-based satellite estimates to state-based emissions estimates, perhaps for the first time. The results for our limited area assessments, indicate that satellite estimates for both Queensland and NSW in 2020 are significantly higher than total reported coal mine fugitive emissions in both states. In NSW, an additional comparison for 2021 identified fugitive emissions levels more than twice as high as officially reported, while only incorporating half the state's coal production.



Chapter 2 | State-level CMM emissions

Coal mine methane higher than reported in both major coal mining states

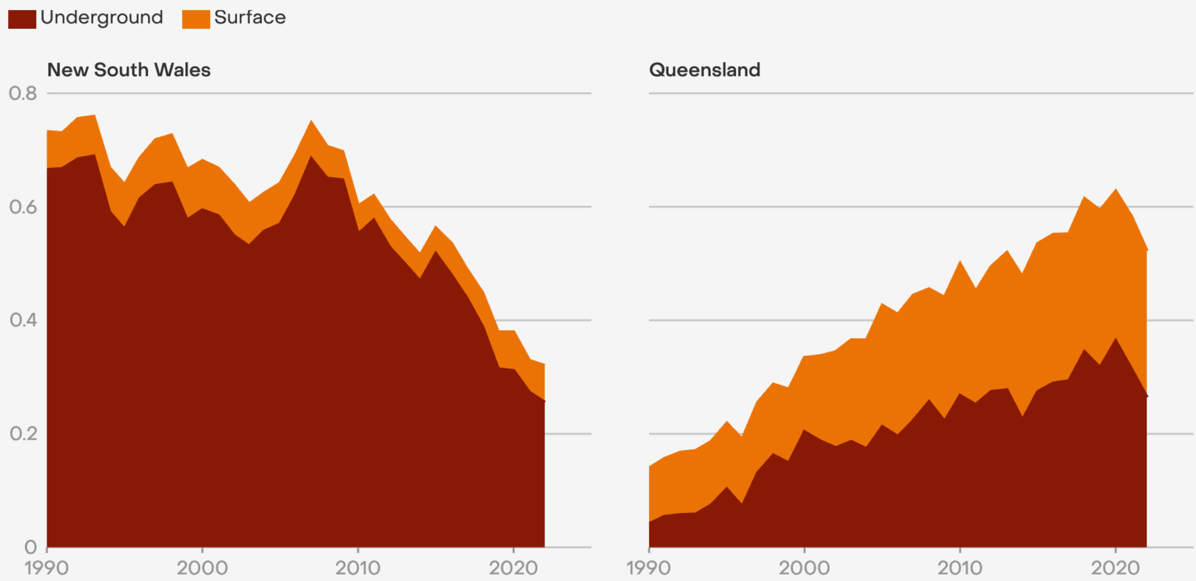
Queensland and New South Wales (NSW) are the two major coal producing states in Australia. Together they contribute more than 98% of Australia's black coal production and all of its metallurgical coal. Queensland is the largest coal producing state in Australia, averaging close to 313 Mt of coal per year between 2015 and 2020, while NSW has produced slightly less, at approximately 252 Mt per year over the same period.

Each state has a unique coal mine methane profile. Queensland recorded 626 kt of coal mine methane in 2020, with 58% of those emissions from underground coal mines and the remaining 42% from open-cut mines. This was the highest year on record for Queensland's reported coal mine methane emissions, having grown 6% higher than 2019, and more than 350% greater than 1990.

In contrast, 2020 was the third lowest year on record for officially reported coal mine methane emissions in NSW. The state recorded 379 kt of methane that year, followed by 339 kt in 2021. This was a significant shift, as emissions reported in 2020 were 40% lower than reported emissions in 1990, and 55% lower by 2021.

NSW's reported CMM emissions are declining while Queensland's are increasing

Coal mine methane emissions (million tonnes CH4)



Source: National Greenhouse Accounts

This was largely due to a significant emissions reduction from underground mines in NSW, which continue to make up more than 82% of all officially reported coal mine fugitive emissions. Fugitive emissions from underground mines had fallen by 53% in 2020 and 58% in 2021, compared to 1990 levels. This emissions reduction trend was largely due to the closure of older, gassier mines, and is further explored in an Ember report published earlier this year.

Open-cut coal mines represent 76% of all black coal production in NSW, but make up a much smaller share of total coal mine methane fugitives. In 1990, open-cut mines recorded 67 kt of methane, representing less than 10% of the state's total coal mine fugitives. By 2020, this relative share of coal mine fugitives had grown to 18%, but the total quantity of emissions recorded from open-cut mines had barely changed, recording 68 kt of methane that year.

In this study, we sought to undertake a preliminary verification of these officially reported fugitive emissions, and to provide what we believe is the first representative satellite estimate of coal mine fugitives in each state. Through our six clusters, we assessed four key coal mining areas across Queensland's Bowen basin. The average area of the four Queensland clusters was 16,661 km^2 and collectively incorporated 79% of the state's black coal production. Additionally, two clusters in NSW—incorporating the Hunter Valley and Illawarra coal fields—accounted for 60–64% of the state's coal production in 2020 and 2021, with an average cluster area of 10,341 km^2.

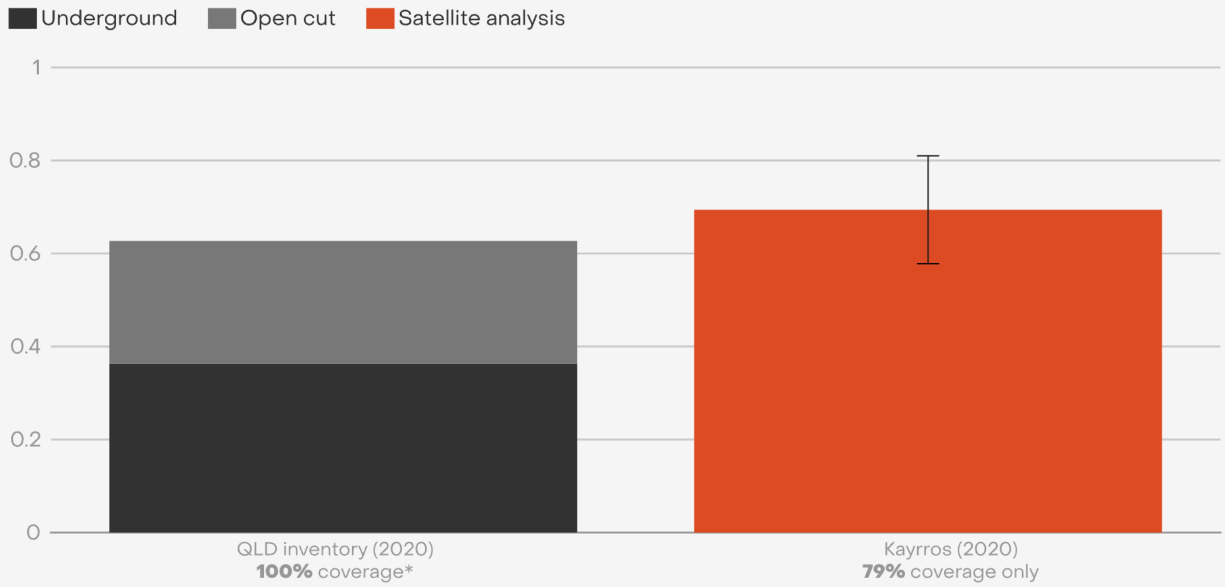
Operational oil and gas pipelines were found to cross through clusters in NSW and Queensland. Solid waste and landfill sites were also identified as potential methane sources in one cluster in NSW. A full explanation as to how uncertainty around methane sources was handled in this study is included in the Methodology section attached to this report.

Higher methane emissions identified in Queensland

Our TROPOMI-based satellite estimates reveal that methane emissions in Queensland could be significantly higher than reported. In 2020, Kayrros data indicate emissions of 0.69 ± 0.12 Mt methane—11% more than the total reported fugitive emissions from Queensland's coal mines—despite modelling only four sub-regions of the state. This result is consistent with two other satellite studies that also suggest underreporting at the mine level.

Queensland’s major coal mines may emit more methane than State's total reported emissions

Coal mine methane emissions (million tonnes CH4)



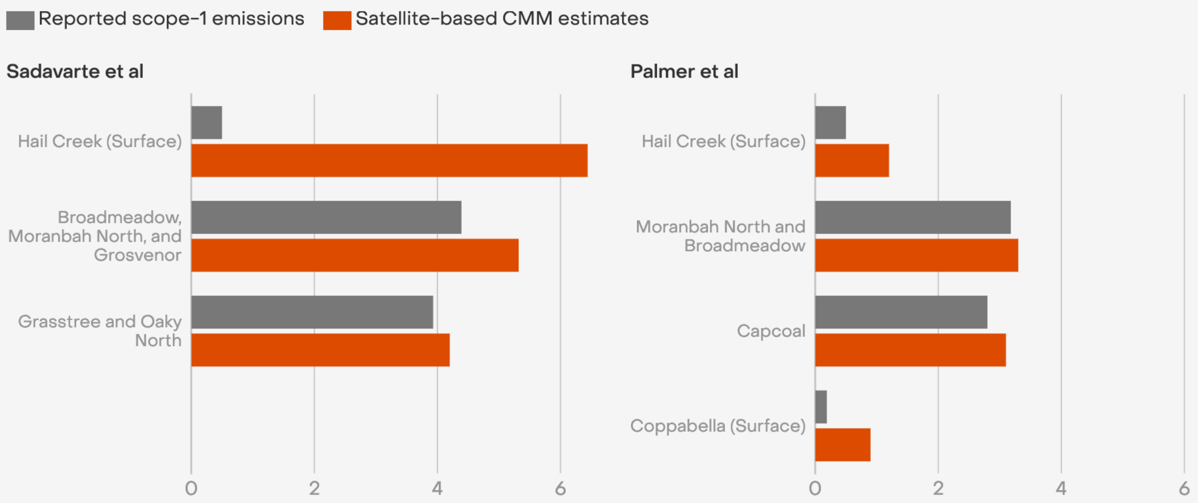
Source: National Greenhouse Accounts, Kayrros and Ember analysis
*Queensland's total coal production

Consistency in under-reporting across satellite studies

Several satellite-based studies have been conducted in the Bowen Basin, Queensland, using TROPOMI observations. In 2021, Sadavarte used TROPOMI data to identify methane emission sources between 2018 and 2019. Another study by Palmer also used TROPOMI to identify major emission sources for 2019. In both studies, satellite-derived emission estimates were higher than Scope 1 emissions reported by the identified sources.

Independent analysis has identified significantly higher fugitive methane emissions than currently estimated at surface mines in Queensland

Reported emissions and satellite-based CMM estimates (million tonnes CO2e)



Source: National Greenhouse and Energy Reporting (NGER), Palmer et al (2021), Sadavarte et al (2021)

Scope-1 emissions from coal mines include fugitive methane, diesel combustion and land clearing emissions. Satellite based estimates would only incorporate fugitive methane, which is estimated on surface mines.

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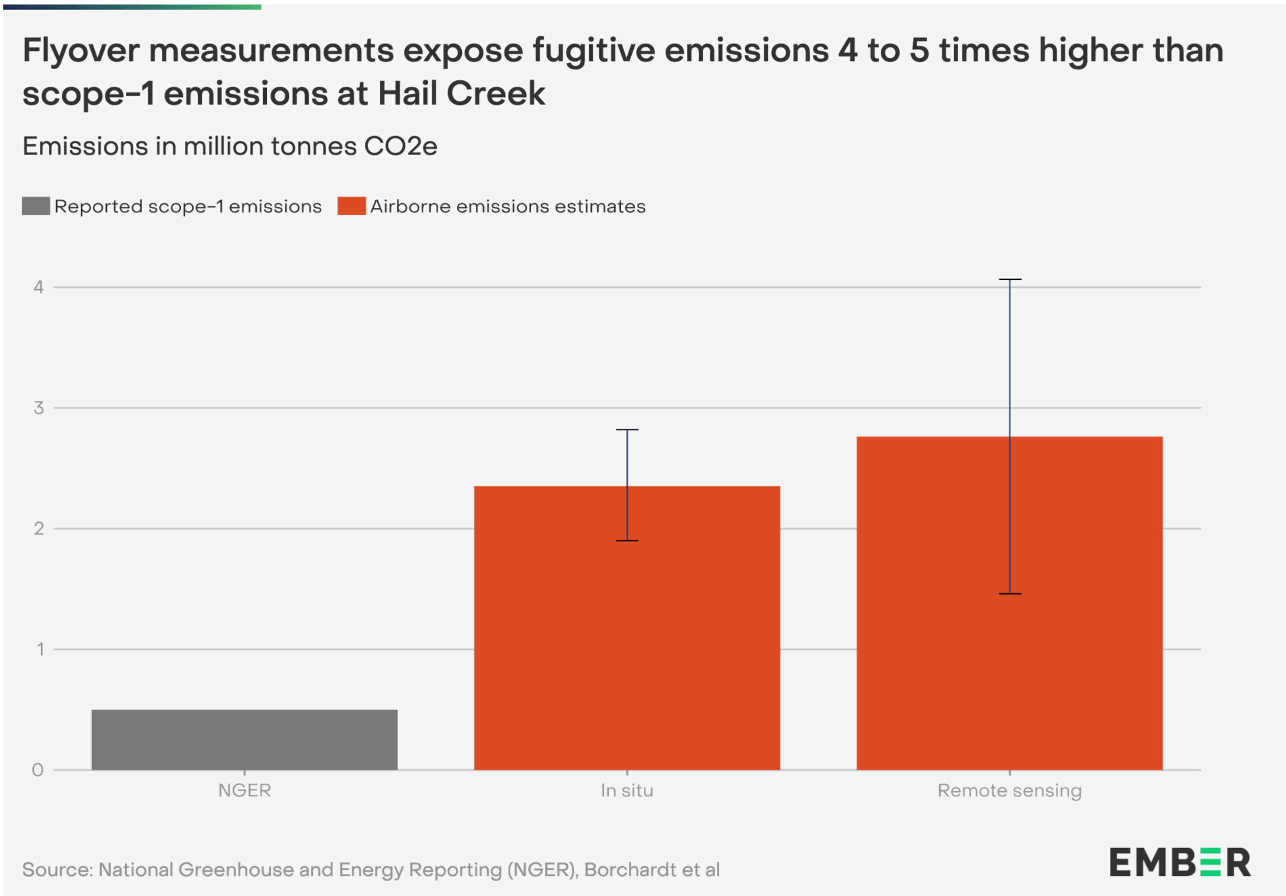
Sadavarte's study identified three major methane plume sources across one surface mine and two underground mine clusters. This includes (1) Hail Creek (surface), (2) Broadmeadow, Moranbah North, and Grosvenor, and (3) Grasstree and Oaky North. Total emissions from these sources were estimated to have reached 0.57 ± 0.098 Mt CH_4 per year, equivalent to approximately 15.96 Mt CO_2e. This is 80% higher than the total reported scope-1 emissions for these sites and is largely attributed to Hail Creek.

Similarly, Palmer identified four major methane sources: (1) Hail Creek (surface), (2) Moranbah North and Broadmeadow, (3) Capcoal, and (4) Coppabella (surface). The total emissions from these sources were estimated at 8.5 Mt CO_2e. This is equivalent to a 27% increase compared to reported scope-1 emissions, which includes not only fugitive emissions, but also the emissions from diesel combustion and land clearing.

Both studies highlight a significant discrepancy between reported and estimated emissions, particularly for surface mines. Emissions estimates using satellite analysis on Hail Creek are 2.4 (Palmer) to 12.9 (Sadavarte) times higher than reported values.

Aircraft measurements indicate under-reporting of methane emissions

Borchardt conducted airborne measurements in September 2023 over Hail Creek mine. During the flyover, the aircraft measured methane concentrations in two ways: direct sampling at the aircraft's location during flight and LIDAR mapping, which captured methane distribution at a high spatial resolution. Using these observations, they estimated methane emissions from the mine.



The results indicate that emissions were 4–5 times higher than reported, assuming they were representative of average operational conditions over the reporting period. Both methods produced comparable estimates, with direct measurements at 2.36 ± 0.46 $MtCO_2e$ per year and a slightly higher estimate from LIDAR mapping at 2.77 ± 1.30 $MtCO_2e$ per year.

These estimates fall within the range of satellite observations from 2018–2019, exceeding Palmer's estimate (1.20 ± 0.60 $MtCO_2e$) but remaining lower than Sadavarte's (6.44 ± 1.40 $MtCO_2e$).

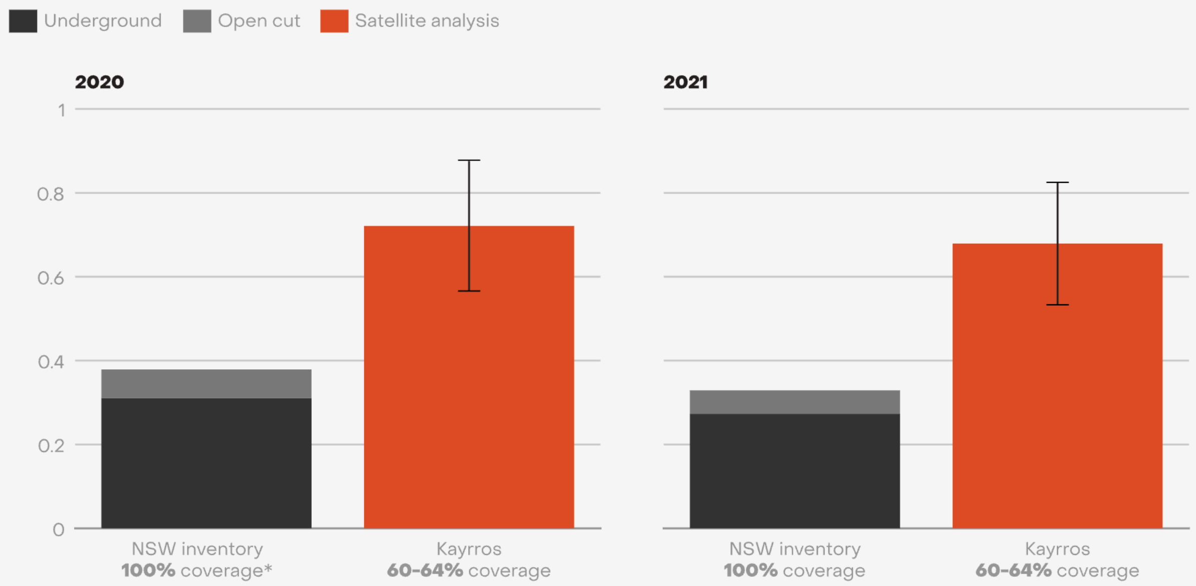
Two-thirds of coal production, double the emissions in NSW

Our findings in New South Wales (NSW) indicate a significant departure from officially reported emissions. While the state reported 379 kt of methane in 2020, our satellite study identified 721 kt of methane that year, while only accounting for approximately 61% of the state's coal production. While this estimate has an uncertainty range of 566 - 876 kt, this still represents a significantly higher figure than official reporting.

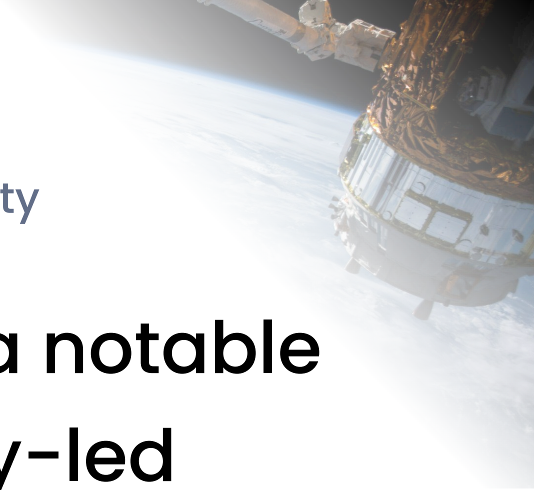
In 2021, our satellite estimate had a similar finding. While officially reported coal mine methane emissions dropped to 329 kt of methane, our satellite estimate identified 679 kt of methane with an uncertainty range of 533 - 825 kt of methane. This represents 106% higher emissions, while only capturing 64% of all coal production in the state that year.

Satellite estimates covering half of New South Wales coal production accounts for double reported fugitive emissions

Coal mine methane emissions (million tonnes CH4)



Source: National Greenhouse Accounts, Kayrros and Ember analysis
*NSW's total coal production. The study area covers the Illawarra and Hunter Valley coal fields.



Satellite analysis shows a notable difference from company-led estimates

Satellite emissions estimates indicate an increase in fugitive emissions from open-cut coal mining, contrasting with a decline in officially reported company-led emissions estimates.

Background

Open-cut coal mines in Australia do not measure their fugitive methane emissions. Instead, their emissions estimates are modelled on bore-hole coal samples to derive a fugitive emissions factor that is then multiplied by annual coal production. Due to the complexity and variability of gas sampling, this approach was first developed at the state level in 1991, with specific emissions factors applied for New South Wales (NSW) and Queensland in 1993. These state-based emissions factors are known as Method 1, under the National Greenhouse and Energy Reporting Scheme, and have been periodically reviewed, to align with a larger sample size and improved scientific understanding of the warming impact of methane on the atmosphere.

In the late 2000s, the Australian Coal Industry's Research Program (ACARP) began working on a methodology for developing an approach to estimating fugitive methane emissions that individual companies could implement in a site-specific manner. This site-specific approach was first implemented in 2011, and is known as Method 2, under the National Greenhouse and Energy Reporting Scheme. Since that time, open-cut mine owners have been able to individually choose to estimate the methane content of their facilities using pre-existing state-based averages, or to individually collect as few as three borehole samples from their own mine, and develop a facility-level 3D model to estimate emissions during production.

In 2023, the Climate Change Authority estimated that 75% of currently reported coal mine methane emissions from open cut coal mines in NSW currently utilise Method 2. In contrast, only 25% of fugitive emissions from open cut coal mines in Queensland were estimated to be using Method 2.

Earlier this year, Ember's assessment of company-led methane estimates highlighted that the shift from state-based to site-specific emissions estimates has consequentially seen a significant reduction in officially reported emissions among the vast majority of mines utilising this methodology. This builds on research from energy insights firm Reputex, which estimates that the shift towards company-led estimates has consistently decreased reported fugitive methane emissions reporting by 65 – 70%.

The impact of Method 2 in NSW

The influence of this reporting shift is especially poignant in NSW. In 2023, the official state-based emissions factor for NSW was 0.061 tonnes of methane per tonne of coal (t CO2-e/t ROM). In Queensland, the equivalent emissions factor was increased in 2023 from 0.023 to 0.031 t CO2-e/t ROM. As such, coal mines in NSW have had a much higher official state-based emissions factor as their respective baseline, and far more coal mines have selectively adopted a company-led, site-specific emissions factor.

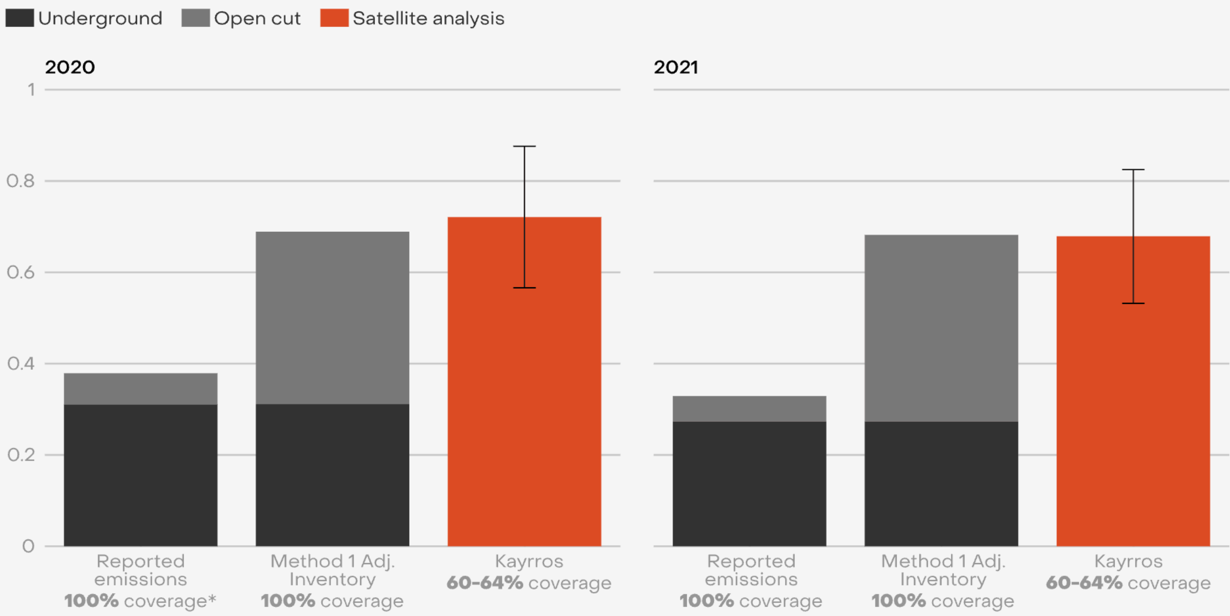
In 2023, the Climate Change Authority estimated that 75% of currently reported coal mine methane emissions from open-cut coal mines in NSW were quantified using this site-specific approach known as Method 2. In Queensland, with a state-based emissions factor that has only recently risen to half the level of NSW, only 25% of all open-cut fugitive emissions are estimated to have been quantified using Method 2.

Reconstructing Method 1 emissions estimates in NSW

In this study, we sought to identify the potential implications of shifting away from state-based emissions factors in NSW by reconstructing the estimated fugitive emissions from open-cut mines and comparing them to our satellite estimates. To do so, we multiplied the state's open-cut coal production by the state-based emissions factor for fugitive emissions, and added this to the officially recorded fugitive emissions from underground coal mines in 2020 and 2021. We then compared this adjusted emissions inventory to the official emissions inventory for all coal mines, and our satellite emissions estimate below.

Satellite analysis suggests a significant impact of Method 2 on open cut fugitive emissions accuracy

Coal mine methane emissions (Million tonnes CH4) in NSW



Source: National Greenhouse Accounts, Kayrros and Ember analysis
*New South Wales's total coal production.
The study area covers Illawarra and Hunter Valley coal fields only.

In Method 1 adjusted inventory scenario, open cut coal fugitive emissions are estimated using NSW state-based emissions factor for that year.

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The result of this reconstruction indicates that our satellite emissions estimates, covering only 60% to 64% of NSW's coal production, have identified fugitive emissions 90% greater in 2020 and 107% higher than reported emissions in 2021. This shows a closer correlation to total estimated emissions from our adjusted Method 1 inventory reconstruction in both years, however, this reconstruction represents potential fugitive emissions from all coal mines across the state, not just those within our satellite study area.

Ongoing Review

This site-specific approach has now been made compulsory for open-cut mines under the Safeguard Mechanism producing more than 10 million tonnes per year, and will become industry standard in 2026 for all Safeguard reporting coal mines. It is currently under federal review "to ensure the method remains fit for purpose". The review is expected to reach its conclusion later this year.

Integrating satellite estimates as a key tool for verification

Estimating methane emissions using satellites requires selecting diverse data sources and modelling methods, taking into consideration spatial and temporal coverage.

The preliminary findings presented in this research highlight the potential value of incorporating satellite estimations within both national and subnational emissions verification processes. This is a necessary addition to Australia's existing emissions quantification approach, which still relies primarily on bottom-up emissions estimates for most of the country's coal production.

This is an especially pertinent consideration for Australia's upcoming Expert Panel on Atmospheric Measurement of Fugitive Methane Emissions, as they consider the potential role and utility of satellite emissions estimations.

Canada uses satellite-based emissions verification

Incorporating satellite-based estimates as a top-down verification tool, without attributing emissions to individual facilities, presents significant challenges. However, it is not an unprecedented approach, and has proven to be a valuable addition to Canada's emissions inventory. Canada has progressively integrated this approach into its emission reporting inventory for its resources sector, following the principle of "continuous improvement".

This principle allows for incremental advancements in accuracy and effectiveness, especially when estimating fugitive emissions from an individual sector. As such, Canada has adopted a hybrid emission reporting framework, incorporating an ensemble inversion top-down method with tower-based atmospheric measurements to independently verify bottom-up facility reporting.

Despite its challenges, satellite data provides a broader, more comprehensive view of emissions, helping to identify discrepancies, monitor trends and support policy decisions aimed at reducing greenhouse gas emissions. By enhancing the overall emission measurement system, this approach complements other methods, contributing to more robust and transparent environmental oversight.

TROPOMI as an effective tool for satellite verification in Australia

There is a large amount of freely available satellite data on open platforms such as the IMEO's Methane Alert and Response System, Carbon Mapper and Kayrros Methane Watch. These platforms provide emissions data at the precise moment a satellite passes overhead. While useful for identifying methane hot spots and leaks, these collective datasets still lack the frequency of coverage needed for a direct comparison or quantification of annual emissions reports.

Assessing coal mine methane emissions at a national or basin-level requires satellite coverage over large regions with frequent and repetitive overpasses. The TROPOMI satellite instrument used in this study provides unique, global daily coverage of methane concentrations. As such, it is widely used in similar studies aiming to quantify and verify global and country level methane inventories.

The TROPOMI satellite is an area concentration mapper, measuring methane over large regions at high temporal frequency. This is in contrast to point-source imagers which detect methane at the facility level, and offer much finer spatial resolution but require targeted observations. This presents a critical trade-off between point-source imagers with higher-resolution and infrequent data in comparison to area mappers, with lower resolution with frequent coverage.

TROPOMI's spatial resolution is 7 km × 5.5 km, which is limited in its ability to detect methane emissions from individual coal mines, but can be used to effectively verify emissions across clustered areas, as has been shown in this study. Despite these limitations, we believe that the TROPOMI satellite is an effective tool for comparing satellite-derived methane estimates with reported emissions data, and could be readily incorporated within Australia's fugitive emissions inventory.

Fortunately, Australia offers some of the most favourable conditions for satellite methane monitoring, with relatively clear skies and bright, flat surfaces. Data coverage from TROPOMI can be affected by environmental conditions, such as cloud cover, mountains and surface brightness, but a recent study by Ember estimated that 91% of Australia's annual coal production occurs in regions well-suited for methane monitoring.

Spatially distributed methane inventories are needed to facilitate comparisons with satellite estimates

Detailed location-based emission data is useful when comparing satellite measurements to reported emissions. This is because many studies, like the Kayrros analysis in this report, focus on specific areas rather than the entire state or country.

In Australia, emissions are reported as methane at the state level, but at the mine level, they are reported as CO2-equivalent (CO2e) under the Safeguard Mechanism. CO2e includes a combination of carbon dioxide (CO2) and methane

(CH4), so assumptions are needed to estimate the methane fraction from the total CO2e value.

This challenge is the motivation to create spatial maps of reported coal mine methane emissions specifically for comparison to satellite estimations. Fortunately, starting in April 2024, the Safeguard Mechanism will release reported methane emissions as methane quantities rather than CO2e. This type of spatial information on reported emissions will make it easier to compare satellite estimates, though significant uncertainties will likely remain.

A hybrid approach needed to approve accountability

Satellite emissions verification highlights a considerable gap in Australia’s existing emissions measurement regime.

Australia’s current method for measuring coal mine methane emissions urgently requires verification. The satellite analysis outlined in this, and previous studies indicates that coal mine methane emissions could be considerably higher than reported at both national and subnational levels. Through an analysis of TROPOMI data across 2020 - 2021 financial years, we have identified significantly increased fugitive methane levels across key coal mining clusters in both NSW and Queensland.

Our cluster-based analysis covered only 79% of Australia’s black coal production, but identified 40% more fugitive methane than officially reported in 2020. The study’s areas included more than 90 per cent of Australia’s metallurgical coal production, indicating significant potential for emissions uncertainty within the key steelmaking coal supply chains, including within the EU. The fugitive emissions uncertainty outlined in this study highlights a potential risk for Australian metallurgical exporters seeking sustained access to European markets in particular.

At a state level, we identified emissions levels twice as high as official reporting in NSW across both 2020 and 2021. This indicates a significant discrepancy between atmospheric measurement-based estimates and emission inventories that is especially relevant for upcoming DCCEEW departmental reviews of site-level facility emissions estimations (Method 2) and Australia's Expert Panel on Atmospheric Measurement.

While only a limited number of source areas were considered, we believe the approach presented in this initial study represents an opportunity for further consideration and potential incorporation within Australia's emissions inventory. By incorporating satellite data, such as the TROPOMI analysis outlined in this study, Australia could identify discrepancies in existing emissions reporting methodologies and actively monitor long-term trends without needing to punitively assess individual facilities.

A hybrid approach, integrating additional top-down satellite or aerial emissions measurements, could enable DCCEEW to pinpoint potential hotspots for further investigation, complementing ground-based measurements and enhancing the accuracy and transparency of emissions data. This would progressively build trust in Australia's fugitive emissions measurement approach, improve regulatory oversight and support more effective policy decisions. Ultimately, it would help Australia reduce coal mining emissions in line with climate goals, fostering greater accountability and strengthening emissions tracking for more robust environmental oversight.

Methodology

Estimating methane emissions from TROPOMI observations

This is a technical description of the method used to estimate coal mine methane emissions from TROPOMI observations. It applies the wind rotation technique to enhance the visibility of the concentrations and uses both the cross-sectional flux (CSF) and integrated mass enhancement (IME) approaches to quantify emissions over six coal mine clusters. A similar approach was used by Schneising et al (2020) using CSF.

The method is used to estimate annual methane emissions for six coal mining regions in Australia from January 2019 until December 2023. Emissions are calculated for both the calendar year and the financial year (July 1 to June 30), as Australian reporting standards follow the financial year timeline. The modelling work was carried out by environmental intelligence company Kayrros.

Wind rotation method

The wind-rotation method consists of rotating the Sentinel-5P TROPOMI L2 CH4 V02.05.00 images over an area in the direction of the ERA5 wind, so that the wind blows southwards. In July 2022, TROPOMI released newly reprocessed data for its Sentinel 5P images. However, this study incorporated only the previous release of reprocessed products to ensure consistency. This process forces the methane plume to move in a specific direction (in our case south) from the centre of the image. Rotating all the TROPOMI images over a year allows us to average them, in order to obtain a mean plume for the area of interest (AOI). By leveraging the high temporal resolution of Sentinel-5P, this approach enhances the signal-to-noise ratio of TROPOMI data and thus, helps distinguishing the methane plume from its background more easily.

The procedure starts with image filtering, retaining only those with a high percentage of valid pixels following the recommendations from the Sentinel-5P user guide. Specifically Kayrros incorporated TROPOMI pixels with qa_value equal to 40 and 100.

Then, TROPOMI images are oversampled, taking advantage of shifts in satellite orbits from day to day resulting in partial overlap between pixels. The next step involves finding the optimal rotation point to identify the methane emission source within the AOI. To achieve this, wind-rotation is evaluated on a dense grid of rotation points encompassing the whole area. By finding which rotated average shows the largest downwind enhancement, it is possible to pinpoint the optimal rotation point within a few kilometres.

To reconcile the wind direction with the methane propagation direction, an artificial correction is applied to the hourly ERA5 100m wind speed. This correction involves determining the delta angle that, added to the wind direction, best aligns with a simulated Gaussian plume-oriented southwards. After subtracting the mean background upwind of the source, we have a time-averaged plume of the area for the period.

Emissions quantification

The plume mask is computed statistically, considering the methane plume as an outlier in the enhancement image. The CSF and the IME methods are then employed to estimate the methane flow rate based on the masked enhancement image and the mean wind over the period. The uncertainty in emissions (error bar) is calculated using the range of emissions calculated by the two quantification methods.

Modelling assumptions

Several assumptions were made for this modelling work.

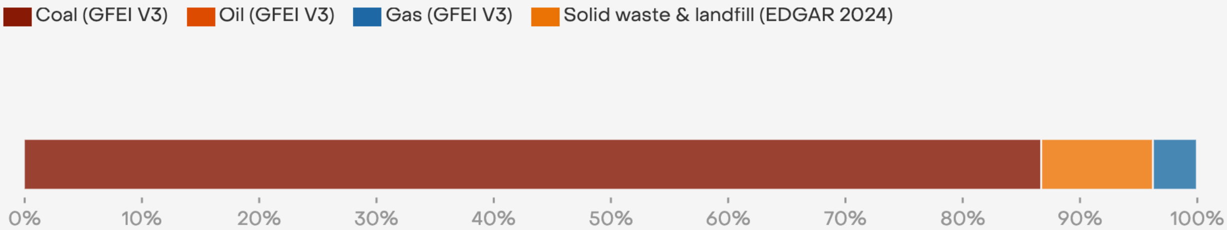
Assumption 1. The dominant methane source in the clusters is from coal mining

Operational oil and gas pipelines were found to cross through clusters 1, 3, 4, and 5, as identified by overlaying data from the oil and gas database onto the cluster regions. The assumption is that any leaks from these pipelines would be short-lived and unlikely to significantly affect the mean-averaged plume. It is assumed that agricultural emissions are generally too diffuse to be detected by TROPOMI.

Gridded emissions inventories for 2020 estimate that the majority of methane emissions, (87%) originate from coal. This is illustrated below, where emissions within the cluster regions are summed using data from the Global Fuel Exploitation Inventory (GFEI) v3 and EDGAR 2024 solid waste and landfill data.

Coal is the dominant methane source in the study regions

Methane sources over the study region for the year 2020, derived from gridded inventories



Source: Coal, oil and gas emissions are from the Global Fuel Exploitation Inventory (GFEI) v3 , Solid waste and landfill emissions are from EDGAR 2024

Oil emissions were estimated at 0.4 kt/year CH4, less than 0.001%

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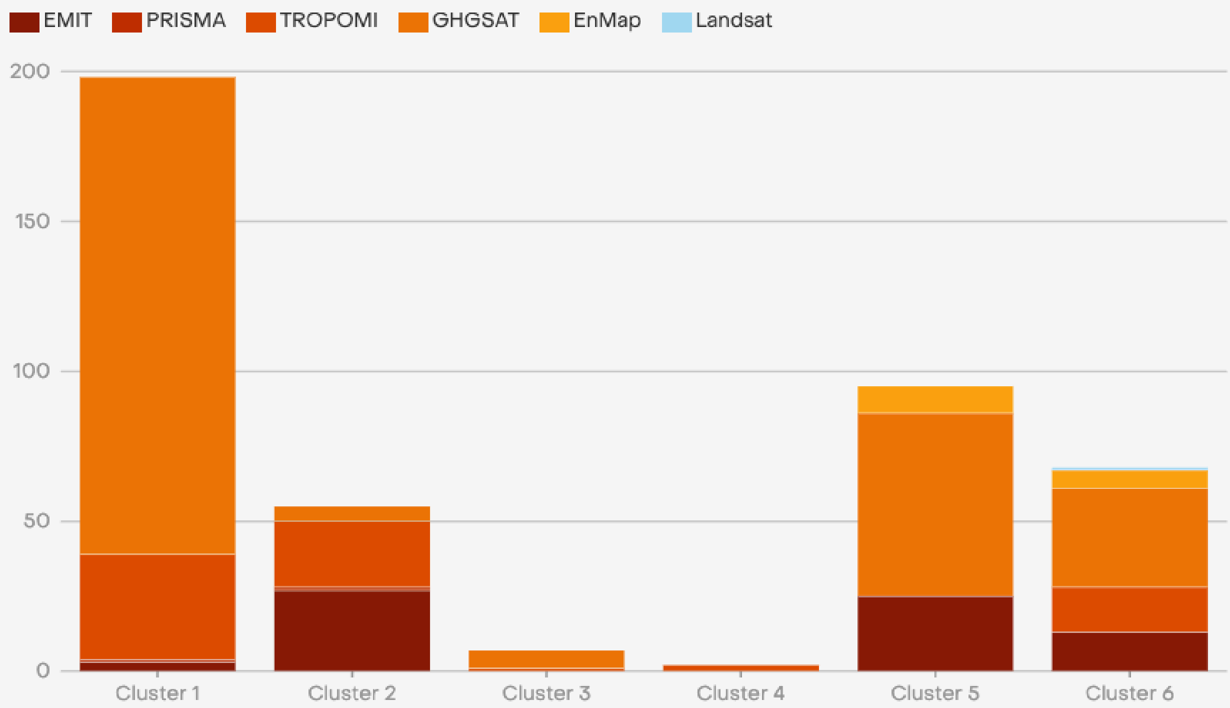
While the inventories indicate small methane contributions from gas and landfill overall, satellite detections over the cluster regions show that major emissions events within the clusters are exclusively from coal. Analysis of point-source emissions data from both open and commercial providers confirms that all detected emissions within the cluster boundaries are attributed to coal mining.

We aggregated emissions data from Kayrros Methane Watch, the Methane Alert and Response System (MARS), and Carbon Mapper. These detections come from a range of satellite sensors, including TROPOMI, PRISMA, EMIT, EnMap, and Landsat. GHGSat data was provided to Ember through the UK Space Agency Catapult programme. In total, 425 methane detections were identified, all of which were attributed to coal mining, with none linked to gas infrastructure or landfill sites.

However, within specific clusters of this study's focus, gas and waste have the potential to influence our findings within clusters 3 and 5. This study was not able to conclusively rule out or estimate the potential influence of these emissions sources.

All satellite-detected methane emissions inside six Australia's cluster regions are attributed to coal mining

Number of emissions observations



Source: Open data from Kayrros Methane Watch, Methane Alert and Response System and Carbon Mapper (accessed 11/03/2025). GHGSAT data provided though the UK Space Agency Catapult project (accessed 23/09/2024).

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Assumption 2. There is no transport of methane into the clusters from sources outside the clusters

To minimize interference from methane emissions coming from neighbouring assets, images with wind directions aligned with nearby sources are filtered out.

Assumption 3. The wind rotation method, often used for smaller regions, can be applied to these large clusters

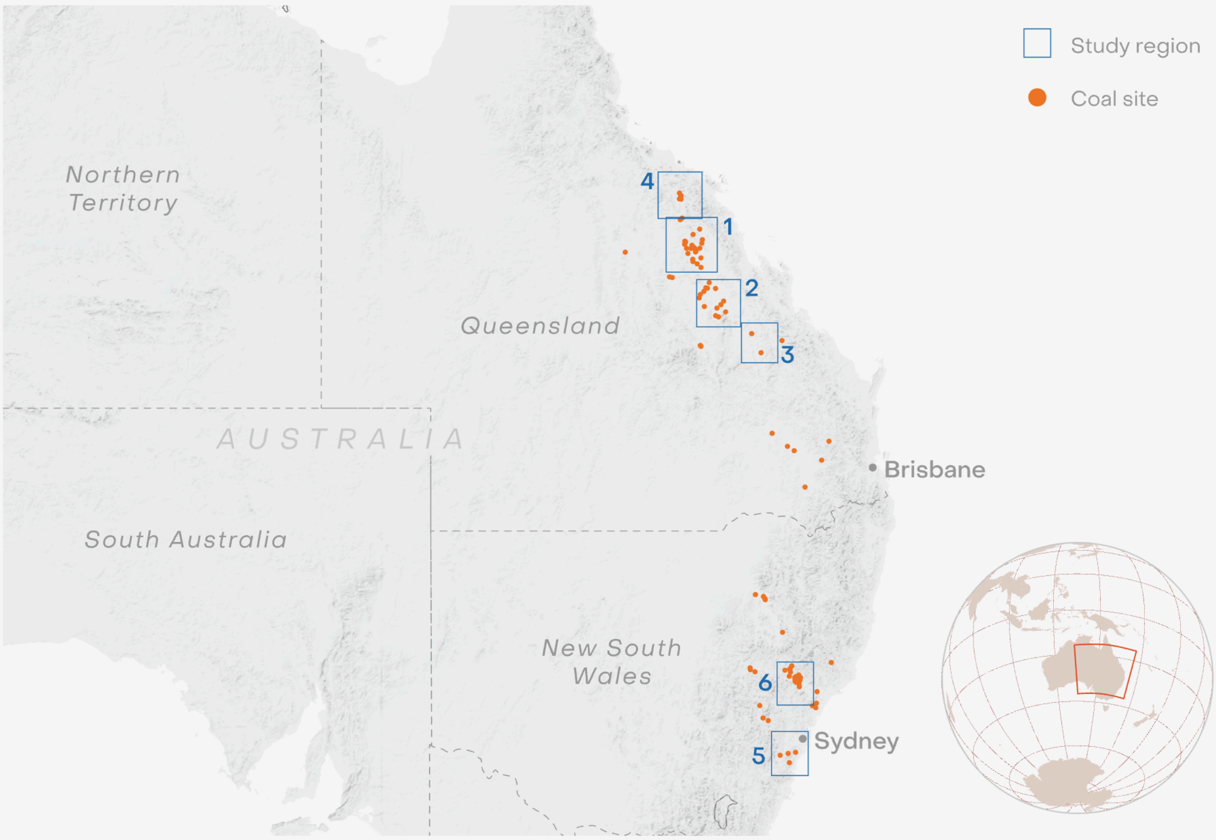
Traditionally, CSF and IME methods have been used for individual plume quantifications. This analysis applies these methods to emissions from larger regions. A similar approach was used by [Schneising et al (2020)](#) using the CSF method to study emissions over oil and gas basins. Our analysis assumes the IME method is also appropriate over larger scales.

Cluster selection

The six clusters were selected for study because they represent regions of intense coal mining, and account for approximately 90% of the country's metallurgical coal production.

Four clusters are modelled for Queensland, accounting for 79% of coal production in the state. Two clusters are selected for New South Wales which covers 60 to 64% coal production in the state.

Locations of study areas in Queensland and New South Wales



Source: Ember, Global Energy Monitor
The locations of operational coal mines are from the Global Energy Monitor, Coal Mine Tracker, release 2024

TROPOMI data coverage

TROPOMI data coverage over Australia is generally good in contrast to other regions, as demonstrated by Gao (2023). This is largely due to low cloud cover and the presence of flat reflective surfaces, which create favourable conditions for satellite detection. A study by Ember also showed that environmental conditions in Australia are favourable for satellite-based methane monitoring. The study estimated that 91% of coal production occurs in regions well-suited for satellite monitoring.

Despite this, cloud cover did impact the number of images required to estimate emissions at some of the clusters during some years (see table below). This limited the comparison of satellite estimates with national reported values to the financial year 2020 where all six clusters are modelled.

In Queensland, a comparison with state reported data was possible for the financial year 2020. In New South Wales, it was possible to compare satellite emissions to state reported data for the financial years 2020 and 2021.

Assessment period of satellite analysis

Number of satellite images

Clusters	State	FY2020	FY2021	FY2022	FY2023
Cluster 1	QLD	121	97	95	78
Cluster 2	QLD	122	108	98	95
Cluster 3	QLD	122	104	87	72
Cluster 4	QLD	85			45
Cluster 5	NSW	98	69		
Cluster 6	NSW	110	82	71	57

Source: Kayrros

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Uncertainties

Several uncertainties of the wind-rotation methodology are intrinsically linked to the TROPOMI sensor onboard Sentinel-5P. Primarily, measurements are significantly influenced by observational conditions. Factors such as cloud cover and water surfaces, which have low reflectance in the short-wave infrared (SWIR) bands, make observations difficult. Filtering images with excessive cloudy pixels may introduce a seasonal bias, as yearly estimations could predominantly rely on periods of favourable weather. However, the cloud free conditions in Australia are expected to minimise this bias. Additionally, the daily overpass time of Sentinel-5P at approximately 1:30 PM local time may introduce a temporal bias.

The methane detection threshold of the TROPOMI sensor varies between 4.2 tons per hour under optimal conditions and up to 25 tons per hour under less favourable conditions. Consequently, smaller emission sources may remain undetected. Furthermore, the spatial resolution of TROPOMI, which is 7.5 km x 5.5 km, can pose challenges in attributing emissions to specific sectors or assets. To mitigate this, a cluster-based approach is employed to isolate emissions. However, for a cluster that is close to others, images with wind directions aligned with these neighbouring clusters are discarded in order to prevent their contamination in the final methane estimate.

Alternative methods to estimate methane emissions from satellite

Satellites measure methane concentrations, but an extra step is needed to convert these observations into emissions estimates that can be compared with reported figures. This study uses the wind rotation method and the CSF and IME methods to quantify the emissions. However, alternative methods are also available for estimating emissions from satellite observations.

Integrated Methane Inversion

An alternative approach, as used by Shen shown above, involves the integrated methane inversion (IMI), a tool for estimating methane emissions. It uses methane concentration data from the TROPOMI sensor to derive emission estimates.

This approach begins with an initial guess of emissions, which is then fed into a model that tracks how methane moves through the atmosphere. The model's results are compared to satellite measurements, and the emissions estimate is adjusted to reduce any differences. This process helps refine the original estimate, making it more accurate. One key benefit of the IMI method is its ability to spatially distinguish emissions by source—such as oil, gas, coal, and agriculture—enabling the estimation of emissions by both location and source type

The OpenMethane project, run by the Superpower Institute, focuses exclusively on Australia, allowing it to incorporate higher-resolution weather data and more detailed initial emissions estimates. This higher-resolution inversion builds on the approach outlined by Shen and can potentially lead to more accurate methane emissions estimates that could also play a valuable role within an emissions verification approach.

Acknowledgement

Contributors

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Cover image

View out of the International Space Station which hosts the EMIT methane sensor.

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