Steel Methane Programme
Coal Methane Database Methodology

Methodology for mine-level methane emissions estimates from coal mines

Version Beta 2.0 – May 2026

UN environment programme | International Methane Emissions Observatory

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Abbreviations and acronyms

BF-BOF	Blast furnace-basic oxygen furnace
EI	Emission intensity
GCMT	Global Coal Mine Tracker
GEM	Global Energy Monitor
GHGRP	Greenhouse Gas Reporting Program
GWP20	20-year Global warming potential
IEA	International Energy Agency
IME	Integrated Mass Enhancement
IMEO	International Methane Emissions Observatory
IPCC	Intergovernmental Panel on Climate Change
MARS	Methane Alert and Response System
Met coal	Metallurgical coal
MDL	Minimum detection limit
MF	Match-filter
MLE	Maximum likelihood estimation
ROM	Run of Mine
SMP	Steel Methane Programme
SWIR	Short-wave infrared
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

Introduction

The steel sector faces an urgent challenge in reducing its overall greenhouse gas footprint. Coal mine methane emissions add approximately a quarter to the climate impact of steel produced through the blast furnace-basic oxygen furnace (BF-BOF)[1] route measured through the 20-year global warming potential (GWP20). At the same time, they represent a significant and cost-effective mitigation opportunity: up to 90 per cent of abatable emissions could be reduced at a cost of less than 1 per cent of the retail price of steel. Current global inventories, however, remain largely dependent on default emission factors that inadequately reflect real-world conditions, underscoring the need for more accurate and comprehensive data to guide effective mitigation.

Accurately assessing the steel industry's climate impact and prioritizing mitigation interventions requires robust quantification of methane emissions from metallurgical coal, or met coal, mining. However, existing estimates often remain fragmented, inconsistent or incomplete because methodologies differ and data quality varies across jurisdictions. To address these limitations, the United Nations Environment Programme's (UNEP) International Methane Emissions Observatory (IMEO) developed an integrative modelling framework that combines heterogeneous data sources into unified, probabilistic mine-level emission estimates.

This model is the centrepiece of IMEO's Steel Methane Programme's (SMP) Coal Methane Database. It integrates empirical and other relevant information from the database to generate probabilistic methane emission estimates for each mine and quantifies the uncertainty associated with each estimate. This approach is intended to strengthen both the scientific credibility and the policy relevance of the emission data.

The database model probabilistically combines diverse data sets in a Bayesian framework. This process produces emission estimates that are broadly comparable across regions and explicitly account for uncertainty. These estimates enable stakeholders to prioritize mitigation measures in line with international best practice. IMEO disseminates mine-level results through the SMP Coal Methane Database on IMEO's Eye on Methane // GLOBAL. These estimates are intended to support transparency and help prioritize methane mitigation. They should not be interpreted as an endorsement of operational performance, regulatory compliance or a licence to operate.

This document provides a description of the methodological framework behind the model, currently in Version Beta 2.0. All emission values presented in this database are model-derived estimates based on publicly available and third-party data sources. They are subject to uncertainty and should not be interpreted as exact measurements or definitive representations of emissions at individual mines or companies.

Future iterations of the model will expand on the current set of data inputs as well as model features by adding internal validation, refining assumptions and further automating data ingestion.

[1] Blast furnace-basic oxygen furnace (BF-BOF) is the most widespread steel production route, accounting for 70 per cent of production (International Energy Agency [IEA], 2023).

Conceptual framework

Methane emission estimates from met coal mining vary widely, reflecting differences in data availability and quality across mines. The SMP Coal Methane Database model integrates multiple sources of information on emissions from the database, each carrying its own uncertainties, spatial and temporal coverage, and methodological assumptions to produce modelled estimates.

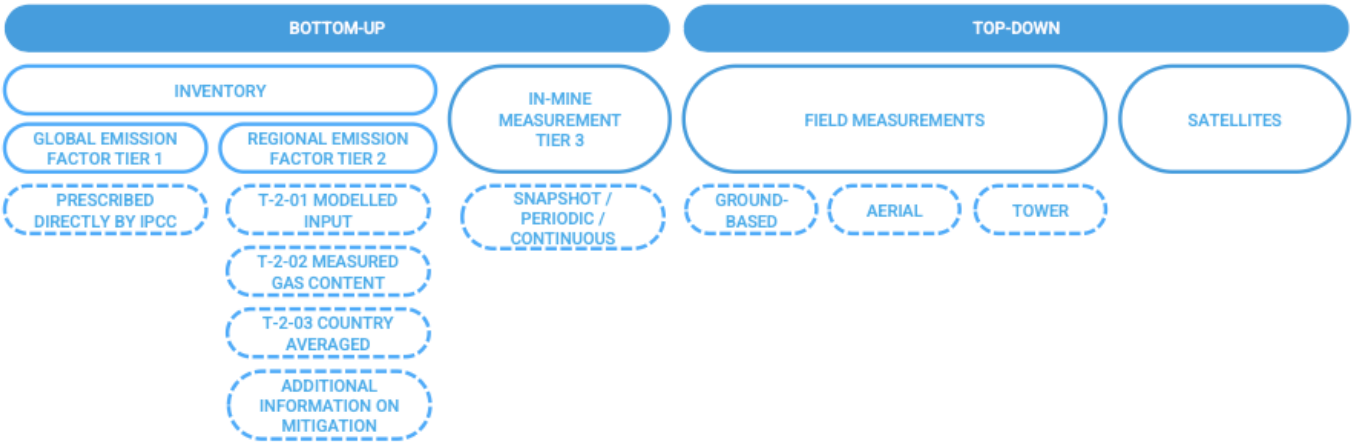
Multi-source approach

The database draws on the following data approaches and sources:

Data approaches are the methods used to estimate emissions (Figure 1). These broadly include "inventory" and "in-mine" data, based on bottom-up approaches, as well as estimates derived from atmospheric measurements using top-down approaches. Top-down estimates are further categorized as "field measurements" and "satellites".

i. ***Bottom-up approaches*** are based on production data, emission factors and direct measurement. This category encompasses bottom-up data from regional and national inventories widely used in greenhouse gas reporting, including data developed in accordance with the tiers described in the IPCC 2006 Guidelines. Tier 1 and Tier 2 estimates use emissions factors while Tier 3 is based on direct in-mine measurements.
ii. ***Field measurements*** provide mine-level or basin-level measurements and analyses that official inventories do not capture. They are usually derived from atmospheric measurements in and around mines, through the use of ground, tower or aerial-based instruments. IMEO incorporates research findings to enrich data coverage and improve model performance. One example is mine-level quantification based on aerial and remote sensing data in an Australian mine (Borchardt et al., 2025).
iii. ***Satellite measurements*** provide independent, observation-based constraints on methane emissions. While spatial resolution and attribution remain challenging, satellite data can offer independent points of comparison on reported or inferred emissions. This approach includes a limited set of data from sub mine-level emissions sources.

Figure 1: Data Classification Used in the Database



Data sources refers to the place where data can be found. It includes:

i. Science study (IMEO/external): data obtained from peer-reviewed scientific journals. The data could come from IMEO's science studies and other in-house publications or from external research groups' published work.
ii. Company reporting: data reported directly by companies. These are usually available through the countries' web portals as part of their regulatory schemes. Examples include data published by the Polish State Mining Authority, the United States Greenhouse Gas Reporting Program and Australia's Safeguard mechanism.
iii. Independent reporting: data published as part of analyses carried out by independent organizations which are not published in peer-reviewed journals. They are directly sourced from the organizations' data portals or through direct communication. Examples include the Coal Mine Tracker of the Global Energy Monitor (GEM) and the Methane Tracker of the International Energy Agency (IEA).
iv. Intergovernmental Panel on Climate Change (IPCC)/ United Nations Framework Convention on Climate Change (UNFCCC): data obtained from IPCC databases or reports (example: IPCC 2006 guidelines) or emissions reported by countries as part of their national greenhouse gas reporting to UNFCCC in their national inventory reports (Annex-I countries) or biennial update reports and national communications (Non-Annex-I countries).
v. IMEO's Methane Alert and Response System (MARS): satellite-based plume quantification from the IMEO's MARS.

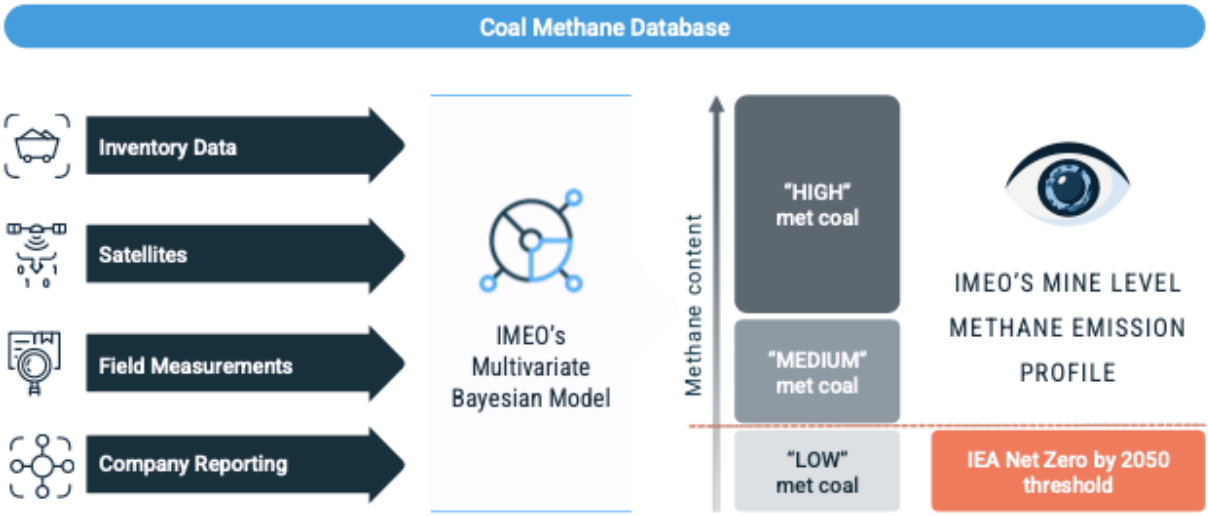
Integration framework: a Bayesian model

To reconcile the multiple and sometimes divergent inputs in the database, IMEO combines deterministic standardization methods with a Bayesian probabilistic framework. This approach enables a consistent approach to integrating available data sources using the same transparently stated procedures and assumptions for all mines. Each data input comes with information about its accuracy, which can be combined to improve the overall estimate. Data points with lower uncertainty exert greater influence on the final estimate while still allowing less certain data to contribute information. The Bayesian integration yields a posterior distribution, representing relative probabilities of emission levels for each mine, from which IMEO reports a central estimate (posterior median) along with a quantified uncertainty range (median absolute deviation). This ensures that the model provides a central estimate along with the associated uncertainty.

Mine-level assessment

IMEO built the database on a mine-level framework that consolidates diverse data inputs into a single probabilistic methane emission estimate for each mine (Figure 2). The results are categorized according to methane intensity ranges (low/medium/high). These categories are threshold-based classifications derived from estimated emission intensity ranges and do not imply any assessment of company performance or regulatory compliance.

Figure 2. Conceptual Framework



This design offers several key advantages:

- **Comparability:** IMEO's framework enables consistent comparison of emission intensity across mines and regions.
- **Transparency:** the model reveals where uncertainties are greatest and where improved measurements are urgently needed.
- **Actionability:** IMEO's outputs may inform analysis of potential mitigation opportunities.
- **Flexibility:** mine-level modularity makes the database scalable, allowing for systematic updates as new data become available for individual mines.

Scope

In Version Beta 2.0, IMEO designed the mine selection process to balance production significance and data diversity, ensuring representation across geological settings and mining practices. IMEO used Global Energy Monitor (GEM) Coal Mine Tracker 2025 data as a baseline and prioritized operating mines with high met coal output, as these account for most of the global production and methane emissions. The selection captured diverse mining methods and regions, covering mines from 19 countries, including both underground and mixed (underground/surface) operations (Table 1). The emissions reported here represent only those arising from active operations in underground (i.e., ventilation air methane and drainage stations) and surface mines. Other sub-sources of emissions within the coal sector that include fluxes from post-mining and abandoned mines will be included in future updates.

Table 1. Mines in Scope: Breakdown per Country and Geography

Country	Underground Mines	Surface or Mixed Mines	Total
Australia	14	40	
Canada	0	4	
China	91	0	
Colombia	2	0	
Czech Republic	1	0	
India	2	7	
Indonesia	0	1	
Kazakhstan	7	0	
Mongolia	0	3	
Mozambique	0	1	
New Zealand	0	1	
Norway	1	0	
Poland	7	0	
Russian Federation	18	8	
South Africa	0	1	
United Kingdom	1	0	
United States of America	31	1	
Venezuela	0	1	
Zimbabwe	1	0	
Total	**174**	**68**	**242**

Emphasis on transparency and improvement

A key feature of the framework is transparency: All mine-level estimates are traceable to their sources and the role of each input is explicitly documented. By making uncertainties visible, IMEO highlights where better measurements or disclosures are needed to improve estimates. Beyond delivering integrated and transparent emission estimates, IMEO aims to motivate companies and stakeholders to improve data sets and progressively reduce uncertainties. Better understanding of the emission rates may help inform targeted mitigation — SMP's ultimate goal.

Data inputs

i. Bottom-up (inventory and in-mine data)

All mines included in this database have inventory data as the input to the data integration model.

These refer to estimates derived from bottom-up approaches. Based on data availability, IMEO applies a tiered framework to estimate methane emissions from coal mining, which reflects progressively higher data specificity and reliability across tiers.

Tiered approach

The inventory-based estimates in the database follow IPCC guidelines, which recommend a tiered approach to emission estimation and reporting based on the quality of available input data. The approach includes three tiers: Tiers 1 and 2 rely on production data and emission factors (emissions per unit of coal produced), while Tier 3 incorporates direct measurements, as described below.

$$Emissions_{Tier\ 1\ and\ 2} = Coal\ Production \times Emission\ Factor$$

- **Tier 1** uses default emission factors as provided by the IPCC Guidelines. These factors represent global averages by mine type (surface or underground) and mining depth, offering broad coverage but limited accuracy for site-specific assessments.

- **Tier 2** incorporates regional or country-specific data, where available. Tier 2 is subdivided into three categories to reflect different types of information based on available emission factors:
    - ***T2-01*** uses modelled gas content based on Langmuir isotherms, which account for coal rank and depth. This predominantly includes estimates derived from the Global Coal Mine Tracker (GCMT) database developed by Global Energy Monitor (GEM) (GCMT Methodology). It may also include similar estimates based on modelling that are not derived directly from empirical data.
    - ***T2-02*** applies predominantly to measured gas content data derived from site- or basin-specific borehole sampling and desorption tests.
    - ***T2-03*** uses empirically derived emission factors that are specific to a basin, country or subnational region (such as a province).

- **Tier 3 (in-mine)**, unlike Tier 1 and 2, does not use emission factors, but relies on direct measurements of methane concentrations within the mine, ventilation airflow and operational mitigation. This tier offers the most accurate and site-specific emission estimates but is limited by data availability and reporting transparency.

For estimates derived through the tiered approach described above, additional information is collected to reflect coal mine methane mitigation. Mitigation data may be available at the mine level or only at the national level. Where only national figures exist, they are allocated to individual mines either equally or distributed across high-emitting mines proportionally to emissions production or capacity. If no mitigation information exists, emissions estimates are recorded as “gross”. Where mitigation is accounted for, estimates are recorded as “net”. In many cases, net emissions are reported without a clear, separately quantified mitigation amount.

Table 2 presents input data for seven top-producing countries for which information is available beyond Tier 1.

Country-specific data sources

Table 2. Input Data for Selected Top-Producing countries

Country	Activity Data	Emissions Factor / Emissions	Mitigation	Tier Information
China	Annual coal production (or capacity*) from GEM's Coal Mine Tracker data set.	Mean underground coal mine methane emissions factor for each province and gas-rating combination as compiled in Wang et al., 2019.	Country-level utilized methane amount as reported in an article is distributed only among large emitting mines in proportion to their emissions.	Tier 2
India		Mean underground coal mine methane emission factor at state level, estimated by combining mean emission factors by degree of gassiness from Singh et al., 2022 and state-wise share of coal production by degree of gassiness from Ministry of Coal report (Tier 2). For surface mines, mean country-level emission factor as reported in India's Fourth Biennial Update Report submitted to UNFCCC (Tier 2). For certain underground mines, mine-specific emission factors based on one-time direct in-mine measurements and mine-specific coal production data as reported in Singh et al., 2022 have also been used to estimate emissions. These emissions are allotted as Tier 3.	No reported information on mitigation found.	Tier 2 and 3
Australia		Gross implied emission factor for underground mining at country level obtained from UNFCCC reporting (Tier 2). Direct emissions obtained at mine level from Safeguard Mechanism reporting. Emissions from surface mining allotted as Tier 2 as these are based on measured gas contents. Emissions from underground mines allotted as Tier 3 as these include direct mine-level measurements. The frequency of these measurements is unclear.	National-level mitigation included from reported values in the National Inventory Report submitted to UNFCCC. The national mitigation coefficient is assumed for all underground mines.	Tier 2 and 3
United States of America		Gross implied emission factor for underground mining at country level obtained from UNFCCC reporting (Tier 2). For surface mines, basin-level emission factors based on measured gas content is used as reported in the National Inventory Report (Tier 2). Direct emissions allotted as Tier 3 are obtained at mine level from the Greenhouse Gas Reporting Program (GHGRP) for underground mines. Information on these measurements is reported on a quarterly basis.	National-level mitigation is sourced from reported values in the National Inventory Report submitted to UNFCCC. The national mitigation coefficient is assumed for all underground mines. Additional mine-level data is collected from the GHGRP database.	Tier 2 and 3
Poland		Net implied emission factor for underground mining at country level obtained from UNFCCC reporting (Tier 2). Direct emissions allotted as Tier 3 are obtained at mine level from reports published by the State Mining Authority.	Mine-level information on total drained gas is available from official reports. However, the percentage of methane utilization is only available at the national level, which is subsequently applied uniformly for all mines to estimate the share of drained gas that is emitted vs used.	Tier 2 and 3
Russian Federation		Gross implied emission factor for underground mining at country level obtained from UNFCCC reporting (Tier 2).	Mitigation included from reported values in the National Inventory Report submitted to UNFCCC.	Tier 2
Kazakhstan		Mean gas content assumed for all mines in Karaganda basin.	No reported information on mitigation found.	Tier 2

*For China's mines, GCMT provides information on capacity, not production.

ii. Field measurements

This stream of data refers to quantifications and estimates based on inversions of atmospheric measurements in and around the mine using ground, tower or aerial-based instruments.

The current version of the database includes a limited set of data in this category. IMEO aims to expand data input from this category in future updates.

iii. Satellite measurements

IMEO's source-level satellite-derived estimates build on the MARS methodological framework and incorporate GEM's analyses of mine boundaries and potential point-source of emission, which support plume attribution of hyperspectral methane emissions imagery. Surface mines, often characterized by diffuse and spatially extensive emissions, are not currently included in the MARS workflow, which at this stage focuses on underground mines. For additional background information on the MARS system and retrieval algorithms, see *[MARS Process]*.

Starting point: mine boundaries and points sources

To enable accurate attribution of methane plumes detected by satellites, IMEO collaborated with the Global Energy Monitor to provide spatial data on mine boundaries, represented as polygons, and locations of potential emission sources (such as ventilation shafts, drainage stations, etc.), represented as points. These features were subsequently incorporated within the MARS framework and standardized, ensuring full interoperability between all publicly available GEM data sets and subsequent satellite analyses. Where no monitoring areas exist for a given mine, IMEO adds a new monitoring location to incorporate historical imagery and maintain future coverage.

The current scope of source integration is limited to emission sources expected to exceed current satellite detection thresholds (Table 3), such as ventilations systems and degasification systems, including drainage stations and flares.

Retrieving satellite imagery and analysis

Once MARS monitoring areas and potential emission sources are defined, satellite imagery covering these locations is retrieved to identify and quantify methane plumes. Hyperspectral data are processed to detect methane plumes over mining sites, following IMEO's retrieval methodology. Each satellite observation contributes to building a consistent record of emissions across time and space, forming the basis for the analyses presented below.

The table below summarizes the hyperspectral satellite missions that MARS uses to detect point-source methane plumes. These represent the analytical foundation for detecting and quantifying emissions at the mine level.

Table 3. Methane-Detecting Satellites Used by IMEO for Metallurgical Coal Emissions

Type[a]	Agency [b]	Satellite System	Launch Year	Pixel Resolution [km]	Approximate Minimum Detection Limit (MDL)[c] [tonnes CH_4 per hour]	Tasking[e]
Point Source Imagers	ASI	PRISMA	2019	0.03 x 0.03	0.5	Y
	DLR	EnMAP	2022	0.03 x 0.03	0.5	Y
	NASA	EMIT[i]	2022	0.06 x 0.06	0.3	N

[a]**Point Source Imagers** are high-resolution with pixel size on order of 60 m or less. They are useful for localization of emissions to facility scale and can be *targeted* or *continuously monitoring.*
[b]**Agency** NASA = National Aeronautics and Space Administration. DLR = Deutsches Zentrum für Luft-und Raumfahrt. ASI = Agenzia Spaziale Italiana.
[c]**Minimum Detection Limit (MDL**) is the level below which satellite is unable to detect emissions from point sources. The inability to detect does not necessarily indicate that emissions don't exist, as they may be below the MDL. MDLs are a function of sensor characteristics *and* environmental/observing conditions. Generally, they are provided for the best observing conditions (homogenous, bright, dry surface with no vegetation, no clouds, and moderate wind). Further from these ideal conditions, the detection limit will be higher.
[e]**Targeted** or tasked instruments take data over provided locations, rather than continuously everywhere along orbit.

Hyperspectral satellites such as PRISMA, EnMAP, and EMIT combine high spatial resolution (30 m x 30 m to 60 m x 60 m) and high spectral resolution (i.e., 10 – 7 nm spectral bands). The hundreds of thin bands of these space sensors allow for accurate measurement of radiation in the short-wave infrared (SWIR) area around 2.3 µm, where methane has its strongest absorption window. Methane retrievals from these satellites are computed using a match-filter (MF) approach, as detailed in numerous scientific papers (PRISMA *Guanter et al.,* 2021; EnMAP Roger et al., 2023, 2024; and GaoFen-5 *Irakulis-Loitxate et. al.*, 2021), which involves detecting methane's absorption spectrum using statistics extracted from the hyperspectral image. Most of these missions require a tasking process: data users must specify in advance the locations of interest and make targeted requests. IMEO applies the MF retrieval method to derive methane from Level 1B satellite products provided by the respective space agencies.

During the analysis of satellite images, MARS team systematically evaluates all methane retrievals intersecting mine boundaries to identify methane plumes. This analysis includes visual inspection of plume and source validation, as well as cross-mission consistency checks, to produce reliable methane emission estimates at the mine scale. Emission quantification is based on the Integrated Mass Enhancement (IME) method (Frankenberg et al., 2016), which combines the mass of methane quantified in the observed enhancement (the plume) with wind speed at 10 metres and the plume length. To ensure accurate estimation, a plume mask — defined as the spatial boundary outlining the detected methane enhancement — is first applied to distinguish real methane signals from background noise. Reanalysis wind data products, typically from Copernicus' ERA5 and NASA's GEOS-FP, represent a primary source of uncertainty in methane emission quantifications. Given these uncertainties, and depending on atmospheric conditions and sensor resolution, each MARS emission estimate is reported with an associated uncertainty value.

Although multispectral data from satellites such as Sentinel 2 and Landsat 8 and 9 can be successfully applied by MARS in oil and gas regions under favourable surface and atmospheric conditions, in the typically highly heterogeneous mining environments, with strong surface reflectance variability over time and mixed pixels, the background noise and retrieval artifacts increase strongly, raising the detection threshold. Consequently, the multispectral satellite methane retrieval results in mining areas are not sufficiently robust, restricting the analysis hyperspectral observations only.

Integration of complementary satellite detection metadata

To enhance spatial coverage and strengthen verification, MARS incorporates complementary detections from high spatial resolution satellite and airborne missions, including all GHGSat constellations and instruments available in the Carbon Mapper's data portal (Tanager 1, AVIRIS-3, AVIRIS-NG and AUS-GAO). Once potential emission sources

are added to the system, a systematic spatial analysis is conducted to integrate all available plume detections from these missions within a 100-metre radius of each source. This step is performed independently of the hyperspectral analysis conducted with PRISMA, EnMAP or EMIT. If a detection falls within the perimeter of a given source, it is attributed to that source.

A standardized dictionary is applied to harmonize field names and ensure full compatibility between data sets. This integration guarantees methodological consistency across missions and facilitates comparative analysis of detections.

This complementary integration strengthens confidence in MARS plume identification, improves detection completeness across instruments and provides a consistent analytical basis for cross-mission validation of methane emission events.

Mine-level observations

At the mine scale, MARS compiles all validated satellite observations per potential point source of emission for each mine within the SMP Coal Methane Database scope, covering positive detections, non-detections and periods of bad observability, to build a complete observational record of methane activity as seen from space. Following GEM's mine boundary and potential points source of emission analysis, each source is assigned a corresponding mine ID and all observations linked to that source are aggregated at the mine level.

The aggregated outputs are stored in a standardized table, including all validated observations with their metadata (mine IDs and source information), and source-level attributes (observation categories, tile data and methane flux values) for mines within the database scope. This structure enables systematic mine-level evaluation of observation frequency, persistence and magnitude across multiple satellite missions.

This standardized data set provides an integrated spatial and temporal overview of positive, negative and bad observability and is used for statistical analysis, temporal trend assessment, cross-mission comparison and as input for generating mine-level statistics and estimates used in data integration and further analyses. Consolidated data for all point sources in scope of this version of the database and publicly available plume-level data are accessible through Eye on Methane // GLOBAL.

Integration model

Introduction to the Bayesian approach

Bayesian inference, used to model integrated SMP Coal Mine Database mine-level emissions, is a statistical method that combines existing information (such as an inventory estimate) with new data (for example, a satellite measurement) to update an estimate of a quantity of interest (total mine-level methane emission rate). Alternative methods like regression, frequentist maximum likelihood estimation (MLE) or machine learning were tested but failed to meet the database's needs due to issues with transparency or difficulties with missing and incomplete data.

Key elements of the Bayesian inference are:

- *Prior* represents existing knowledge before new data are integrated (for instance, expected methane content based on langmuir isotherms).
- *Likelihood* describes new information from inventories, science studies, satellites, etc. and are combined with the prior.
- *Posterior* represents the integrated emission estimate and thus the best of current knowledge based on available data.

Each mine begins with a *prior* emission estimate derived from estimations of the coal methane content of all mines, separated into three categories: underground, surface and underground and surface, calculated using langmuir isotherms. The model then updates this *prior* using available observations (inventory data, satellite retrievals, reported emissions or comparable mine data). The result is a *posterior* distribution describing the relative probabilities of different levels of annual emissions, which are summarized as the median and associated median absolute deviation of the posterior distribution.

The model operates in logarithmic space to maintain positive values, represent proportional (percentage-based) uncertainty and stabilize large differences between mines. The *posterior* is calculated exactly using the lognormal conjugate *prior*, eliminating the need for computation-intensive sampling methods.

Input data

The Bayesian model consolidates bottom-up inventory data, including companies' and countries' reporting, field measurements and satellite data. IMEO uses these data streams to update the prior emission estimates. The probabilistic combination of input data allows for a "weighted average" where the weights are determined by the input data uncertainty. All input data are standardized and reported in units of megagrams (Mg) of methane (CH_4) per gigagram (Gg) of coal produced, which is equivalent to kilograms of CH_4 per metric ton of coal produced, referred to as methane intensity. This unit formulation avoids ambiguity between short tons and metric tons and aims for comparability between mines and across years.

Source-level (or sub-mine-level) measurements of coal mines by satellite and aerial measurement have been implemented though the sub-mine-level emission quantification, which uses a progressive windowed Bayesian inference to calculate annual average mine-level emission estimates from source-level measurements (i.e., ventilations shafts). This is necessary because satellite quantifications quantify individual ventilation shafts and drainage stations in a snapshot in time. These quantifications must be expanded to the mine level and scaled up in time to be comparable to other input data. This approach also enables satellite clear-sky non-detections to inform emission rates through probability-of-detection combination.

Data processing and standardization

Unit harmonisation and uncertainty assignment

To support data processing, IMEO converts all emissions to common units, annotated with relative uncertainties (uncertainty values divided by the mean). Where uncertainty is reported explicitly, IMEO uses the source value. Where uncertainty is not provided, IMEO assigns one based on the source type (national inventory or scientific study) and method (in-mine measurement, modelling or emission factor derived).

Table 4. Data Sources and Corresponding Relative Uncertainties

Source	Relative Uncertainty
IPCC emission factors, pre-2010 measurements.	75%
• Company reported data NOT based on measurement. • Predicted emissions or emission factors. • Basin/region/country-level emission factors.	50%
• Company reporting based on measurements. • Independent studies of coal methane content.	30%
Whole mine quantification with satellite or aircraft (science studies).	Usually source-reported. 10% applied only in rare cases where not reported.

Converting emissions to emission intensity

Emission rates are converted to emission intensity values using the nearest year available production data. This introduces limitations, particularly for mines undergoing changes in operational status, because a mismatch between the production year and the emission observation year can distort estimated methane intensity. When same-year emission/production values do not exist, uncertainties in the intensity observation increase.

Handling mines with alternate production data

For some mines, only capacity (rather than production) data are available. In these cases, IMEO assumes that the production equals 75 per cent of the capacity to ensure consistency in comparing mines. Other mines report production in “saleable” units instead of Run of Mine (ROM). For these mines, the saleable production value is multiplied by 5/4 for underground mines and 4/3 for surface mines, consistent with literature average values for mass loss during conversion to a saleable product. This ensures that all mine intensities are in comparable ROM-equivalent values.

Categorizing observations by physical quantity

Because not all measurements represent the same physical quantity, IMEO categorizes observations as:

- Gross emissions: total methane emitted before mitigation.
- Net emissions: methane reaching the atmosphere after mitigation.
- Mitigation data: performance indicators describing methane capture or destruction efficiency.

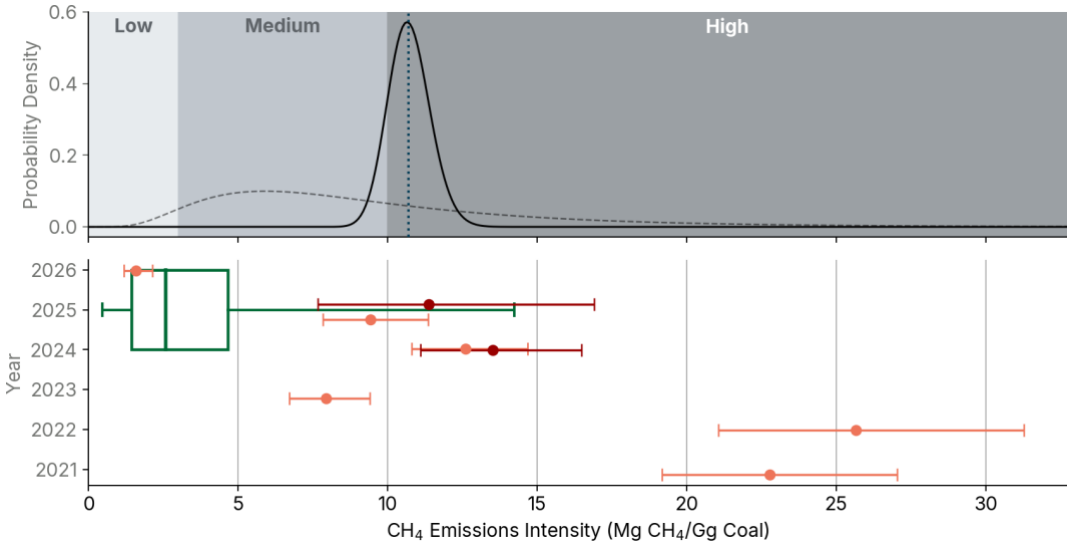
Borrowing data from similar mines

When mines are relatively near to each other – thus extracting from the same coal basin – and from approximately the same depth, it is reasonable to assume that their coal methane contents may be similar. This is useful information when little other data is available from a given mine. To incorporate this into the model, mine locations and depths are compared against each other. When found to be substantially similar (within a few kilometers in distance and similar magnitude of depth) it is then assumed that they share gross emission values. Given the uncertainty in this comparison and the underlying assumptions, the uncertainties associated with the shared data points are increased as a function of their distance and depth, with greater uncertainty inflation applied across dissimilar mines. This approach increases the data contribution for mines with limited data, improving the accuracy of emission estimates, while the added uncertainty does not substantially affect estimates for mines with sufficient data.

Output and interpretation

IMEO reports the final model-derived estimate as the median of the posterior distribution and expresses the uncertainty as the median absolute deviation – adjusted to approximate one standard deviation of uncertainty. This output is meant to be a digestible representative value for stakeholders and policymakers and assumes a symmetric uncertainty profile, while the actual output is an asymmetric lognormal distribution.

Figure 3. Example of Model Output



In addition to quantitative measures, and to enhance transparency for met coal methane emissions intensity, IMEO defines the emission intensity (EI) – a qualitative indicator based on defined methane intensity thresholds.

- **"Low" = EI < 3 Mg CH4/Gg coal**
  Lower estimated emission intensity range, representing ~45 per cent of the selected 242 mines.
- **"Medium" = 3 < EI < 10 Mg CH4/Gg coal**
  Average methane emissions (IEA's 2022–2024 met coal methane intensity average), representing ~39 per cent of the selected 242 mines.
- **"High" = EI > 10 Mg CH4/Gg coal**
  Higher estimated emission intensity range, representing the remaining ~16 per cent of the selected 242 mines.

Uncertainty

A major benefit of this model is the use of uncertainty. No measurement of emissions is exact and, as many measurements are presented without uncertainty, the accuracy of the measurements is difficult to determine. The final model output provides uncertainty as a fraction of the value, where 10 +/- 20% Mg CH_4/Gg coal indicates that the underlying emission estimate follows a probability density function with a median of 10 and a standard deviation of 2.

Limitations and future developments

Data coverage limitations

Satellite data availability

- **Diurnal variability:** satellite measurement techniques rely on sunlight and can only measure emissions during the day.
- **Overpass frequency:** many satellites take several days to return to a place where they can measure the same mine. Occasionally, clouds or other meteorological effects may constrain observations, increasing data sparsity.

Reporting gaps

- **Emissions reporting frequency:** when company data is available, it is often an annual emission estimate. Even in countries with robust reporting schemes, emissions are collected only quarterly.

Methodological limitations

Data quality and availability

- **Incomplete data:** In-mine methane measurements are often unavailable, so the model relies on estimates from bottom-up modeling, satellite data and field measurements, which can only indirectly quantify the total emissions.
- **Inconsistent sources:** emission data come from different methods that vary in quality and resolution, making them difficult to combine. The model performs deterministic conversions and probabilistic combinations to combine disparate data sources into one estimate.
- **Gross versus net emissions:** some sources quantify emissions before mitigation, while others quantify emissions after mitigation. This difference must be reconciled to properly compare the values. While the model handles the differences in emission type, this introduces further assumptions.

Model assumptions

- **Dependence on priors:** when data are limited, results depend heavily on assumed prior information, which may introduce bias. However, the influence of priors on the best estimate is transparently quantified.
- **Simplified emission patterns:** the model considers mine emission intensity as constant over the inference period. New mitigation capacity, significant changes in mine depth or changes to the active face/mining method may weaken this assumption.
- **Statistical simplifications:** mathematical assumptions, such as treating emissions as having a lognormal distribution, are a necessary part of any model. Certain mathematical assumptions may oversimplify natural phenomena and lead to biases. All best estimate emission values and associated uncertainties are determined by the publicly available input data.

Transferability and similarity

- **Comparable mines:** estimates borrowed from “similar” mines assume key conditions are alike, but small geological or operational differences can cause large emission differences.

Computational and technical factors

- **Validation limitations:** independent measurements for verifying model outputs are limited, making full validation difficult.

Future updates

Future updates may cover:

- Inclusion of additional source-level aerial and satellite measurements.
- Expansion of mine coverage.
- Model refinement.

Learn more

Read about IMEO's Steel Methane Programme.

Explore the data on Eye on Methane // GLOBAL.

Frequently Asked Questions

1. **How does IMEO combine different types of methane emissions data into a single mine-level estimate?**

IMEO combines different methane emissions data through an integrative modelling framework designed to produce a single, probabilistic estimate for each mine.

The model brings together multiple data inputs, including bottom-up inventory estimates, in-mine measurement data (many of which are used for company reporting), field measurements, satellite observations and other relevant sources.

IMEO uses a Bayesian framework to integrate the data. Deterministic calculations are used to enhance transparency in the standardization of input data, while the Bayesian model is used to probabilistically combine all standardized inputs. The Bayesian model starts with an initial estimate based on known physical properties of the mine (e.g., mine depth) and then updates that estimate as additional observations (e.g. satellite emission estimates) become available. Data points with lower uncertainty carry greater weight in the final estimate, while more uncertain data carry less weight but still contribute useful information.

The result is a model-derived, mine-level methane emission estimate, accompanied by an uncertainty range. This approach allows IMEO to combine fragmented and sometimes seemingly inconsistent data sources in a transparent and comparable way across different mines and regions.

2. **How should users interpret the methane intensity estimates and uncertainty ranges in the database?**

The methane intensity values in the database should be viewed as model-derived estimates that are informed by atmospheric measurements depending on data availability.

The uncertainty range is an approximate standard deviation about the median which depicts the probabilistic spread of confidence for the emission intensity value. Where available data are detailed, recent, reported with clear uncertainty information, or in general agreement with other similar data, the resulting estimate may be more constrained. Where data are sparse, indirect, incomplete or reported without clear uncertainty information, the uncertainty range will generally be wider.

3. **Coal Methane Database: how does the model weigh different data sources?**

IMEO's integration model combines data from different sources, including satellite observations, inventory estimates, and in-mine measurements (many of which are used for company reporting) among others. The model does not automatically prioritize one data source over another. Instead, each input is integrated probabilistically, accounting for both its value and uncertainty, which reflects information about data type data quality, and transparency on measurement methods.

In some cases, in-mine measurement data are reported as annual estimates. However, they often lack sufficient meta-data on which emission sources were measured, over what period, how measurements were aggregated, or what uncertainty should be assigned to the reported value. Where these details are not available, the model applies a more conservative uncertainty range.

Satellite observations, by contrast, may in some cases include repeated detections over many sources at the same mine, quantified uncertainty for individual observations and non-detection information. The model also adjusts satellite-derived estimates to account for missing observation periods when converting emissions rates into emissions intensity. As a result, satellite data can sometimes carry more weight in the integrated estimate, particularly where uncertainty for company-reported data is not reported and methodological detail is lacking.

This does not mean that satellite data are inherently better than in-mine measurements. Rather, it reflects the level of uncertainty and transparency associated with each available input, which varies across mines. More detailed company reporting – including measurement coverage, duration, methods, calibration and uncertainty – would allow such data to carry greater weight in future assessments. Properly situated and calibrated in-mine sensors that measure continuously are expected to provide particularly high quality data.

4. How are satellite plume observations integrated to produce mine-level emission estimates?

Satellite observations are first linked to specific potential methane sources associated with a mine, using mine boundaries and source-location analysis. Each satellite observation is then assigned to the relevant mine, including positive plume detections, non-detections and observations where conditions were unsuitable for reliable measurement, such as cloud cover or poor observability.

Because satellite measurements are instantaneous – rather than continuous – observations, they need to be converted into annual estimates. This is done through an additional modeling process that groups observations and non-detections by source and by three-months time windows. For each source and period, the model uses Bayesian inference to estimate emissions, with information from the previous time window informing the next one.

The resulting emission estimate is then treated as representative of that time window. Annual emissions are calculated by multiplying the estimated emission rate by the number of hours in each period and summing across the year. Mine-level emissions are then estimated by adding together the annual emissions from the known sources associated with that mine.

This approach allows satellite plume observations to inform mine-level estimates, but it also introduces uncertainty, particularly where observations are sparse, affected by cloud cover or do not capture all possible emission sources. For this reason, additional uncertainty processing is applied to avoid overconfidence in satellite-derived estimates. Further methodological refinements are under development.

5. Coal Methane Database: how should surface or open-cut mine estimates be interpreted, given that methods for estimating methane from these mines are still evolving?

Surface and open-cut coal mines present different methodological challenges for emission estimates from those for underground mines. Their emissions are often more diffuse, spatially dispersed and harder to attribute to individual sources, which means that available estimates may rely more heavily on inventory methods, emission factors, reported data or assumptions about gas content and production.

Estimating methane from surface mines is an evolving field of inquiry, and future updates may refine these estimates as new measurements, science studies and methodological improvements become available. For this reason, estimates for surface or open-cut mines are subject to higher uncertainty, though they remain informative with current evidence.