Global Energy Monitor

Bigger than Oil or Gas?

2022

SIZING UP COAL MINE METHANE

Ryan Driskell Tate

ABOUT GLOBAL ENERGY MONITOR

Global Energy Monitor (GEM) develops research and analysis on fossil fuel projects in support of the worldwide movement for clean energy. Current projects include the Global Coal Mine Tracker, Global Coal Plant Tracker, Global Gas Infrastructure Tracker, Global Oil and Gas Extraction Tracker, Europe Gas Tracker, CoalWire newsletter, Inside Gas newsletter, Global Gas Plant Tracker, Global Registry of Fossil Fuels, Global Steel Plant Tracker, Latin America Energy Portal, and GEM.wiki.

ABOUT THE GLOBAL COAL MINE TRACKER

The Global Coal Mine Tracker (GCMT) is a worldwide dataset of coal mines and proposed projects. The tracker provides asset-level details on ownership structure, development stage and status, coal type, production, workforce size, reserves and resources, methane emissions, geolocation, and over 30 other categories. For further details, see the tracker landing page and methodological overview.

AUTHOR

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ABOUT THE COVER

The cover photo shows a coal mine in Hunter Valley, Australia. Photo by Max Philips (Jeremy Buckingham MLC), licensed under CC by 2.0.

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FURTHER RESOURCES

To obtain primary data from the Global Coal Mine Tracker (GCMT), use the Data Request Form. For additional data on methane emissions, see Summary Data of the GCMT. For links to reports based on GCMT data, see Reports & Briefings.

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EXECUTIVE SUMMARY

Coal mining emits 52.3 million tonnes of methane per year, rivaling oil (39 million tonnes) and gas (45 million tonnes), and comparable to the climate impact of the CO_2 emissions of all coal plants in China, according to new mine-level data and modeling from Global Energy Monitor.

A slate of new coal mine projects currently under development could further emit 11.3 million tonnes of methane per year if the projects proceed as planned, and would effectively lock in new emissions equivalent to the coal-based CO_2 emissions of the United States.

Global Energy Monitor's analysis is the first assessment to estimate coal mine methane emissions worldwide at the asset level, using its newly enhanced Global Coal Mine Tracker in combination with the Model for Calculating Coal Mine Methane (MC2M), a peer-reviewed emissions methodology developed by experts at Pacific Northwest National Laboratory, Raven Ridge Resources, the U.S. Environmental Protection Agency, and Ruby Canyon Engineering and published in 2020.

Our findings support new data from satellite campaigns and academic research that suggest coal mine methane emissions have gone underestimated in previous assessments and national inventories.

To remain within reach of the International Energy Agency's roadmap for Net Zero 2030, coal mine methane emissions must fall 11% each year until 2030, according to GEM's analysis. A wind down to that extent requires proactive planning and careful scrutiny in climate governance, including targeted mitigation plans and closures, and a faster phase-out of coal production.

Highlights:

- The world's operating coal mines emit 52.3 million tonnes of methane per year, more than the IEA's emissions assessments of oil (39 million tonnes) or gas (45 million tonnes). While mining receives less scrutiny in climate governance, mining emissions translate to CO_2-equivalent (CO_2e) emissions of 1,560–4,320 million tonnes (Mt) per year when averaged over a 100-year and 20-year timeframe, respectively. 4,320 Mt CO_2e20 is comparable to the climate impact of the CO_2 emissions of all coal plants in China.

- Proposed coal mine projects could further emit 11.2 million tonnes of methane per year, translating to 338–936 Mt of CO_2e100 and CO_2e20, respectively, and equivalent to the coal-based CO_2 emissions of the United States. As of 2022, 30% of these projects are under construction, suggesting new emissions remain a concern for the near future.

- Shanxi, China is the primary source of the world's coal mine methane emissions. The province emits roughly the same amount of coal mine methane (13.1 Mt) as the rest of the world combined (13.8 Mt).

- In the gassiest coal mines, up to 50% of the operation's greenhouse gas profile is composed of methane, meaning that some mines have a similar climate impact as burning the coal itself.

- The reduction of coal mine methane emissions requires a highly targeted approach, since some mines emit 67 times more than mines of similar size, so which mines close, and when, will heavily influence methane emissions in the future.

- Coal mine methane emissions must fall 11% each year until 2030 to remain within reach of the IEA's roadmap for Net Zero 2030.

- Outright cancellation of new mine projects is the only way to guarantee zero emissions from new sources in line with the IEA roadmap for net zero emissions.

- Without proactive steps, coal mines continue to release large amounts of methane gas even after they have closed, meaning a phase down in coal power will not resolve the problem on its own and coal mine methane requires careful scrutiny in climate governance.

WHAT'S THE BIG DEAL ABOUT COAL MINE METHANE?

Coal mining releases trapped methane gas from fracturing seams and rock strata underground. Operators and miners have worried for years about the workplace hazards of methane exposure, including firedamp and underground outbursts and explosions. Those hazards have led to a number of mitigation measures and reforms in the mining sector to improve workplace safety, though deadly accidents still occur across the word, even in technologically advanced coal mines.

But methane also poses a climate threat. Methane gas is the second biggest contributor to global warming after carbon dioxide (CO_2). The gas is a short-lived climate pollutant with an average atmospheric lifespan of roughly 12 years, yet it has a much stronger warming potential in that timeframe. The latest figures from the Intergovernmental Panel on Climate Change (IPCC) suggest that methane traps heat in the atmosphere 82.5 times more than CO_2 when averaged over 20 years and 29.8 times more than CO_2 when averaged over 100 years. In 2021, a team of scientists led by the Environmental Defense Fund (EDF) concluded that slashing methane emissions would "immediately slow" global warming by 30%, and avert 0.5 degrees warming before the end of the century.

Still, today's coal mine methane mitigation measures—designed to remove methane from the underground workplace and keep miners safe—emit methane into the atmosphere through vent holes, open pits, storage piles, and fissures in the ground. The latest Global Methane Budget has found coal mining methane emissions rose throughout the 2010s because of the global increase in coal production. Unless operators mitigate methane leakage prior to and after mining, coal mines continue to leak methane for decades even after operators have closed and abandoned them.

HOW MUCH METHANE DO COAL MINES EMIT?

Global Energy Monitor has produced a first-of-its-kind analysis using worldwide coal mine level activity data to assess coal methane emissions (read our methodology "How do we do this research?")

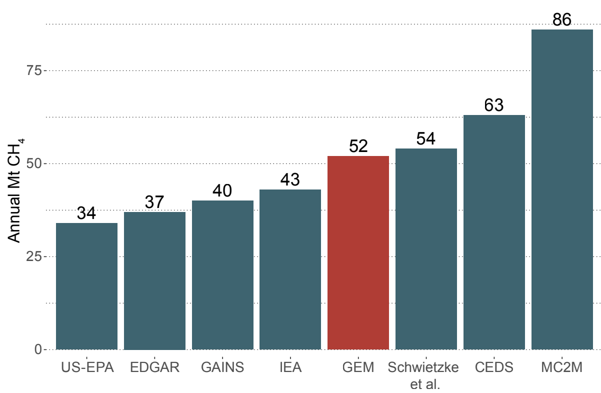
GEM found that operating coal mines emitted 52.3 million tonnes of methane per year—rivaling the methane emissions of oil (39 million tonnes) and (45 million tonnes). Using the IPCC's sixth assessment guidelines on methane's global warming potential, that means the world's operating mines currently emit 1,560 to 4,319 million tonnes of CO_2e100 and CO_2e20 each year, respectively, comparable in short-term impact to the CO_2 emissions of China's coal plants.

Global inventories of coal mine methane emissions can differ a great deal (read GEM's explanation for "Why do coal mine methane assessments vary?") GEM found emissions are 20% higher than current global estimates by the IEA, but 20% lower than assessments by the Community Emissions Data System (CEDS) (Figure 1 on the next page). In all, our figures are comparable to the average (52 Mt) of seven of the most well-known global coal mine methane assessments taken together.

One of the newest sources of data is remote sensing satellite missions that have documented methane hot spots in coal mining regions across the world. By using mine level activity data, GEM's figures provide a means to groundtruth those recent satellite observations and reveal the source of emissions through geolocation data in our Global Coal Mine Tracker (Figure 2); several satellite campaigns already make use of GEM data for this purpose.

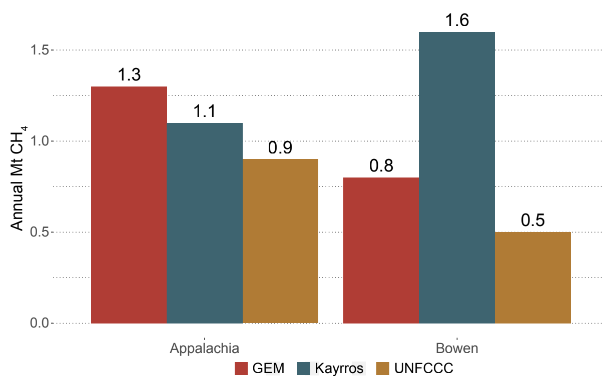
We found that in the Bowen Basin, Australia, GEM's assessment was 50% lower than new satellite observations and closer to the official figures reported in national inventories submitted to the United Nations Framework Convention on Climate Change (UNFCCC). But in Appalachia, GEM's figures are 18% higher than observed satellite emissions (Figure 2) and 44% higher than the UNFCCC national inventory. Whatever the discrepancies, one issue remained clear: GEM's figures and satellite observations agree that official figures reported in national inventories are likely too small. The IEA has also recently concluded that underreporting methane in national inventories is widespread and endemic (read GEM's explanation for "Why do coal mine methane assessments vary?").

Figure 1: Global coal mine methane assessments



Comparison of annual global coal mine methane emissions assessments of the United States Environmental Protection Agency (US-EPA), Emissions Database for Global Atmospheric Research v. 6 (EDGAR), International Energy Agency (IEA), Global Energy Monitor (GEM), Schwietzke et al. (2016), Community Emissions Data System (CEDS), and Kholod et. al (MC2M) (2020).

Figure 2: Global Energy Monitor's mine-level analysis compared to atmospheric remote sensing satellite data and national inventory data in Appalachia, USA and Bowen Basin, Australia.



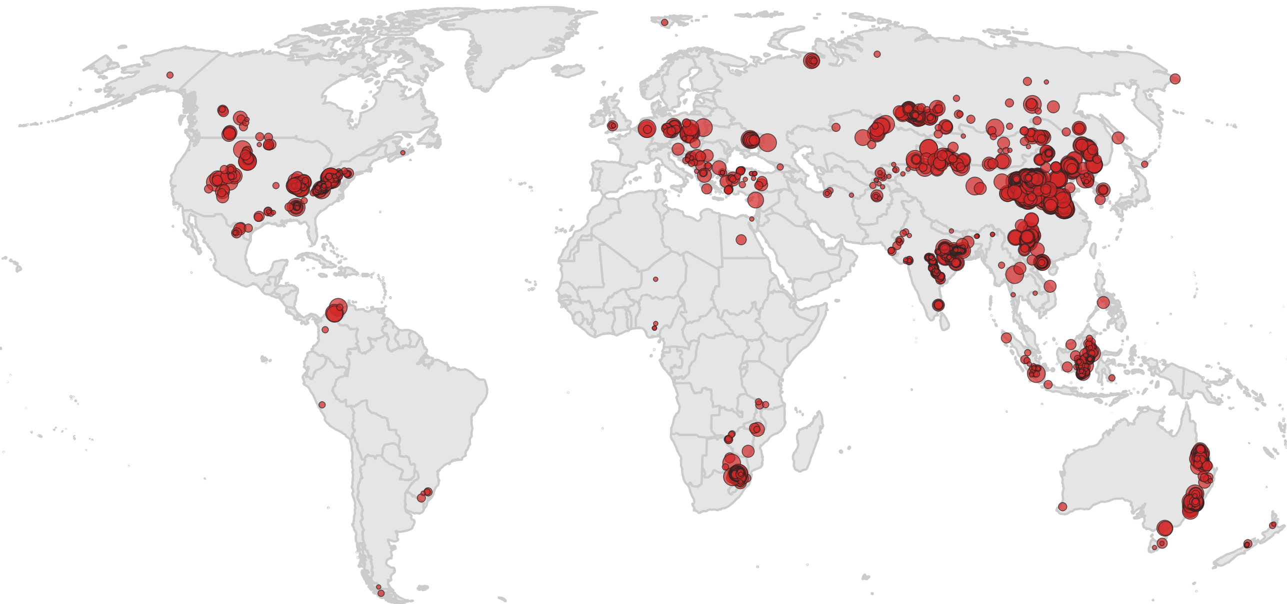
Source: Global Coal Mine Tracker, Kayrros satellite observations for Appalachia, USA and Bowen Basin, Australia, UNFCCC data from US EPA (Appalachia) and National Greenhouse Gas Inventory (Bowen Basin, Queensland).

WHERE ARE EMISSIONS COMING FROM?

Coal mine methane emissions are highly concentrated in the world's production-heavy and gassy coal deposits (Figure 3).

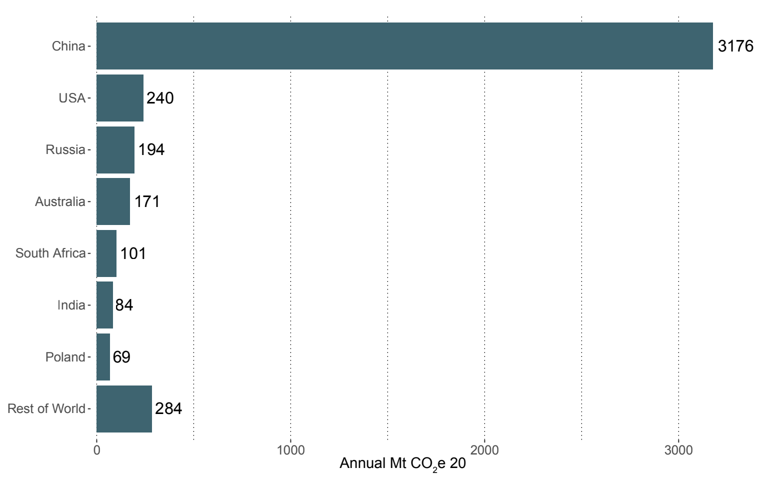
The major emitters in GEM's data, measured in million tonnes of CO_2e100 and CO_2e20, respectively, remain clustered in the world's major coal producers (Figure 4). But the data also demonstrate the nuances

Figure 3: Global methane emissions at operating coal mines



The red dots represent operating coal mine methane emissions, scaled to emissions in million cubic meters per year. Source: Global Coal Mine Tracker and GEM analysis.

Figure 4: Coal mine methane emissions in 7 countries



Methane emissions (CO_2e) from operating coal mines equal over 4.3 Gt per year, when measured on a 20-year horizon, led by proposals from China (3,176 Mt CO_2e), United States (240 Mt CO_2e), and Russia (194 Mt CO_2e). See Table 1 for more information. Source: Global Coal Mine Tracker.

of how coal type and operational depth heavily influence methane emissions (see our explanation "Why do mines emit such different amounts?"). Poland (ranked 7th) emits about the same amount of coal mine methane as Indonesia (ranked 8th), a country that produces over 5 times the amount of coal. The reason for the discrepancy is that Poland's mines are particularly deep, and deep mines correlate to higher pressure and gas content. Similarly, South Africa (ranked 5th), a country that relies primarily on underground mining, emits more methane than the world's second largest coal producer India (ranked 6th), which relies primarily on surface mining (Table 1).

China's mines are the primary source of global emissions

China, the world's largest producer and consumer of coal, is quite predictably also the biggest emitter of coal mine methane. The country's major mines—not including small operations under 1 million tonnes, which are excluded from GEM's mine tracker—emit 38.4 million tonnes of methane per year and account for 73% of global coal mine methane emissions.

Just three provinces—Shanxi (13 Mt), Inner Mongolia (7 Mt), and Shaanxi (6 Mt)—are responsible for the bulk of China's coal mine methane emissions. Together, these three provinces emit 792–2,192 million tonnes of CO_2e100 and CO_2e20, respectively, which is fully one half of all coal mine methane emissions in the world. Only the countries of the United States, Russia, and Australia can match the emissions of China's three leading provinces.

Shanxi is the primary source of the world's coal mine methane emissions (Figure 5 on the next page). The province's massive emissions have been previously documented in a study published in 2019 by scientists at MIT, Harvard, and the Environmental Defense Fund. To put Shanxi's staggering figures in perspective: the province emits roughly the same amount of coal mine methane (13.1 Mt) as the rest of the world combined (13.8 Mt), and that's despite producing less than 15% of the world's coal (1060 million tonnes of coal mined in 2020 out of 7350 million tonnes globally).

China has not reported its coal mine methane emissions to the UNFCCC since 2014. Even then, China relied on simplified assumptions that, according to researchers at Tsinghua University, could have significantly underestimated coal methane emissions. As a

Table 1: Top 10 emitters of coal mine methane (same data as shown in Figure 4).

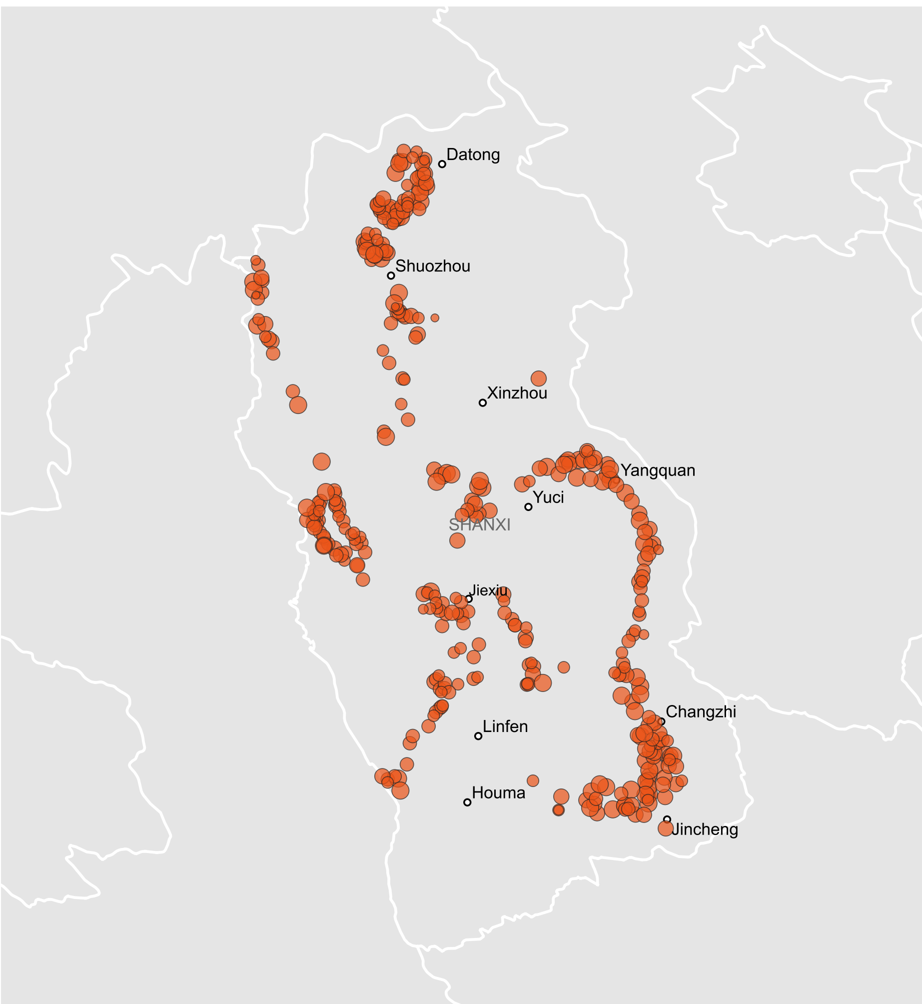
Country	Coal Production (Mtpa)	Annual Methane Emissions (Mt CO_2e20)	Annual Methane Emissions (Mt CO_2e100)
China	3,558	3,176	1,147
United States	399	240	87
Russia	484	194	70
Australia	493	171	62
South Africa	247	101	36
India	754	84	30
Poland	100	69	25
Indonesia	564	58	21
North Korea	20	36	13
Kazakhstan	100	35	13

Source: Global Coal Mine Tracker and GEM analysis. Coal production figures in 2020 from IEA, rounded to the nearest million tonnes.

result, there is much disagreement about China's coal mine methane emissions, which may represent up to 90-95% of methane emissions from the country's entire energy sector, given the dominance of coal in China's energy mix and the gassiness of many of its coal fields.

To help mitigate methane emissions, government policy previously required Chinese operators to use drained gas for coal mines with greater than 30% methane content, but the U.S. EPA has suggested that operators were circumventing those requirements. According to a 2019 study in Nature, those regulations have had "no discernible impact" on continued emissions. Since 2020, environmental impact assessments require utilization of the methane gas when concentrations are above 8%, but whether compliance is any better than it was for earlier efforts remains to be seen. While the Global Coal Mine Tracker relied on some capacity figures in China when exact production figures were unavailable, the mine-level data account for 86% of coal mining production in China, suggesting emissions may be even higher with the inclusion of smaller, village-based mine operations.

Figure 5: Coal mine methane emissions in Shanxi province in China



The red dots represent coal mine methane emissions, scaled to emissions in million cubic meters per year, in Shanxi, China. Source: Global Coal Mine Tracker and GEM analysis.

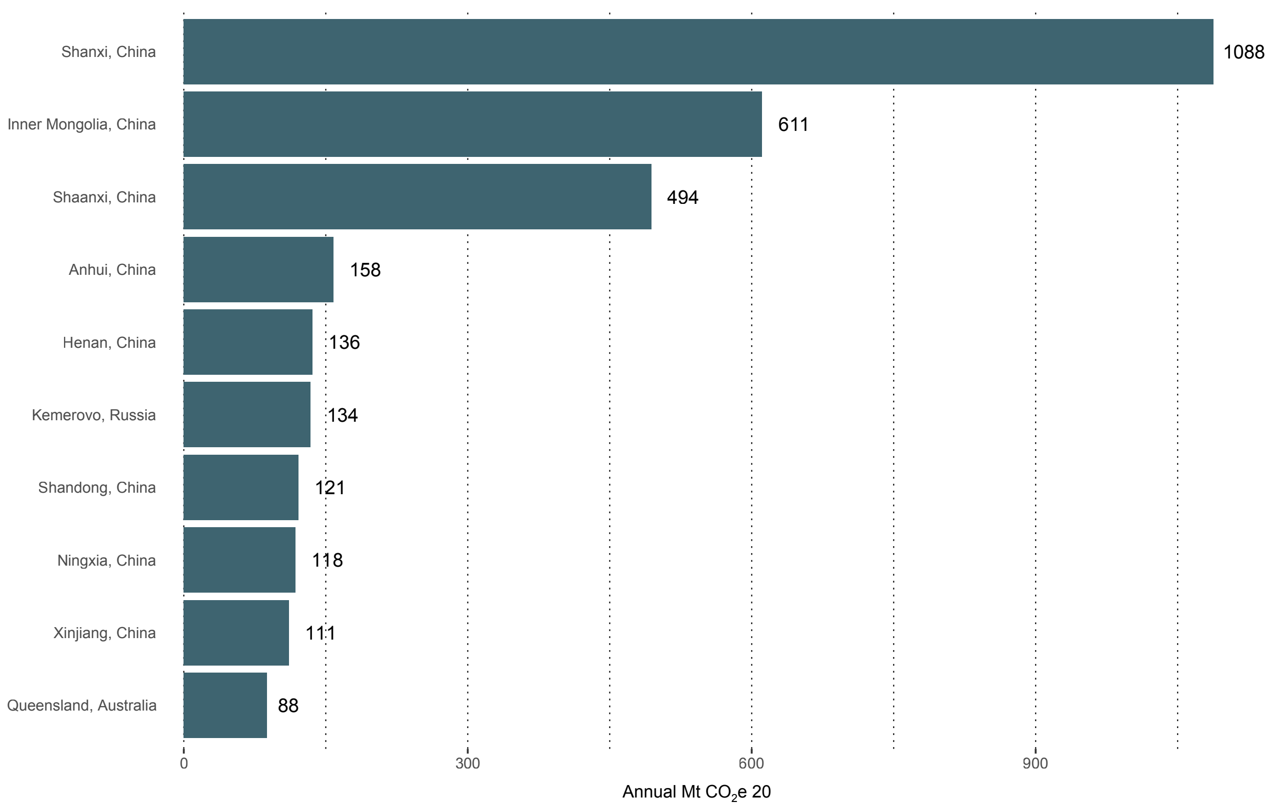
Coalfields in Russia and Australia rank among the Top 10 worst emitters

The global concentration and density of coal mine methane emissions is even more apparent when examining the subnational level (Figure 6). Just ten states and provinces around the world emit over 70% of the world's coal mine methane (1,104–3,058 Mt CO_2e100 and CO_2e20, respectively). The world's Top 5 biggest sources of methane are all Chinese provinces: Shanxi, Inner Mongolia, Shaanxi, Anhui, and Henan. Besides China's provinces, Russia's Kemerovo coal region in Siberia and Australia's coal-rich Bowen Basin in Queensland are the only other regions that make it into the Top 10.

Only three other states and provinces outside of China make it into the ranks of the Top 15 worst emitters (Table 2 on the next page). Mpumalanga, South Africa ranks 11th; New South Wales, Australia ranks 12th; and the Appalachian region of West Virginia, United States ranks 13th. Besides China, only Australia has more than one state or province among the 15 worst emitters.

GEM also noted irregularities and points of discrepancy: West Virginia's total coal mine methane emissions are nearly three times higher than official figures reported to the UNFCCC in 2020 (10 Mt CO_2e100).

Figure 6: Annual Coal Mine Methane Emissions Ranked by Province or State



Source: Global Coal Mine Tracker and GEM analysis.

Table 2: Annual Coal Mine Methane Emissions Ranked by Province or State

State or Province	Country	Annual Methane Emissions (Mt CO_2e20)	Annual Methane Emissions (Mt CO_2e100)
Shanxi	China	1088	393
Inner Mongolia	China	611	221
Shaanxi	China	494	178
Anhui	China	158	57
Henan	China	136	49
Kemerovo	Russia	134	48
Shandong	China	121	44
Ningxia	China	118	43
Xinjiang	China	111	40
Queensland	Australia	88	32
Mpumalanga	South Africa	86	31
New South Wales	Australia	77	28
West Virginia	USA	74	27
Hebei	China	65	23
Gansu	China	63	23

WHICH COAL MINES EMIT THE MOST METHANE?

Unsurprisingly, individual coal mines in Shanxi and Inner Mongolia top the list of the worst emitters in the world (Table 3). The world's single largest potential emitter of coal mine methane is the Buertai coal mine in the northwestern part of China which underwent macromolecular testing by chemists at Xi'an University of Science and Technology who confirmed the coal has the capacity to hold very high levels of methane gas (known as the adsorption rate).

In the rest of the world, the coal mines that emit the most methane are ranked in Table 4. While these coal mines emit the most methane on an absolute basis, they are not necessarily the gassiest coal mines in operation—some of them emit large volumes of methane because they produce a large amount of coal.

The gassiest coal mines are those that emit a disproportionate amount of methane relative to their total greenhouse gas emissions, no matter their size. When it comes to mitigation, it is necessary to make this

Figure 7: Buertai coal mine, in northwest China, is potentially the largest single source of coal mine methane in the world.

Source: Google Maps.

Table 3: Five coal mines that emit the most methane in the world

Coal Mine	Province	Annual Methane Emissions (Mt CO_2e20)	Annual Methane Emissions (Mt CO_2e100)
Buertai Coal Mine	Inner Mongolia	23.3	8.4
Daliuta Coal Mine	Shaanxi	21.0	7.6
Jinjie Coal Mine	Shaanxi	21.0	7.6
Ningtiaota Coal Mine	Shaanxi	21.0	7.6
Suancigou Coal Mine	Inner Mongolia	21.0	7.6

TABLE 4: Coal mines that emit the most methane in 7 Countries

Coal Mine	Country	Annual Methane Emissions (Mt CO_2e20)	Annual Methane Emissions (Mt CO_2e100)
KPC Operation	Indonesia	17.7	6.4
LW Bogdanka	Poland	13.0	4.7
Yalevsky Mine	Russia	10.4	3.8
Bogatyr Mine	Kazakhstan	9.3	3.4
Grootegeluk Mine	South Africa	8.6	3.1
Oaky Creek Mine	Australia	6.5	2.3
No. 7 Coal Mine	United States	6.0	2.2

Source: Global Coal Mine Tracker and GEM analysis distinction, since the gassiest mines are often the worst performers and identifying them early is necessary to post-operations planning and closure scenarios.

The gassiest coal mines in the world can emit up to 40–50% of the mine's total greenhouse gas emissions (CO_2e20) in the form of methane. That means the amount of methane emitted from the gassiest coal mines is almost equivalent in short-term climate impact to the CO_2 produced from the burning of the coal itself.

The IEA has found that closing the worst-performing quartile of coal mines would remove more than 20 Mt of methane emissions, but closing the best-performing quartile would remove only 3 Mt. In other words, from the perspective of methane emissions, sometimes mitigating the emissions of a small coal mine in a gassy seam makes a bigger climate impact than mitigating a large coal mine in a low-gas seam.

GEM's Global Coal Mine Tracker shows that China has 284 particularly gassy coal mines scattered across its northern anthracite coal basins. We found that very few coal mines in South China provinces, some of which use anthracite "stone coal" in local villages and domestic settings, made the list.

Outside of China, gassy coal mines—those that produce roughly 40%-50% of their emissions in the form of methane—were found in North Korea, Russia, South Korea, and Poland. Table 5 lists the major gassy coal mines in each of those countries. The Pniowek coal mine in Poland, for instance, is known for such high methane content that mining is restricted at some coalfaces in order to keep gas levels within safe operating range. The Sangdeok coal mine in South Korea is one of the few privately owned and operated mines (Kyungdong Company) in the country.

Table 5: Gassiest coal mines in 4 countries

Coal Mine	Country	Annual Methane Emissions (Mt CO_2e20)	Methane Emissions in GHG Profile
Anju Coal Mining Complex	North Korea	20.8	45%
Sadkinskaya Coal Mine	Russia	4.8	45%
Gyeong-dong Sangdeok Coal Mine	South Korea	1.7	44%
Pniówek Coal Mine	Poland	4.2	37%

WORKERS AT RISK

Coal mine methane has posed a serious risk to workers ever since mining began. The earliest inventors of mining technologies during the Industrial Revolution sought to protect workers and animals from gas explosions underground. Today, coal operators have access to more advanced technologies, like drainage systems to recover methane before mining begins (known as "pre-mine drainage") and ventilation systems to move fresh air into the mine during operation and move the methane out. The primary focus of coal mine mitigation measures in place today is to ensure safety in the workplace.

Despite these best efforts, methane remains a danger to miners. In November 2021, a suspected methane-gas explosion at the Listvyazhnaya mine in Kemerovo region of Russia killed more than 50 workers and left dozens injured. A subsequent investigation found an explosion originated in a fire in a ventilation shaft. The rescue operations were temporarily suspended because of high methane concentrations that put search teams at risk. The accident was the country's deadliest since the Raspadskaya mine explosion in 2010 that killed 66 people and left 99 injured from a methane buildup.

In 2020, a methane gas explosion at the Grosvenor coal mine in Queensland, Australia, owned by Anglo American, seriously injured five workers who suffered extensive burns. An investigation found high methane levels and 14 reported "near misses" at the mine in the eight weeks prior to the accident. In 2022, the Office of the Work Health and Safety Prosecutor decided not to prosecute the company over the incident.

A coal mine explosion at a mine operated by the Feng Yan Group in Shanxi, China—likely the Yangdong Coal Mine which is known for coal gas outbursts—made international news in 2019 when it killed 15 miners and left 9 injured.

These incidents have occurred in mines with at least some methane mitigation technologies, and yet hundreds of smaller and "artisanal" coal mines spread across the developing world have no access to pre-drainage or ventilation systems. Coal mine methane poses a deadly hazard for workers and puts coal communities at risk. And coal mine methane's climate impacts spread the hazards of mining across the globe.

WHAT ABOUT CORPORATE EMISSIONS?

In all, 50 companies are responsible for over half (30 Mt) of the world's coal mine methane emissions. Together, they emit more methane than the entire global onshore oil industry (28 Mt).

But the source of even these major emitters is highly concentrated. Those 50 coal companies are headquartered in just twelve countries: China, USA, India, UK, Switzerland, Poland, Russia, Australia, Indonesia, North Korea, South Africa, and Vietnam. But overwhelmingly, China's state-owned enterprises are the primary culprits of methane emissions—including major entities like the National Energy Investment Group, State Power Investment Corporation (SPIC), Shanxi Coking Coal Group, Yankuang Group, and more. The 10 largest Chinese state-owned enterprises account for 14.5 Mt of coal mine methane emissions. Coal India, the world's largest coal producer, is the only non-Chinese state owned entity to rank in the Top 10 (Figure 8 on the next page).

The private or investor-owned coal companies with the largest methane emissions are primarily the world's major producers, including Glencore, Siberian Coal Energy Company (SUEK), American Consolidated Natural Resources, Peabody Energy, Anglo American,and Poland's JSW Group, among others (Figure 9 on the next page).

Figure 8: The 10 largest state-owned emitters of coal mine methane (Mt CO_2e100)

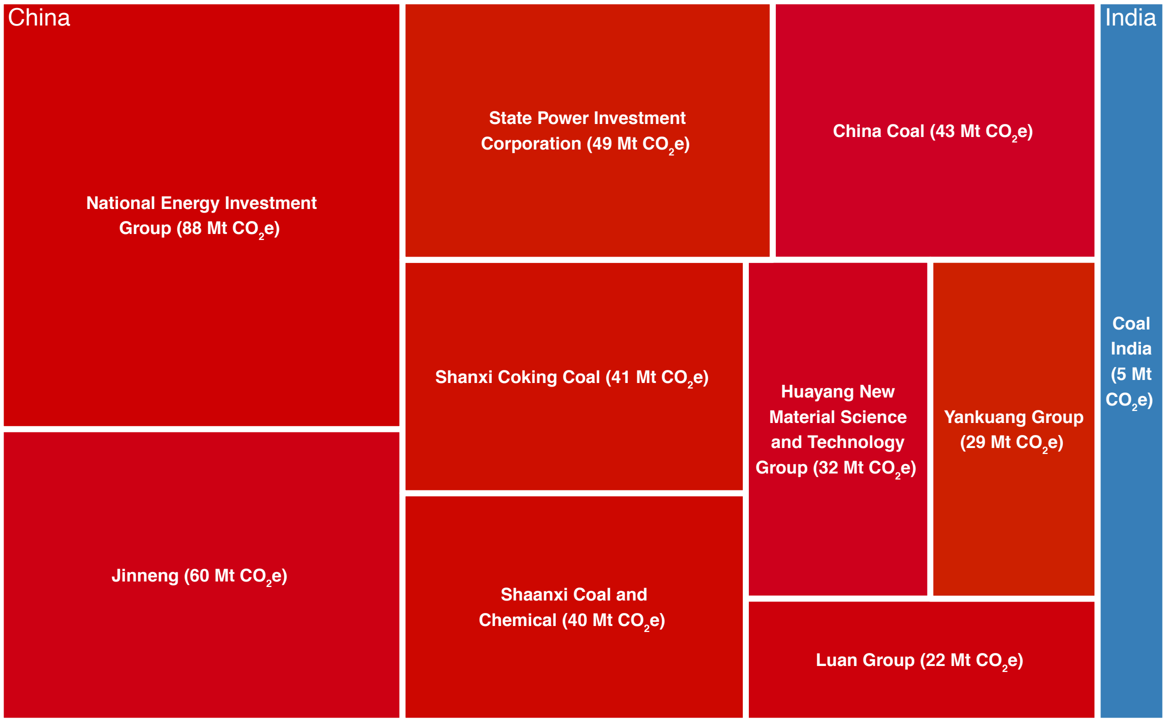
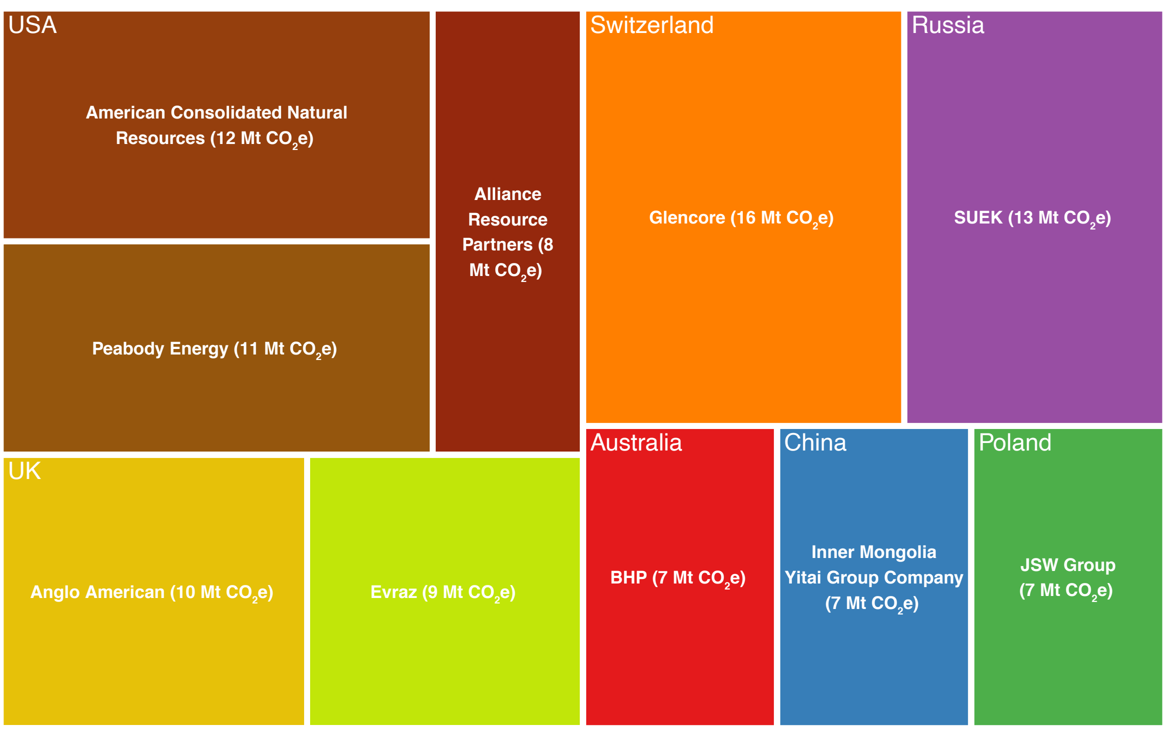


Figure 9: The 10 largest private or investor-owned emitters of coal mine methane (Mt CO_2e100)

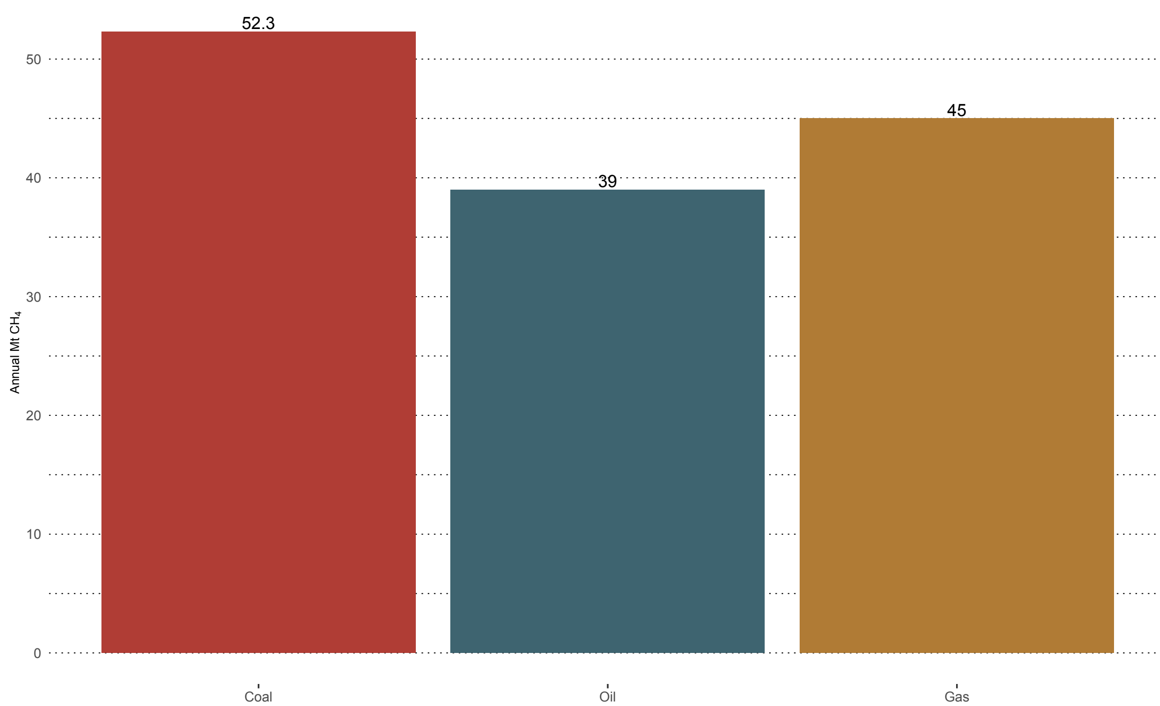


HOW DO COAL EMISSIONS COMPARE TO OTHER SECTORS?

Coal mining emits more methane than the IEA assessments of oil and gas (Figure 10), but more granular sector comparisons provide a sense of how emissions stack up. GEM's Global Coal Mine Tracker has documented thermal coal, metallurgical coal, mixed-grade coal operations (mines with coal that is usable for thermal or metallurgical consumers) and coal that is unspecified in use. We found that thermal coal operations (intended for power generation) emit 28 million tonnes of methane, a number identical to the IEA's findings in its latest Methane Tracker (2022), and comparable to the emissions from vented and flared onshore oil (28.8 Mt). GEM also found metallurgical coal operations—intended for steelmaking and other industry—emit 9.4 million tonnes of methane, more than vented and flared emission from offshore oil (7.8 Mt). Mixed thermal and metallurgical coal operations emit an additional 5 million tonnes and unspecified bituminous coal emits 9.5 million tonnes.

Understanding sector level emissions is necessary to ensure pathways for industrial decarbonization. The IEA's roadmap for Net Zero anticipates a precipitous fall in coal power generation that would dampen thermal coal production (coal use plummets by 55% from 2020 to 2030, and by almost 90% by 2050). But metallurgical coal (or coking coal) used for steelmaking and heavy industry is an ongoing concern since IEA's forecasts rely heavily on the adoption of carbon capture, utilization, and storage for conventional fuels in the industrial sector. While there's movement towards green steel technologies, some coal operators are still bullish about their prospect of mining metallurgical grade coal in the future. Given that metallurgical grade coal is bituminous, which tends to have a higher methane gas content at depth, coking coal mines may become a primary emitter of coal mine methane in the future—though that is not yet true today.

Figure 10: Coal mine methane emissions compared with sector emissions in oil and gas



Source: Coal data from Global Coal Mine Tracker and GEM analysis and oil and gas data for vented and flared and fugitive emissions from IEA Methane Tracker Database (2020).

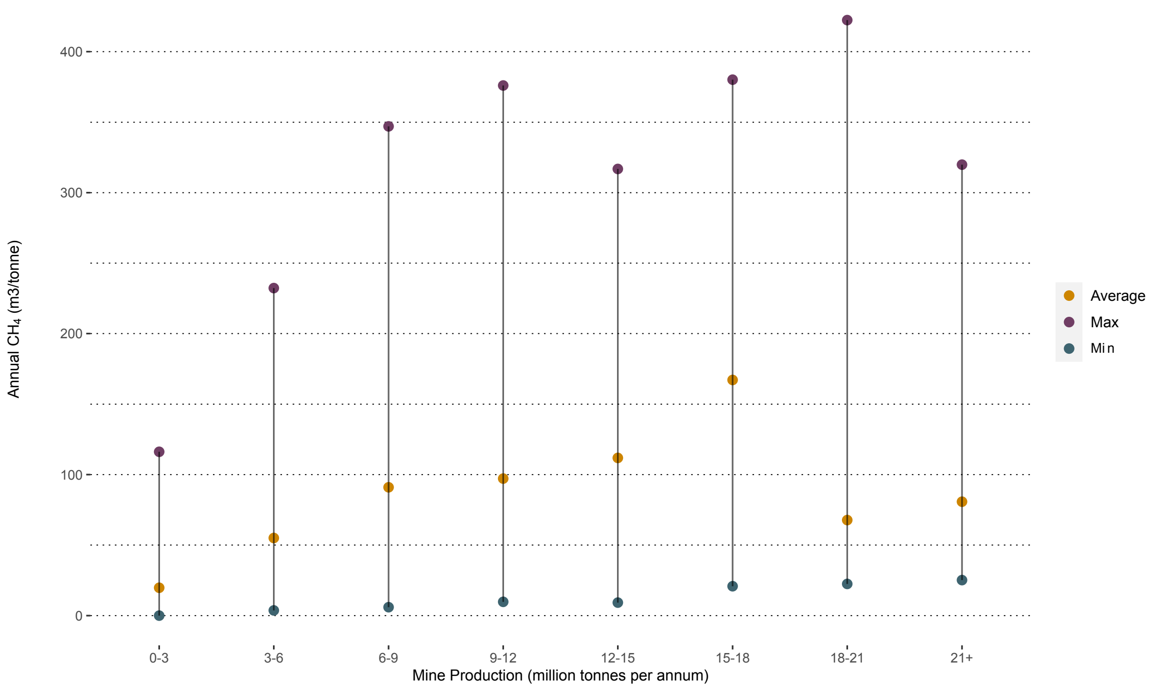
WHY DO MINES EMIT SUCH DIFFERENT AMOUNTS?

On average, we estimate that methane is responsible for 9.6% to 23% of a coal mine's greenhouse gas (GHG) emissions, for CO_2e100 and CO_2e20, respectively. These percentages have changed since our previous estimates, and the latest estimates by the IEA (2021), which found that methane accounted for approximately 7.5 to 20% of a mine's typical greenhouse gas emissions for CO_2e100 and CO_2e20, respectively, to reflect the IPCC's new global warming potentials for methane.

Some mines release far greater amounts of methane per tonne of coal mined than others. We found the world's gassiest coal mines can emit 67 times more methane than operations with a similar productivity level. We also found that the worst performing small gassy coal mines can emit 4.5 times more methane than the best performing large mines (Figure 11).

Underground mines typically emit more methane than surface mines since methane content increases with pressure and depth. As can be seen in Figure 11 above, the average level of methane emissions per tonne of coal mined (orange dots in the Figure) falls after operations surpass 18 million tonnes in production, as these larger mines tend to be surface

Figure 11: The range of methane emissions at mines with similar productivity



The range of emissions demonstrates that the worst performing small gassy coal mines can emit as much as 4.5 times more methane per cubic meter of coal mined than the best performing large mines. Source: Global Coal Mine Tracker.

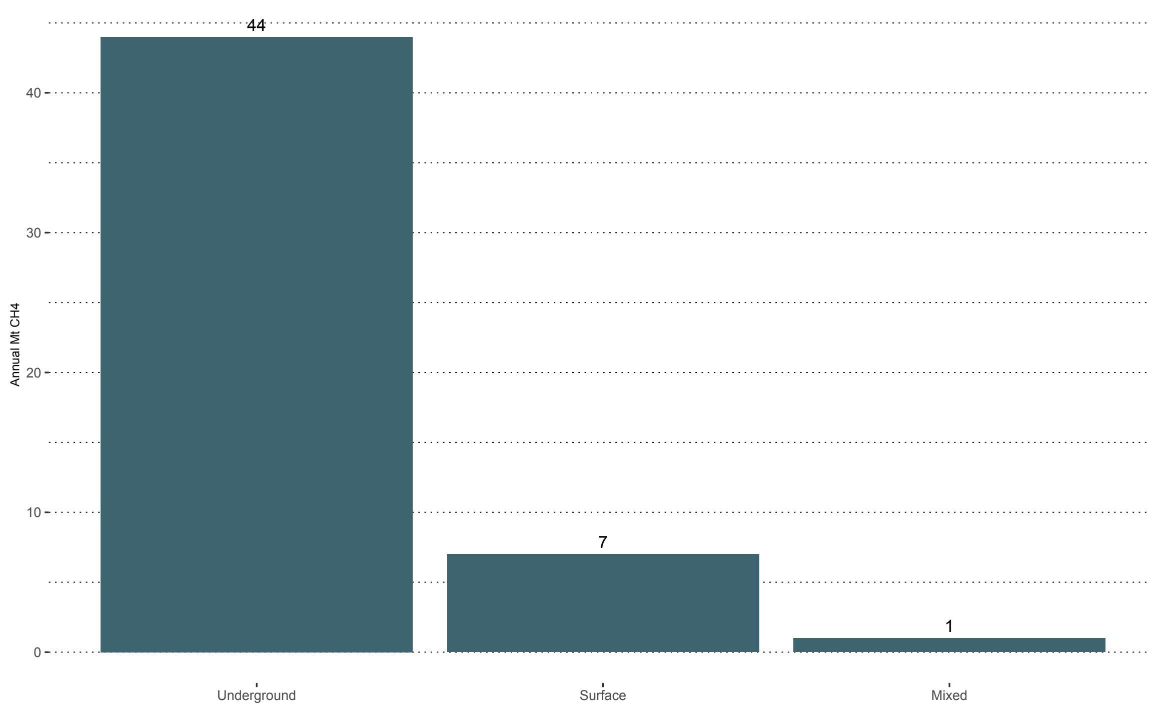
operations. In all, GEM found that 85% (44 Mt) of all coal mine methane emissions came from underground mines, compared to 15% (8 Mt) for surface and mixed mines (Figure 12).

Methane emissions from surface mines are particularly difficult to track given the size of the exposed area. But since they operate at shallow depths, most assessments presume they are relatively small emitters, especially compared to deep underground operations where the methane gas content is higher. The US EPA estimates that underground emissions currently account for 98% of global coal mine methane emissions, yet the MC2M model forecasts that surface operations could occupy a larger share before the end of the century, and comprise 23% of coal mine methane emissions, based on production forecasts of the SSP2-Baseline scenario, which examines how global society and economics might change over time.

New research from academics at SRON Netherlands Institute for Space Research—and independently verified by Kayrros in a separate analysis—further suggests that emissions at surface mines may pose a larger concern than previously thought. A series of methane hotspots has been observed near surface mines like Hail Creek in Australia, which, if so, emits far more methane than its national inventory, planning approvals, or industry estimates would suggest.

GEM's analysis shows several surface mines emitted far more methane than average—especially open pit mines operating in gassy seams at deeper ranges than normal, which is often the case in parts of China and Russia. Table 4 above shows that some surface mines made the list of the largest coal mine methane emitters (KPC Operation in Indonesia and Grootegeluk Mine in South Africa).

Figure 12: Coal mine methane emissions by mine type.

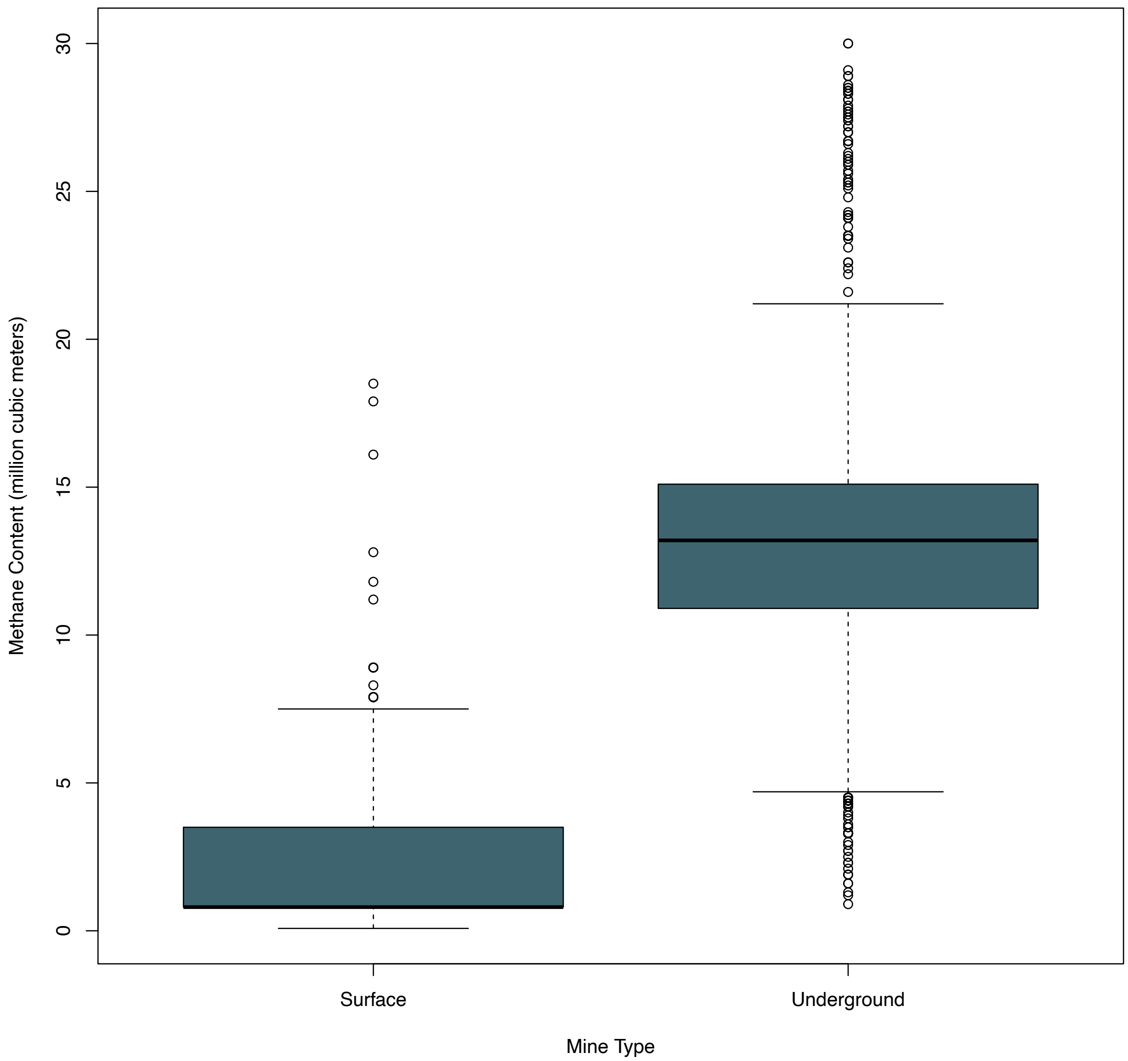


Source: Global Coal Mine Tracker

But even more noteworthy is the number of statistical outliers GEM found in surface mine operations. The median emissions from a surface mine was 0.8 cubic meters per tonne of coal mined, but some surface mines in this study emitted up to 18 million cubic meters per tonne, which is comparable to underground operations.

Our findings reinforce the urgent need for more data and research into the emissions from surface coal mines, especially since independent satellite tracking has found a number of methane hotspots in their vicinity. If surface mines are larger emitters than previously known, then almost every global assessment will have undercounted them, making underestimated coal mine methane emissions even larger than anticipated.

Figure 13: Methane content of coal mines



The median methane gas content for surface coal mines (left) is 0.8 cubic meters (m3) per tonne with an interquartile range of 0.8 m3 to 3.5 m3 per tonne. In comparison, the median for underground mines (right) is sixteen times higher at 13.2 m3 a tonne with an interquartile range of 10.9 m3 to 15.1 m3 per tonne. This can be compared with the IPCCs weighted global emission factor of 11.9 m3/t (2006) for surface and underground mining in all countries. In GEMs analysis, some of the gassiest surface mines, circles in top left, are outliers in Inner Mongolia and Shanxi, China, with deep surface operations. The gassiest underground mines—outliers clustered in top right reach 30 m3 per tonne (circles in top right). Source: Global Coal Mine Tracker and GEM analysis.

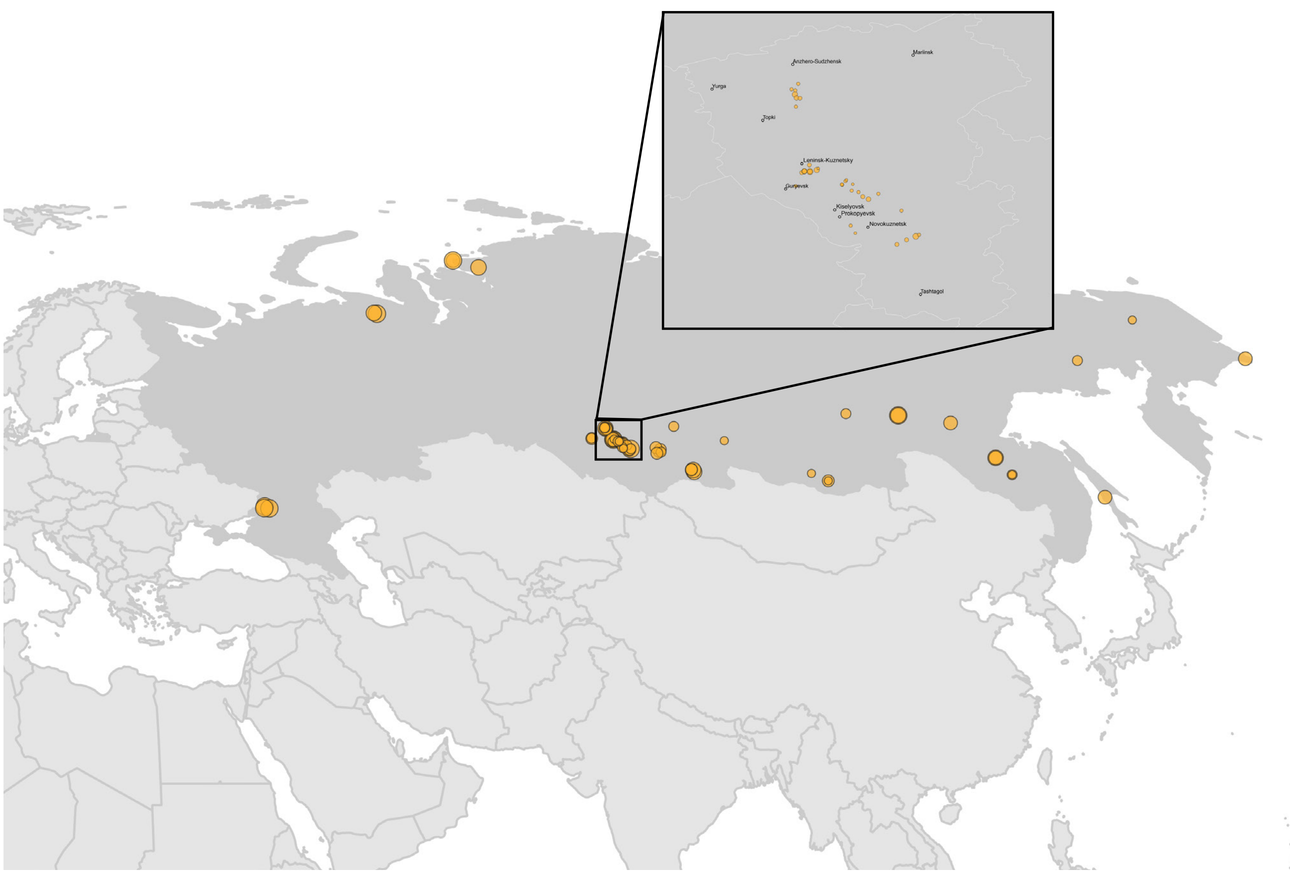
WHAT ABOUT PROPOSED MINE PROJECTS?

Until our first coal mine methane briefing last year, no study had estimated the potential methane emissions from coal mines in development. We previously found that 432 new mines or mine expansions would emit 13.5 Mt of methane annually, but the amount of proposed mines has since changed due to project cancellations, project scaledowns, and new projects entering the development pipeline.

The Global Coal Mine Tracker shows that 465 new mines or mine expansions are currently under development. Together, these mines could emit 11.3 million tonnes of methane per year, equivalent to 936 Mt of CO_2e20 or 338 Mt of CO_2e100 each year. By comparison, 936 Mt of CO_2 exceeds the short-term climate impact from coal-based CO_2 emissions of the United States (888.65 Mt CO_2 in 2020). If only the mines currently under construction open, proposed projects will still introduce roughly half those emissions—473 Mt of CO_2e20 or 171 Mt CO_2e100.

By far, the largest potential increase in global coal mine methane emissions comes from 169 new mines currently under development in China. If all China's proposed mines open as designed, GEM estimates that China will emit an additional 6 million tonnes of

FIgure 14: Potential coal mine methane emissions from proposed mines in Russia



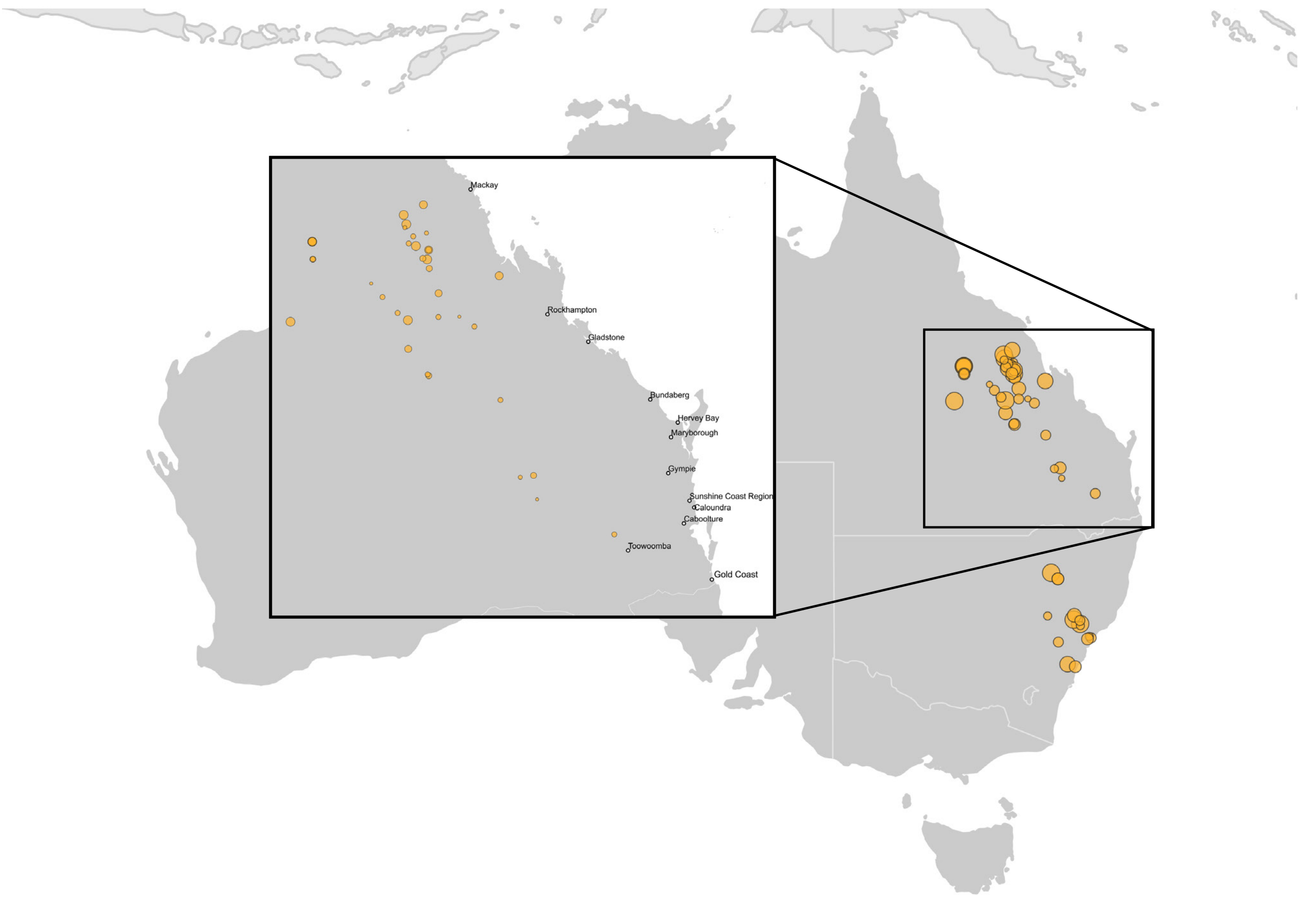
The yellow dots represent proposed coal mine methane emissions in Russia, scaled to emissions in million cubic meters per year. The pullout box shows proposed mines in Kemerovo, the country's largest potential source of new emissions. Source: Global Coal Mine Tracker and GEM analysis.

methane per year from these projects. At present, 82% of these projects are under construction, suggesting new methane emissions may be already locked in, requiring steeper production cuts at existing operations and the widespread adoption of post-mine mitigation schemes to curb further emissions increases.

Second to China is Russia, which could also make a large contribution to new methane emissions from mining activities. Russia has 69 projects under development, according to our Global Coal Mine Tracker, with a potential emission of 1.53 million tonnes more tonnes of methane per year. But two-thirds of these projects are in the early phases of planning and have yet to receive full permits, suggesting these projects may still be shelved or canceled in the years ahead.

Australia is the third potential emitter of new methane emissions, closely behind Russia, with 53 mine projects under development and the potential to emit 1.47 more tonnes of coal mine methane per year. Similar to Russia, almost two thirds of these projects are still in early phases of planning, and yet to be fully permitted, suggesting there is still time to halt these projects before they become new sources of emission.

Figure 15: Potential coal mine methane emissions from proposed mines in Australia



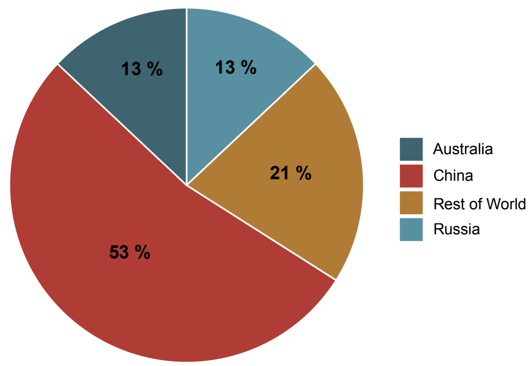
The yellow dots represent proposed coal mine methane emissions in Australia, scaled to emissions in million cubic meters per year. The pullout box shows proposed mines in Queensland, the country's largest potential source of new emissions. Source: Global Coal Mine Tracker and GEM analysis.

Together, China, Russia, and Australia comprise 80% of potential emissions from new coal projects (Figure 16).

As for the gassiest mines, those with the potential to unleash the most methane relative to their total greenhouse gas emissions, several proposed mines in China, Russia, United Kingdom, Uzbekistan, and Australia could emit 40-50% of their greenhouse gas emissions in the form of methane, ranking among the gassiest mines in the world, as shown in Table 6.

Although these mines could emit 40-50% of their annual greenhouse emissions in the form of methane, GEM finds that other mine projects with a larger capacity could emit more methane per year on an absolute basis. Such mines include the Red Hill Project in Australia, the only non-Chinese proposal to rank in the Top 10. If developed, the project could emit 6.2–17.1 Mt CO_2e100 and CO_2e20 per year, respectively, making it one of the largest emitters in the world

Figure 16: Share of annual methane emissions by country from proposed mines



Source: Global Coal Mine Tracker and GEM analysis.

Table 6: Gassiest mines under development in 5 countries

Proposed Coal Mine or Expansion	Country	Annual Methane Mt CO_2e20	Annual Methane Mt CO_2e100
Bailongshan No.1 Coal Mine	China	6.4	2.3
Obukhovskaya No. 1 Coal Mine	Russia	6.2	2.2
Aberpergwm Coal Mine	United Kingdom	0.8	0.3
Shargun Coal Mine	Uzbekistan	1.8	0.6
Tahmoor South Coal Mine	Australia	2.9	1.0

WHAT ABOUT ABANDONED COAL MINE METHANE?

To date, GEM has not systematically tracked abandoned and closed mines in the Global Coal Mine Tracker, although inclusion of these mines is planned for future updates. As a result, abandoned coal mine methane emissions are not currently estimated in this study. Yet research suggests that abandoned coal mines may pose a serious climate concern now and increasingly in the future, especially given the sheer number of mines that will close as multiple countries have pledged to phase out the use of coal over the next few decades. Without proactive planning and post-mining mitigation procedures, abandoned mines can continue to leak methane for decades. Given this, Global Energy Monitor plans to analyze abandoned coal mine methane in future iterations.

WHAT IS TO BE DONE?

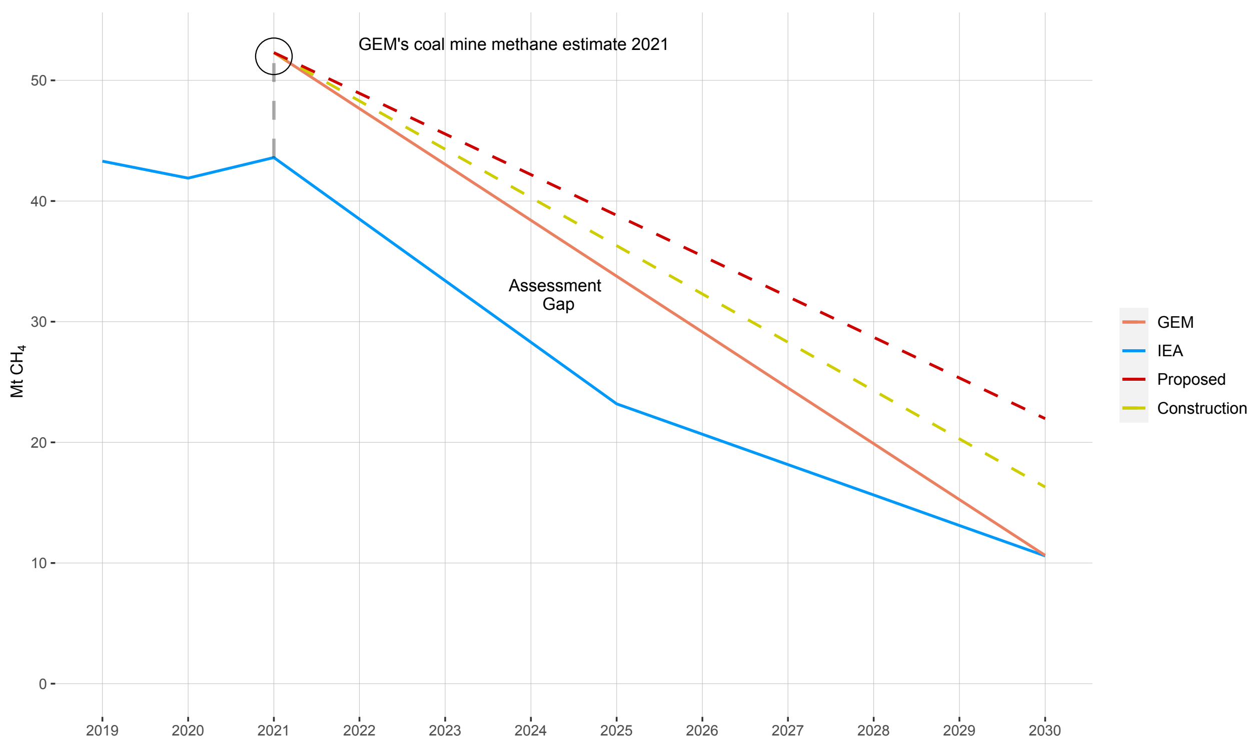
Despite being larger than the methane emissions from either oil or gas production, methane emissions from coal mining have received much less attention from researchers and governments. IEA's Methane Tracker estimates that coal producers need to reduce mine methane emissions 75%, or 31 Mt, before 2030. But according to IEA analysis, country pledges to phase out coal power will only get us half way there (15 Mt), with nearly half the amount (7 Mt) coming from countries that have yet to commit to such policies. The IEA anticipates that mitigation actions, such as "minimising methane leaks" and supporting "well-managed mine closures", will reduce emissions a further 8 million tonnes.

But if coal mine methane emissions are higher than IEA assessments—as GEM has found from a mine-level analysis—then even steeper cuts are needed over the next 8 years to remain in line with IEA's Net Zero 2030 scenario (Figure 17).

GEM's global assessment suggests coal methane emissions need to fall 41.7 Mt to meet IEA's Net Zero 2030 targets, rather than 31 Mt planned for in the IEA scenario. To do so, coal mine methane emissions must fall 11% each year until 2030. Assuming IEA's phase down scenario proceeds as forecasted, methane gas capture technologies would need to almost match the impact of the phase-out of coal by reducing emissions by 19.7 Mt, 2.5 times more than IEA's expectations. But without new and unprecedented regulations on coal mine methane emissions—especially in major emitter countries like China, Russia, and Australia—then a faster coal phase-out is the only means to keep emissions on track.

Additionally, proposed coal mines pose a problem of their own: the outright cancellation of new mine projects—in line with IEA's roadmap for net zero emissions—is the only way to guarantee zero emissions from new sources. But operators of new projects are not always making methane mitigation a top

Figure 17: Coal mine methane emissions reductions necessary under Net Zero 2030



priority. Operators of the recently proposed expansion of the Aberpergwm Colliery in South Wales, for instance, have confirmed to the British media that it has no methane mitigation in planning. That means proposed and new mines could continue to blunt reductions made from the phase down of existing operations. Without mitigation measures, just the coal mines already under construction will add 5.7 million tonnes of methane before 2030, nudging the phase out to net zero more than 50% higher than required, and necessitating precipitous declines in production elsewhere to make up for new sources of emission (Figure 17, yellow and red dashed lines).

Coal mine methane is mitigated with capture technologies implemented prior to mining (such as degasification and drainage) and during active operations (such as ventilation air methane), or the methane is transformed into CO_2 through flaring. But neither capture nor destruction are industry standards. In fact, even the utilization of coal mine methane for energy is still uncommon. The only guaranteed way to produce no new emissions from coal mines is to open no new mines, in line with the IEA's recommendations for its Net Zero 2050 roadmap.

WHY DO COAL MINE METHANE ASSESSMENTS VARY?

For many years, the most authoritative emissions data were found in the national inventories self-reported to the UNFCCC by national governments. These assessments provided a foundation for several international estimates, including those by the U.S. Environmental Protection Agency (EPA), the Emissions Database for Global Atmospheric Research (EDGAR), and the International Energy Agency (IEA).

Yet non-Annex 1 parties—such as major coal producers China, India, Indonesia, and South Africa—report with less frequency, and in some cases, have not updated emissions figures in 25 years. When those figures are reported, mining methane emissions are sometimes irregular: Indonesia, the third largest coal producer in the world (564 Mt), for instance, last reported solid fuel methane emissions in 2000, with a figure 17 times lower than the solid fuel methane emissions reported in 2013 by Mexico, a country that only produces 9 Mt of coal. If the most recently available data were aggregated, then national governments only take responsibility for about 31 Mt of coal mine methane emissions, a figure at least several tonnes smaller than even the smallest major global assessment.

One reason for the discrepancies in global estimates is the variance in methodology. Coal operators rarely use continuous emissions monitoring systems (the most accurate) nor do they report spot measurements to government agencies or third-party organizations unless they're under regulatory obligations to do so. The sparseness of fugitive emissions data has required many governments and international agencies to estimate global emissions using one of two main methods: (1) a "bottom-up" approach that matches mining sector activity data with an appropriate emission factor or (2) a "top-down" approach that uses atmospheric observations and models to infer emissions.

The "bottom-up" methodology tends to correspond to IPCC's three tiers of assessment: Tier 1 requires the use of a global average range of emission factors and country-specific activity data to estimate emissions; Tier 2 requires the use of country- or coalfield-specific emission factors to estimate emissions; and Tier 3 requires the direct measurements of emissions at the mine itself.

Australia, India, and the United States report that they aggregate at least some of their national coal mine methane emissions using Tier-3 methodologies, which has the highest degree of confidence. Still the methodology is not foolproof since even measurements can fluctuate depending on the monitoring system, monitoring frequency, and user experience. According to a satellite monitoring study by scientists at SRON Netherlands Institute for Space Research, coal mines in Australia, for instance, may emit far more methane than currently accounted for, suggesting a "large underreporting of methane emissions in the national inventory."

The suggestion that even high-quality methodologies used in reports to the UNFCCC may underestimate emissions is supported by observations from Kayrros, a French geoanalytics firm, that found the methane intensity of Australia's coal mining is 47% higher than estimates from the IEA. Since Australia collects mine-level data but reports it only in the aggregate—at the state and national level—verification of mine-specific methane figures is not always possible. A new study Australian Conservation found that a number of mines are "overemitters", emitting far more CO_2e, including methane, than their project approvals permitted.

Australia is not alone: satellite data from Carbon Mapper, a US-based NGO, found that just four underground mines in Pennsylvania alone accounted for a whopping 22% of total U.S. methane emissions—a highly unlikely scenario and further evidence that emissions have likely gone underestimated for years.

Then in 2022, the IEA reported that methane emissions are 70% higher than UNFCCC official tallies.This important reassessment by the world's leading energy information source comes after years of academic, industry, and NGO research, including studies from the Community Emissions Data System (CEDS) and MC2M, who use different methods of estimation yet still agree that global coal mine methane emission estimates are too low, and could be one or two times higher than previously reported.

"Top-down" assessments provide an abundance of specific cases: in 2021, satellite monitoring detected emission hotspots in the coal regions of South Africa, Australia, United States, and China, raising serious questions about endemic and inadvertent underreporting in each country. These methodologies rely on advances in the use of two types of satellite technology: 1) global monitoring with broad coverage at low resolution (GOSAT, TROPOMI) and 2) site-specific monitoring with high resolution (GHGSat and MethaneSAT).

Figure 18: Satellite detections of methane leaks in coal regions

Top down assessments may use satellites and remote sensing. Source: Kayrros.

HOW DO WE DO THIS RESEARCH?

Global Energy Monitor has used its Global Coal Mine Tracker—a database of operating and proposed coal mines worldwide—to model global methane emissions estimates at the individual mine level and aggregate it for national and global scales.

The Global Coal Mine Tracker monitors every known operating coal mine producing 1 million tonnes per year or more, and smaller operations whenever possible. The current database—updated in January 2022—includes 2,312 operating coal mines that account for 7,085 million tonnes, or 93% of global coal mining production. The Global Coal Mine Tracker also includes proposed coal mines and mine expansions with a designed capacity of 1 million tonnes per year or more (currently 448 projects that amount to 1,944 Mt of capacity).

We have estimated methane gas content at each mine in our dataset based on the mine's depth and its rank of coal. The methodology follows that of the Model for Calculating Coal Mine Methane (MC2M). Whenever possible, the Global Coal Mine Tracker

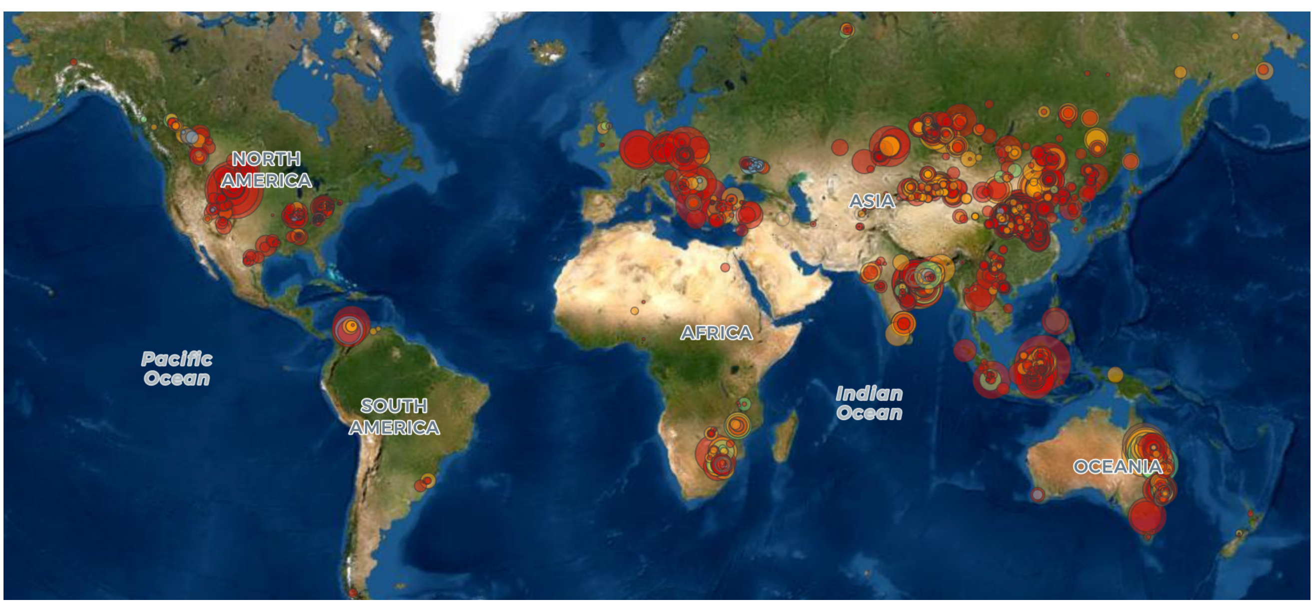
WHAT IS THE MC2M MODEL?

A 2020 study led by Nazar Kholod of the Pacific Northwest National Laboratory and industry experts developed a methodology (MC2M) to calculate methane emissions at specific depths. MC2M uses a Langmuir isotherm formula for the appropriate rank coal at the depth of mining. The equation, which is an industry standard, infers coal's gas sorption capacity at a certain pressure or depth. MC2M further supplemented its model with the isotherm testing of 200 coal samples collected from various coal basins worldwide.

MC2M uses an emissions factor (EF) coefficient to represent the average ratio of emissions to gas content. The underlying data applied an EF of 1.5 m3/tonne for hard coal surface operations and 1.6 m3/tonne EF for hard coal underground operations. These EFs are similar to those used by Australia's national inventory. While gas content in coal basins vary widely in Australia, the government found an average EF of 1.7 m3/tonne of raw coal (of which 75% is methane and 25% is CO_2).

MC2M factors production, gas content at depth, and the relevant emissions factor to estimate global coal mine methane emissions. Global Energy Monitor has adjusted the methodology to apply it to the individual mine level.

Figure 19: Global Coal Mine Tracker



Global Energy Monitor's Global Coal Mine Tracker is the source data for methane emissions in this study. Source: Global Coal Mine Tracker uses exact data for the coal rank and depth of each mine. We supplement estimates for mine depth for underground and surface operations when those exact figures are not publicly available (Figure 20). Of note, we found that our county-level coal mining depth estimates were broadly similar to those published by the IEA in the World Energy Outlook in 2019, though our data suggest China's coal mines operate at slightly deeper depths.

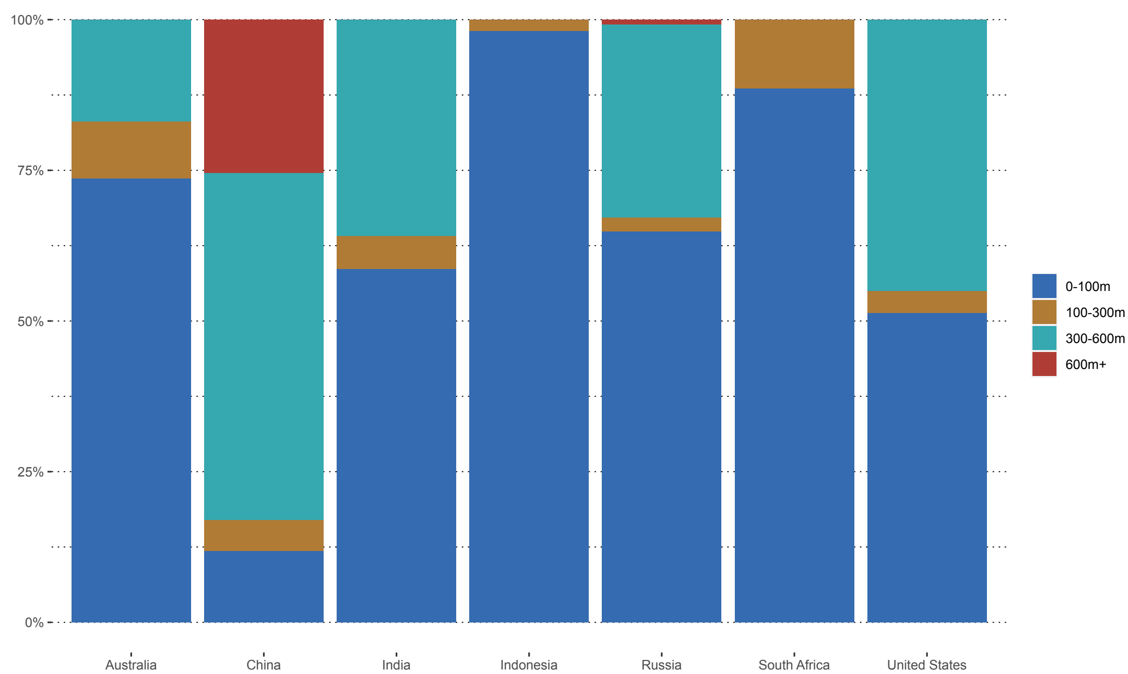
After we modeled methane gas content at depth, we factored mine production and the emissions factor coefficient (EF) based on the type of mine (underground or surface). The activity data combined with an average ratio of polluting emissions to gas content provided us with an estimate of each mine's methane emissions.

While utilization and mitigation activities decrease the volume of methane emitted into the atmosphere, the Global Methane Initiative has found that only a small percent of coal mine methane emissions are used today, with only 156 coal mine methane abatement projects in operation globally, reducing coal mine methane emissions by an average of 0.15 Mt CO_2e100 per year. We have not estimated coalbed methane production where no mining is planned or ongoing.

Table 7: A sample of methane content at depth used in MC2M and Global Energy Monitor analysis

Depth (m)	Anthracite (m3/tonne)	Bituminous (m3/tonne)	Subbituminous (m3/tonne)
100	11.4	5.3	1.4
200	17.1	8.6	2.5
300	20.4	10.9	3.3
400	22.6	12.5	4
500	24.2	13.8	4.5

Figure 20: Coal mine depths in major producers



Source: Global Coal Mine Tracker