Fossil Fuel Operations Sector: Coal Mining Emissions

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1. Introduction

The geological processes that produce coal also produce the potent greenhouse gas, methane (CH_4), which remains trapped in underground coal seams until the coal is mined. During coal mining, methane is released into the atmosphere, and it may continue to diffuse from abandoned mines long after mining operations have ceased [1]. Carbon dioxide (CO_2) is also emitted during mining when coal seams containing sulfide minerals yield sulfuric acid that then reacts with carbonate rocks. As such, coal mine emissions are classified by the Intergovernmental Panel on Climate Change (IPCC) under *1.B Fugitive Emissions from Fuels*. Given the global scale of coal mining operations, efforts to quantify emissions from this sector are valuable, as this data can help inform opportunities to abate emissions and mitigate impacts of global warming.

Global Energy Monitor's Global Coal Mine Tracker (GCMT; https://globalenergymonitor.org/projects/global-coal-mine-tracker/) is an extensive coal mine inventory, with production and capacity data for 4,363 coal mines globally (see Figure 1 for locations). The methane gas content of each mine is also estimated and made available by GCMT. By leveraging these datasets along with mine capacity factors from literature as needed, Climate TRACE estimated annual emissions for every coal mine (asset). Note, in Climate TRACE's 2025 asset-level data release, only methane emissions for only active mines were estimated; emissions from abandoned coal mines and CO_2 emissions from all mines were not included.

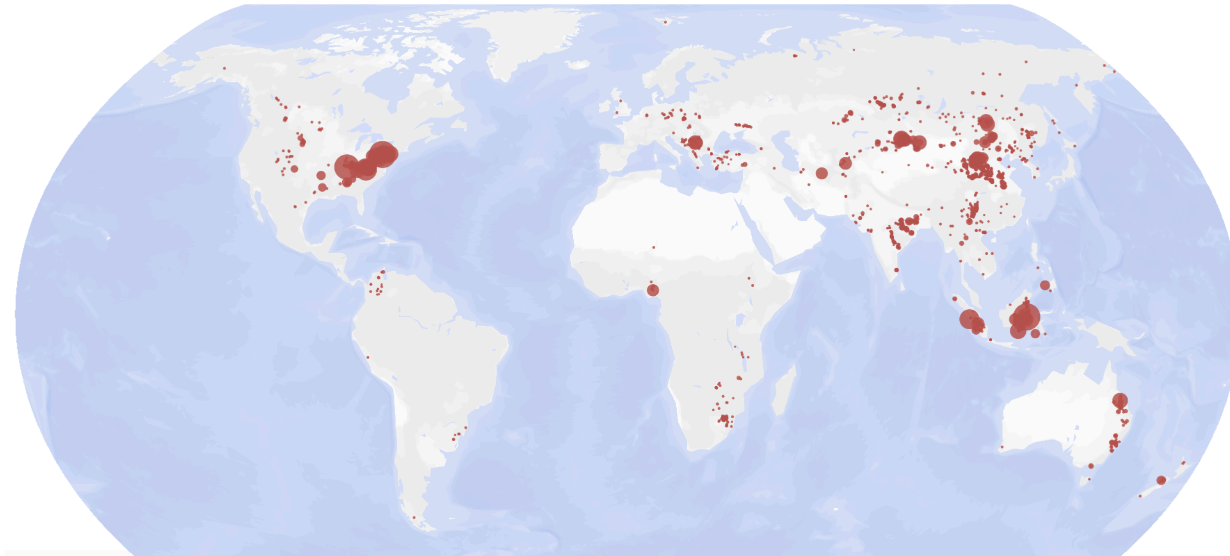

Figure 1. *Coal mines as reported by Global Energy Monitor's Coal Mine Tracker (from GEM website). The size of the dot scales with coal mine production.*

Climate TRACE's comprehensive inventory of asset-level emissions provides the foundation for assessing pathways to reduce emissions from coal mining worldwide. Abatement for this sector can broadly be described as either transforming methane into a less potent greenhouse gas (e.g., CO2) or using methane nearby as an energy source. For each mine in our database, Climate TRACE has compiled "emissions reducing solutions" (ERSs) as catalogued by the International Energy Agency (IEA) to evaluate possible emissions reductions from the coal mining sector. Details on ERS and their effectiveness by mine type and methane release source are discussed in Section 2.

2. Materials and Methods

2.1 Datasets

2.1.1 Global Energy Monitor | Global Coal Mine Tracker (GCMT)

The Global Energy Monitor's Global Coal Mine Tracker (GCMT) is a worldwide dataset of coal mines and proposed projects. The tracker is updated annually and provides source level details on ownership structure, development stage and status, coal type, production at operating mines, capacity at proposed mines, workforce size, reserves and resources, geolocation, and other categories.

The tracker includes data from publicly available sources: (1) government data, including national energy and resource plans, environmental permits and applications; and national datasets; (2) reports by state-owned and private mining companies, including quarterly and annual reports; (3) news and media reports, including local, international, and trade outlets; (4) local non-governmental organizations (NGOS) monitoring companies, mining activity, and developments; (5) on the ground contacts who can provide first-hand information.

The information was collected by an international team of researchers, with fluencies in Chinese, Russian, Spanish, and Turkish. Whenever possible, Global Energy Monitor circulates data for vetting and review to researchers familiar with local mining conditions. Input data from this tracker was used to estimate emissions, described in the sections below.

2.1.2 International Energy Agency | Global Methane Tracker

The International Energy Agency's (IEA) Global Methane Tracker offers country and regional estimates of methane emissions and ERS across various sectors, including coal mining. These estimates are updated annually and developed within the framework of the IEA's Global Energy and Climate Model (GEC) [2]. The underlying data used in the GEC Model is drawn from IEA's own energy databases, collaborators, and external sources, as documented in [2]. Climate TRACE leveraged the IEA's ERS options and associated metadata for the coal mining sector in combination with our asset-level emissions estimates to calculate the total potential for methane reductions from the coal mining sector worldwide.

2.2 Metadata

2.2.1 Emissions

The following metadata was used to estimate emission factors and methane emissions for coal mines.

Coal Mine Data
Coal mine location, name, country, and owner are all based on the dataset provided by Global Energy Monitor in their GCMT. In order to create a temporally comprehensive dataset (2015-2023), GEM collected historical production data for 4,363 mines. These datasets were used to identify mines that were open previously, and closed, or to identify past activity for mines that are currently open.

Capacity Factor
The capacity factor represents the coal mine utilization as a fraction of the mine's capacity, where capacity represents the maximum amount of coal that a mine can produce in a year. Capacity factor values were gathered from relevant literature for specific regions in China and

the U.S. For all remaining regions, a global average capacity factor was used based on China and the U.S.

For Chinese coal mines, Yangpin Ju, et al. (2019) used a stochastic model to estimate the regional capacity utilization for 15 years in China [3]. For U.S. coal mines, the U.S. Energy and Information Administration (EIA) provides state level, annual capacity factors [4]. Climate TRACE used these capacity factors for Chinese and U.S. mines using the following rules:

1. If a mine was in a state or province provided in the paper above, and we were estimating emissions for a year provided in the paper above, the exact capacity factor was used.
2. If a mine was in a state or province provided in the paper above, and we were estimating emissions for a year not provided in the table, the mean across all 15 years for that state was used.
3. If a mine was not in a state or province provided, but we were estimating for a year provided, the mean across all states for that year was used.
4. Finally, if a mine was not in a state, and we were not estimating emissions for a year in the table, the mean of the entire table was used.

All other locations: For all other coal mine locations and years, an average of all U.S. and Chinese capacity factors was applied.

Production

Production represents the coal yield from a given mine. Production from a mine should always be less than or equal to the mine's capacity. GEM's GCMT includes either production and / or capacity information for each mine, including historical production data (back to 2017) for almost half of the operating mines. If both production and capacity values were available, Climate TRACE used the production data. For mines where only capacity was available, production was calculated from capacity using the capacity factors described above.

In some cases production (or capacity) data was only available for a subset of the years modeled. Of these cases, when the missing years of data were *prior* to the year of the earliest data available, the earliest estimate available was used to backfill the missing data. If data was missing for years *between* years with data, an average of the 'nearest' data available was used to estimate the missing data.

Capacity

For mines where only capacity was provided, Climate TRACE used the capacity as provided. If production was provided in GEM's GCMT, capacity was calculated by dividing the production by the capacity factors described above. Capacity values were backfilled to the year that the mine opened.

Emissions Factor
The emissions factor for each mine represents the total amount of methane released during coal mining per amount of coal mined. The emissions factor reflects not only the *methane gas content* released from the mined coal, but also the fugitive methane emissions released from adjacent coal seams and pillars. The methane gas of the mined coal is directly estimated, whereas the methane from adjacent coal seams and pillars is estimated by applying an *emission factor coefficient*.

Methane gas content: The methane gas content released from coal depends primarily on the depth at which it was mined and the coal rank (e.g., anthracite, bituminous, and subbituminous), a measure of the carbon content of the coal that dictates whether it is used for metallurgy (e.g., steel-making) or heating. GEM estimated the methane gas content of each mine using the approach described in *Global methane emissions from coal mining to continue growing even with declining coal production* [5]. GEM provided the value in cubic meters of methane gas per tonne of coal produced (m^3 of CH_4/tonne of coal) and Climate TRACE converted the numerator from m^3 of CH_4 to tonnes of CH_4, using a conversion factor from the EPA [6] shown in the divisor of Equation 1 .

Emission factor coefficient: Emissions from coal seams and pillars in the vicinity of the mined coal also contribute to total methane emissions. These additional emissions are assumed to be proportional to the emissions released from the mined coal; as such, a multiplier (emission factor coefficient) is used to approximate the total methane emissions. Ju et al. (2016) reported that this coefficient range is 1.3 to 2.0 [7].

The methane gas content multiplied by the emissions factor coefficient yields the emissions factor for each mine, as given by Equation 1:

$$Emission\ factor_{mine} = (Methane\ gas\ content\ per\ tonne\ of\ coal_{mine} \,/\, 1.4703e3) \times Emissions\ factor\ coefficient$$

(Eq.1)

Where the emissions factor coefficient used in this work is 1.65, the average of the coefficient range from Ju et al (2016) [7].

2.2.2 Emissions Reducing Solutions

The following metadata was used to estimate the abatement potential for individual ERS strategies in the coal mining sector. *Note: Only rank 1 strategies are provided for assets on the Climate TRACE website and additional strategies will be made available in future releases.*

Release Mechanisms and Specific Sources of CMM

Coal Mine Methane (CMM) is released from a mine as either vented methane, methane from incomplete combustion, or fugitive methane emissions. Each release mechanism stems from distinct operational activities, as outlined below.

- Vented CMM occurs as an intentional release of methane during mining operations to keep methane concentrations below explosive levels. Vented methane comes from ventilation systems, which clear methane from the main airways of the mine, or drainage systems, i.e., borehores or pipelines installed to release methane before it enters the main airways.
- CMM from incomplete combustion can be released as methane slips during the oxidation or flaring activities that occur during coal mining to dilute methane concentrations in active mines.
- Fugitive emissions represent a diffuse loss of CMM either through openings in the subsurface created by mining, outcrops containing methane, or other losses.

The proportion of the total CMM released fugitively or via venting or incomplete combustion varies for underground or surface mines. Table 1, from the IEA Global Methane Tracker Documentation, shows the composition of total CMM by specific release source for an average underground and an average surface mine [8]. For the assumptions used to allocate emissions percentages to these release sources by underground and surface mines, refer to pages 25 and 26 in the IEA report [8].

Table 1: Emissions sources in coal mines IEA's Global Methane Tracker Documentation [8]

Type	Specific source	Underground	Surface
Vented	Ventilation systems	60%	0%
Vented	Drainage systems	25%	15%
Incomplete combustion	Other losses	2%	1%
Fugitive	Other losses	5%	1%
Fugitive	Post-mining	3%	8%
Fugitive	Outcrops, workings	5%	75%
Total	**Total**	**100%**	**100%**

Technologies

The IEA has evaluated various ERS to reduce emissions from coal mining operations. Table 2, from IEA, shows applicability factors and effectiveness factors for each ERS (see "Measure" column in Table 2). The applicability factor indicates the share of emissions for which ERS could be deployed. The effectiveness factor reflects the efficiency of the ERS(e.g., 95% of methane is combusted during flaring). For a given ERS strategy applied to a specific source of methane, the product of the applicability and the effectiveness factors yields the abatement potential of that measure for that source (as percent emissions abated), as shown in the "Abatement potential" column of Table 2.

The strategy is tailored to the type of methane gas release and its specific source. The "Choice of measure" column in Table 2 specifies methane thresholds that dictate whether the ERS is suitable. For example, for methane vented from drainage systems, flaring is appropriate for mines with low methane concentrations, whereas utilization systems (using methane for energy on-site or nearby) are worthwhile for mines with high methane concentrations. Using the parameters in Table 2, Climate TRACE proposed different ERS for each mine in the GEM database.

Table 2: Abatement potential of different ERS strategies [8]

Specific source	Choice of measure	Measure	Type	Applica-bility factor	Effective-ness factor	Abate-ment potential
Drainage systems	Emissions <1 kt	Flare	Vented	75%	95%	**71%**
	Other mines	Drained CMM utilisation	Vented	75%	95%	**71%**
Ventilation systems	Intensity <10kgCH_4/t or emissions <10 kt	VAM oxidation	Vented	70%	95%	**67%**
	Other mines	On-site recovery & use	Vented	70%	95%	**67%**
Other losses	All mines	Efficiency improvements	Incomplete combustion	75%	75%	**56%**
Other losses	All mines	Capture and route	Fugitive	50%	75%	**38%**
Post-mining	All mines	Capture and route	Fugitive	25%	60%	**15%**
Outcrops, workings	All mines	Capture and route	Fugitive	10%	60%	**6%**

The applicable emissions (percent of total) for each category of mine (from Table 1, *T1*) and the effectiveness factor of the technology (from Table 2, *T2*), were used to arrive at an *Emissions Factor Scaling Ratio* for each ERS strategy, *s*, as shown in Equation 2. The *Emissions Factor Scaling Ratios* can be applied to relevant mines to calculate the potential emissions reduction.

$$Emissions\ Factor\ Scaling\ Ratio_s = 1 - (\%\ of\ total\ emissions\ for\ CH4\ source_{T1} \times \%\ abatement\ potential\ for\ ERS_{T2,s}) \quad \text{(Eq. 2)}$$

For example, if the strategy VAM Oxidation (strategy_id: vam001) is applied to underground mines, the emissions factor scaling ratio for this solution would be:

$$Emissions\ Factor\ Scaling\ Ratio_{vam001} = 1 - (0.60 * 0.67) = 0.60$$
(Eq. 3)

where, $\%\ of\ total\ emissions\ for\ CH4\ source_{T1}$= 0.60 (from the “Specific Source” row for ventilation systems in the “Underground” column of Table 1) and $\%\ abatement\ potential\ for\ ERS_{T2,s}$= 0.67 (from the “Abatement Potential” column in Table 2).

For mines that are associated with the ‘vam001’ strategy_id, one can then multiply the CH_4 emissions factor by 0.60 in order to arrive at the new potential emissions factor if this mitigation strategy was applied at this mine.

It should be noted that Climate TRACE did not include efficiency improvements from Table 2 as an ERS because we are not currently estimating the CO_2 emissions from on-site combustion for mines, and are only measuring vented and fugitive emissions.

2.2 Model

2.2.1 Emissions

Climate TRACE calculated emissions for each asset (mine) by multiplying the production for a given mine (in tonnes of coal) by the CH_4 emissions factor for that mine (in tonnes CH_4 per tonne of coal). The result is methane emissions (tonnes of CH_4 emissions per mine), as shown in Equation 4.

$$CH4\ Emissions_{mine} = CH4\ Emissions\ Factor_{mine} \times Production_{mine}$$
(Eq. 4)

Equation 4 was applied to 4,363 coal mines globally to estimate their methane emissions for years 2015 to 2023. To convert annual values to monthly values, refer to the Climate TRACE methodology “*Temporal Disaggregation of Emissions Data for the Climate TRACE Inventory*” in the GitHub repository Post Processing for Global Emissions and Metadata Completeness.

2.2.2 Emissions Reductions

Climate TRACE calculated the potential methane emissions reductions for each asset (mine) by multiplying the emissions for a given mine (in tonnes of CH_4) by the CH_4 emissions factor scaling ratio for the appropriate ERS. The result is methane emissions reduced (tonnes of CH_4 emissions per mine), as shown in Equation 5.

$$CH4\ Reductions_{mine} = CH4\ Emissions_{mine} \times Emissions\ Factor\ Scaling\ Ratio_{s}$$
(Eq. 5)

5. Climate TRACE Reporting of Emissions

Coal mining emissions data for this sector is hosted in the Climate TRACE website: https://climatetrace.org/. This emissions sector is equivalent to the United Nations Framework Convention on Climate Change (UNFCCC) sector "Fossil Fuel Operations 1.B.1.a - Coal Mining and Handling". Climate TRACE default emissions values were reported as CH_4, and CO_2 equivalent 20- and 100-year global warming potential (CO_2e 20yr and 100yr GWP).

6. Supplementary Metadata

This dataset provides emissions estimates for active coal mines. Metadata information is provided in the tables below.

Table S1: *General dataset information*

General Description	Definition
Sector definition	*Fugitive methane emissions from coal mining, and post-mining activities of commercially operating mines and carbon dioxide emissions from on-site fuel combustion for coal extraction, handling, and logistics.*
UNFCCC sector equivalent	*1.B.1.a Coal Mining and Handling*
Temporal Coverage	*2015 – 2023*
Temporal Resolution	*Annual (original); Monthly (on website, see Temporal Disaggregation of Emissions Data for the Climate TRACE Inventory)*
Data format(s)	*CSV*
Coordinate Reference System	*EPSG:4326, decimal degrees*
Number of assets/countries available for download	*4,363 assets*
Total emissions for 2023	*1,873,073,233 tonnes CO_2e*
Ownership	*We used permit data and research to identify ownership information*
What emission factors were used?	*Industry emission factors*
What is the difference between a "NULL / none / nan" versus "0" data field?	*"0" values are for true non-existent emissions. If we know that the sector has emissions for that specific gas, but the gas was not modeled, this is represented by "NULL/none/nan"*
total_CO2e_100yrGWP and total_CO2e_20yrGWP conversions	Climate TRACE uses IPCC AR6 CO_2e GWPs. CO_2e conversion guidelines are here:https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport_small.pdf

Table S2: *Asset level metadata description*

Data attribute	Definition
sector	Fossil Fuel Operations
asset_sub-sector_name	N/A
asset_definition	N/A
start_date	Start date for time period of emissions estimation (YYYY-MM-DD format)
end_date	End date for time period of emissions estimation (YYYY-MM-DD format)
asset_identifier	Internal, unique ID for mining asset and mineral type
asset_name	Mining asset
iso3_country	ISO 3166-1 alpha-3 country code for asset location
location	Well-known text (WKT) MultiPolygon of approximate mine centre
type	Coal Mine classification
capacity_description	Coal Mine Capacity
capacity_units	Tonnes
capacity_factor_description	Proportion of capacity accounted for by activity (production)
capacity_factor_units	N/A
activity_description	t Coal extracted
activity_units	Tonnes
CO2_emissions_factor	N/A
CH4_emissions_factor	Tonnes CH_4/ Tonne coal
N2O_emissions_factor	N/A
other_gas_emissions_factor	N/A
CO2_emissions	N/A
CH4_emissions	Tonnes CH_4
N2O_emissions	N/A
other_gas_emissions	N/A
total_CO2e_100yrGWP	Tonnes CO_2e
total_CO2e_20yrGWP	Tonnes CO_2e
other1_description	Coal Type
other1_units	N/A
other2_description	Coal Grade
other2_units	N/A
other3_description	Total Reserves (Proven and Probable)
other3_units	Million Tonnes
other4_description	Total Resource (inferred, indicated, measured)
other4_units	Million Tonnes
other5_description	Primary Consumer, Destination
other5_units	N/A
other6_description	Coal Plant, Steel Plant, Terminal

Data attribute	Definition
other6_units	N/A
other7_description	Mine Depth
other7_units	m
other8_description	Mine Size
other8_units	km^2
other9_description	N/A
other9_units	N/A
other10_description	N/A
other10_units	N/A

Table S3: ERS *parameters, one table per strategy for a total of 11 strategies. Note: Only rank 1 strategies are provided for assets on the Climate TRACE website and additional strategies will be made available in future releases.*

native_strategy_id	Definitions
strategy_name	Benchmark-based retrofits
strategy_description	Retrofit facility to match emissions intensity of the the 10th percentile of facilities in this sector
mechanism	retrofit
co2_emissions_factor_new_absolute	0.0175
ch4_emissions_factor_new_absolute	0.000898
n2o_emissions_factor_new_absolute	0
benchmark_asset_id	14865

native_strategy_id	Definitions
strategy_name	Capture and route fugitive methane in surface mines
strategy_description	Capture methane from fugitive sources such as outcrops and fractured ground in surface mines. Direct the captured methane to drainage of Ventilation Air Methane oxidation systems.
mechanism	retrofit
ch4_emissions_factor_new_to_old_ratio	0.9393

native_strategy_id	Definitions
strategy_name	Capture and route fugitive methane in underground mines
strategy_description	Capture methane from fugitive sources such as outcrops and fractured ground in underground mines. Direct the captured methane to drainage of Ventilation Air Methane oxidation systems.
mechanism	retrofit
ch4_emissions_factor_new_to_old_ratio	0.9738

native_strategy_id	Definitions
strategy_name	Flare surface mine methane
strategy_description	Combust drained methane to reduce global warming potential of leaked gas.
mechanism	retrofit
ch4_emissions_factor_new_to_old_ratio	0.8931

native_strategy_id	Definitions
strategy_name	Flare underground mine methane
strategy_description	Combust drained methane to reduce global warming potential of leaked gas.
mechanism	retrofit
ch4_emissions_factor_new_to_old_ratio	0.8219

native_strategy_id	Definitions
strategy_name	On-site recovery and use
strategy_description	If methane concentrations are high enough, ventilated methane can be used for heat recovery and used on-site.
mechanism	retrofit
ch4_emissions_factor_new_to_old_ratio	0.5725

native_strategy_id	Definitions
strategy_name	Unspecified solution
strategy_description	Reduce emissions by a factor of 0.1 via unspecified means.
mechanism	retrofit
co2_emissions_factor_new_to_old_ratio	0.9
ch4_emissions_factor_new_to_old_ratio	0.9
n2o_emissions_factor_new_to_old_ratio	0.9
confidence	very low

native_strategy_id	Definitions
strategy_name	Utilize surface mine methane
strategy_description	Utilization of drained coal mine methane either on site, or in nearby markets. This strategy is best applied before a mine is opened.
mechanism	retrofit
ch4_emissions_factor_new_to_old_ratio	0.9003

native_strategy_id	Definitions
strategy_name	Utilize underground mine methane
strategy_description	Utilization of drained coal mine methane either on site, or in nearby markets. This strategy is best applied before a mine is opened.
mechanism	retrofit
ch4_emissions_factor_new_to_old_ratio	0.8338

native_strategy_id	Definitions
strategy_name	VAM Oxidation
strategy_description	Thermal or catalytic oxidation of ventilated air methane.
mechanism	retrofit
ch4_emissions_factor_new_to_old_ratio	0.6010

Data citation format: Lewis, C., Tate, R.D., Mei, D.L., and Piscopo, A. (2025). *Fossil Fuel*

Operations Sector- Coal Mining Emissions. WattTime and Global Energy Monitor, USA, Climate TRACE Emissions Inventory. https://climatetrace.org [Accessed date]

Geographic boundaries and names (iso3_country data attribute): The depiction and use of boundaries, geographic names and related data shown on maps and included in lists, tables, documents, and databases on Climate TRACE are generated from the Global Administrative Areas (GADM) project (Version 4.1 released on 16 July 2022) along with their corresponding ISO3 codes, and with the following adaptations:

- HKG (China, Hong Kong Special Administrative Region) and MAC (China, Macao Special Administrative Region) are reported at GADM level 0 (country/national);
- Kosovo has been assigned the ISO3 code 'XKX';
- XCA (Caspian Sea) has been removed from GADM level 0 and the area assigned to countries based on the extent of their territorial waters;
- XAD (Akrotiri and Dhekelia), XCL (Clipperton Island), XPI (Paracel Islands) and XSP (Spratly Islands) are not included in the Climate TRACE dataset;
- ZNC name changed to 'Turkish Republic of Northern Cyprus' at GADM level 0;
- The borders between India, Pakistan and China have been assigned to these countries based on GADM codes Z01 to Z09.

The above usage is not warranted to be error free and does not imply the expression of any opinion whatsoever on the part of Climate TRACE Coalition and its partners concerning the legal status of any country, area or territory or of its authorities, or concerning the delimitation of its borders.

Disclaimer: The emissions provided for this sector are our current best estimates of emissions, and we are committed to continually increasing the accuracy of the models on all levels. Please review our terms of use and the sector-specific methodology documentation before using the data. If you identify an error or would like to participate in our data validation process, please contact us.

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