Monitoring, reporting and verification of fossil methane in Australia

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ENERGY & RESOURCE INSIGHTS

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Briefing Report

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Executive summary

The launch of the Global Methane Pledge in 2021 dramatically increased the attention that is being paid to methane around the world. The Australian federal government became a signatory to the Pledge in the second half of 2022. Despite signing, Australia does not have concrete plans demonstrating how it intends to play its part in meeting its commitments under it.

The primary purposes of this briefing note are to synthesise what is known about Australia's contribution to global methane emissions through production and processing of fossil fuels and to highlight some shortcomings in Australia's approach to methane reporting and verification.

Australia is a globally significant emitter of fossil methane, driven by the country's very large coal and gas export sectors. Australia is the world's largest metallurgical coal exporter, the world's equal largest liquefied gas exporter and the world's second largest thermal coal exporter. By carbon content, Australia is the world's third largest fossil fuel exporter. Even before these fuels are burned by our export partners overseas, the production and processing of Australia's fossil fuels make a large contribution to climate change. The largest share of the pre-combustion climate burden from Australia fossil fuel production is from methane emissions.

Accurate monitoring of methane is an essential aspect of reigning in methane emissions. There is a substantial gap between the observed increase in atmospheric methane concentrations and the reported cumulative total methane emissions that countries report under the United Nations Framework Convention on Climate Change. This indicates widespread under-reporting of methane emissions. The IEA's Global Methane Tracker 2023 estimates that total annual fossil methane emissions are 70% higher in reality than the cumulative total that is reported to the UNFCCC. While IEA's estimate of the discrepancy is slightly below the global average for Australia - the country's reported emissions should be 60% higher - this is nonetheless a large and concerning gap.

It is essential that Australia take dramatic steps to increase direct measurement of fossil methane everywhere that this is possible and invest in improving the quality and accuracy of estimates where it is not. A select number of large sources of fossil methane are directly measured - including methane produced from underground coal mining activities, which is the largest, and responsible for around half of reported fossil methane emissions. However, the amount of fossil methane released from almost all other emissions sources are estimated using simple equations that multiply some form of easy to obtain activity data by a simple emissions factor.

Where emissions factors must be used, it is essential that the factors have a high degree of integrity. The reported emissions derived from these methods are only as accurate as these factors. Often, the emissions factors are directly taken from research that was conducted on other continents, was conducted at small-scale, was conducted as much as three decades ago, or was conducted under circumstances where it is difficult to guarantee that the outcomes were free of industry pressure and influence. Rarely, emissions factors are determined by on-site sampling. However, there is significant room for intentional under-reporting in this area. Recent evidence of systematic fraud in the related area of coal quality testing demonstrates that this is more than a hypothetical concern, and that a higher quality of integrity should be required of these methods.

This briefing note is broadly in two halves. The first half provides the context for Australia's fossil methane emissions by stepping through Australia's methane emissions as reported by the federal government without canvassing the potential for reporting errors. In the second half, this note discusses the reporting methodologies that are used to create those estimates while identifying a number of potential shortcomings in the approaches that are used.

Methane in a global context

Atmospheric methane concentrations and climate impact

- **Atmospheric methane concentrations are not only increasing, but are increasing at an accelerating rate.** 2020 saw a record increase in atmospheric methane concentrations - with around 15 parts per billion being added - only for this record to be immediately surpassed in 2021 - when a further 18 parts per billion were added.[1] Partial data for 2022 indicates that the most recent calendar year may have again seen a record increase in atmospheric methane concentrations.

- **Methane is the second most important greenhouse gas**, responsible for around one-third of the warming seen since pre-industrial times.[2] During this period, methane concentrations in the atmosphere have increased from around 720 parts per billion in the atmosphere[3] to over 1900 parts per billion.[1]

- Immediately upon reaching the atmosphere, each tonne of methane traps heat at least 120 times more than an equivalent mass of carbon dioxide.[4] Over the course of a decade, methane breaks down through a complex series of chemical interactions and carbon dioxide is one of the ultimate decomposition products. Carbon dioxide in the atmosphere is stable and does not break down over meaningful timescales. This means that over shorter timeframes, which are of critical importance to efforts to curb global warming, methane is a much more potent greenhouse gas than carbon dioxide. Australia currently uses a factor of 28 to quantify the relative potency of methane as a greenhouse gas over a 100 year time frame compared to an equivalent mass of carbon dioxide. [5]

- **Long-term, methane produced from fossil fuel sources is worse for the climate than methane produced from non-fossil sources.**[6] This is because biogenic methane is derived from CO_2 that was recently captured from the atmosphere via photosynthesis whereas fossil-fuel-derived methane breaks down to form CO_2 that has not been present in the atmosphere for many millions of years (and so is effectively additional). For large fossil methane sources that are releasing methane at a continuous rate over time, the difference can prove to be significant. Accounting for this additional burden accurately can reveal a significant additional impact that is often neglected in national accounts, including Australia's.[7]

Sources of methane globally

- **Around a third of all human-induced emissions of methane come from fossil fuel energy production and consumption.** Just over half comes from the agriculture and waste sectors and the remainder from land use change.[8]

- **Around nine-tenths of methane emitted from the energy sector is released as fugitive emissions from coal, oil and gas.**[9] Most of the remaining energy sector methane emissions come from biofuel production and use.

- **The annual change in atmospheric methane concentrations is higher than expected when compared to the cumulative total of methane emissions that are reported to the UNFCCC.** While there is considerable uncertainty about why this has occurred,[10] a substantial share of the difference appears to be attributable to inaccurate reporting of methane emissions from fossil fuel infrastructure.[11]

- **Recent IEA research has pointed to substantial underreporting of fossil methane emissions.**[12] IEA's analysis - which is based on the latest available scientific studies and measurement campaigns - estimate that global methane emissions from the energy sector are approximately 70% higher than the total that is reported by countries.

Methane mitigation in a global context

- **Early action to eliminate sources of methane will have a significant impact on the future of the global climate.**[13] Due to its profound impact on the climate and relatively short atmospheric lifetime, eliminating sources of methane - and avoiding new sources - will rapidly deliver temperature benefits, even as soon as 2050.[14]

- **Avoiding the worst of climate change requires fossil fuel methane emissions from developed countries to fall to 75% below 2020 levels and 2030.** This is confirmed by multiple lines of evidence, including work conducted by the International Energy Agency and modelling conducted for the Intergovernmental Panel on Climate Change's Sixth Assessment Report.

    - The International Energy Agency's Net Zero by 2050 scenario - which notionally limits global temperature increase to 1.5°C above pre-industrial levels - methane emissions from fossil fuels fall by 75% between 2020 and 2030.[15,16]

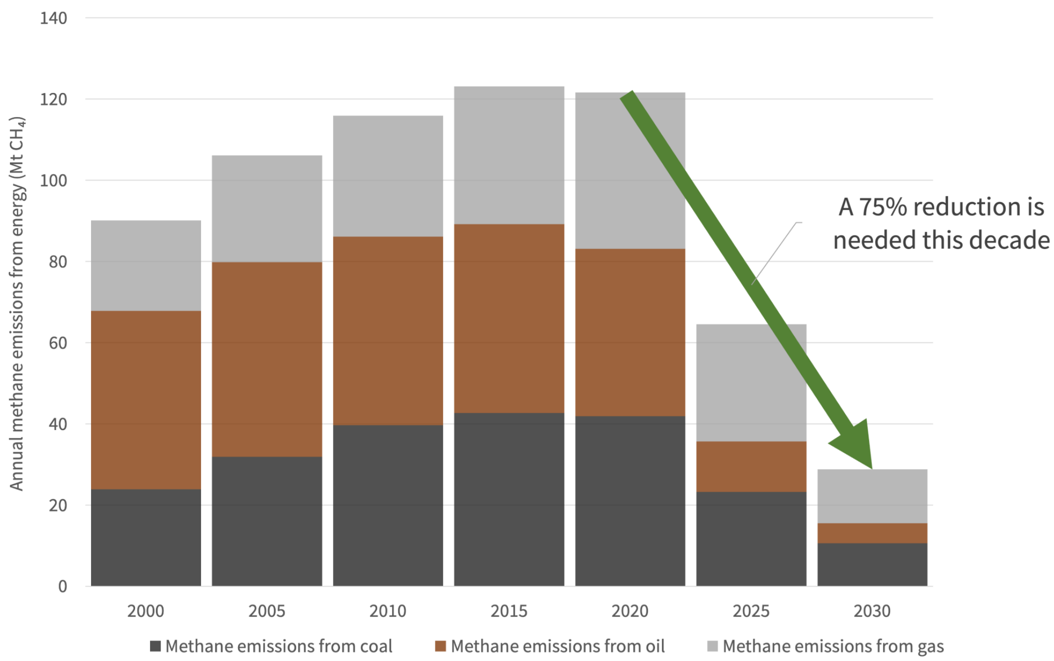

Figure 1: Methane emissions from energy in the IEA's Net Zero by 2050 scenario. Data source: IEA.[17]

- Achieving this pathway requires dramatic reductions in coal production. In the International Energy Agency's NZE2050 scenario, about two thirds of this overall reduction comes from improving the efficiency of overall fossil fuel infrastructure, and one third from decreased production.[16] However, for coal mines, this is reversed. Around three quarters of methane reductions in that scenario come from decreased production and only one quarter from improved efficiency.

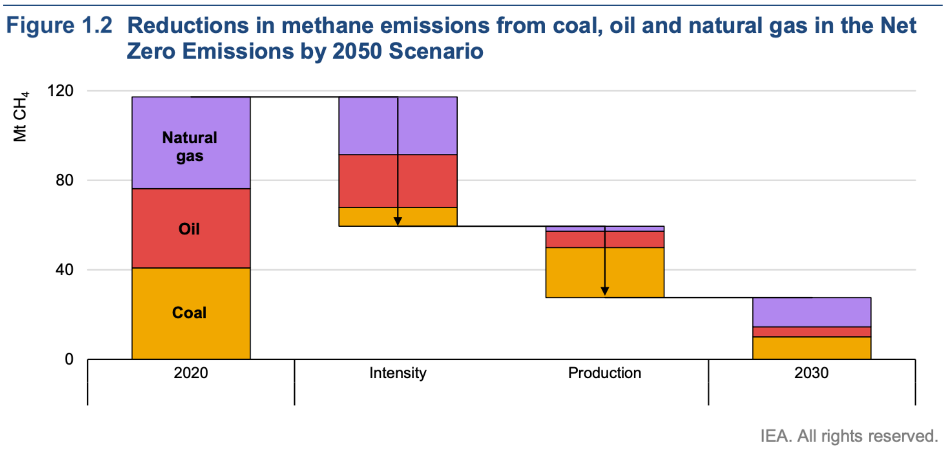

Figure 2: Methane emissions reduction from energy sources in the IEA's Net Zero by 2050 scenario. Chart source: IEA.[16]

- **The IEA is no outlier.** The IEA's 75% reduction is backed up by the most recent IPCC assessment report. In working group III's contribution to the sixth assessment report,[18] those illustrative mitigation pathways where global temperature increase in 2100 was less than 1.5°C above pre-industrial levels see methane emissions from energy in developed countries fall by 70 to 75% between 2020 and 2030. Scenarios to limit temperature increase to well below 2°C likewise see significant reductions in methane emissions from energy. In these scenarios methane emissions from energy in the OECD would fall by between 30 and 55% between 2020 and 2030.[19]

- **The short-lived, but very high, impact nature of methane means that it is not suitable to offset, and should be reduced at source.** The unique traits of methane, including its short lifespan and intense heat-trapping potential means that it is often poorly managed when emissions from methane and carbon dioxide are considered interchangeable, even after applying a conversion factor.[20] Unique technical and policy approaches are required to effectively manage this greenhouse gas.

- **There are a broad range of established, viable options to dramatically reduce methane emissions from fossil fuel infrastructure.**[16] Many of these are very cheap, and others would bring substantial overall economic benefits. In several instances, mitigation of methane emissions is profitable in its own right.[21] The economics of methane mitigation has improved even further since the Russian invasion of Ukraine.[12]

- **Options required to reduce agricultural methane are frequently still in the early stages of development.**[21] While many developments in this space are novel and show potential, from both a technical and policy development perspective considerable work needs to be done to shore up the viability of many measures to reduce agricultural methane emissions.[22]

- **50 countries have or are developing national methane action plans.**[23] Countries with completed methane action plans include the USA, Mexico, Canada, and Norway, and the European Union has also released one covering its member nations. Importantly, Japan - which is the largest recipient of Australian coal and gas - joined a US-led declaration late in 2022 that had the explicit purpose of cutting fossil methane emissions from trade.[24] Of Australia's largest coal and gas export partners, Japan, Korea, and Vietnam have signed the Global Methane Pledge. These nations cumulatively account for $55.3b (48.8%) of Australia's total $113.3b of annual coal and gas exports.

Australia's reported methane emissions: by the numbers

The following section describes Australia's annual methane emissions as reported to the UNFCCC. In reading this section, it should be noted that later sections of this report raise potential methodological issues which affect the accuracy of this reporting. The potential scale of underreporting is very large. A recent assessment from the International energy agency found that Australia could be underreporting its fossil methane emissions by as much as 60%. This is equivalent to the fossil methane emissions of Germany, the United Kingdom and France combined.

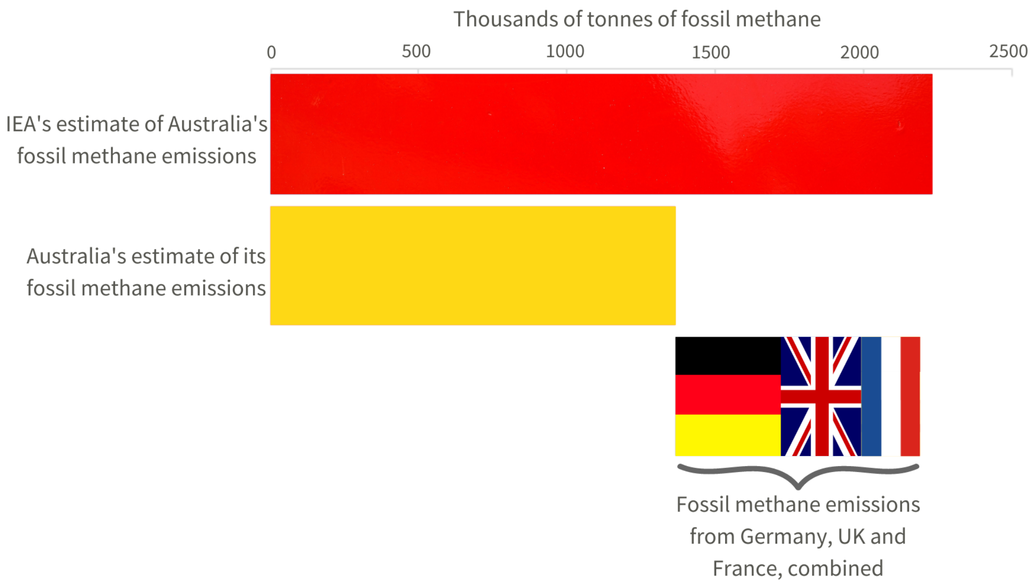

Figure 3: Methane emissions from energy in the IEA's Net Zero by 2050 scenario. Data source: IEA[12] and AGEIS[25]

Australia's methane emissions generally

- **Australia is a globally significant methane emitter.** Australia is responsible for a greater share of global methane emissions than many major developed economies including France, Germany, Great Britain and Italy and many major fossil fuel producers such as Saudi Arabia, Canada, Norway, Qatar, and Poland.[9]

- **Australia reports that its total methane emissions have been falling.** Since 1990, most years have been reported as having lower total methane emissions than the year preceding it. On average, emissions in each year have been 0.89% below the preceding year, with an average annual reduction of 46 kt per year.

- **Australia reports that its fossil methane emissions have been stable over time.** Since 1990, reported emissions have fluctuated by a few percent per year, but the total increase at the end of three decades is less than 5%. In this time, Australia's black coal production has increased by 175%, and its production of gas has increased by 650%.[26] Fossil fuel production is the largest source of fossil methane.

- In the 2020 calendar year:
    - **Australia reportedly emitted 4.4 million tonnes of methane (1.3% of the world total).** Australia was the world's 12th largest methane emitter.[9]
    - **Australia was the world's 7th largest coal mine methane emitter** - after China, Indonesia, Russia, India, South Africa and the USA.[9] Australia is the world's 14th largest fugitive methane emitter (1% of the global total).

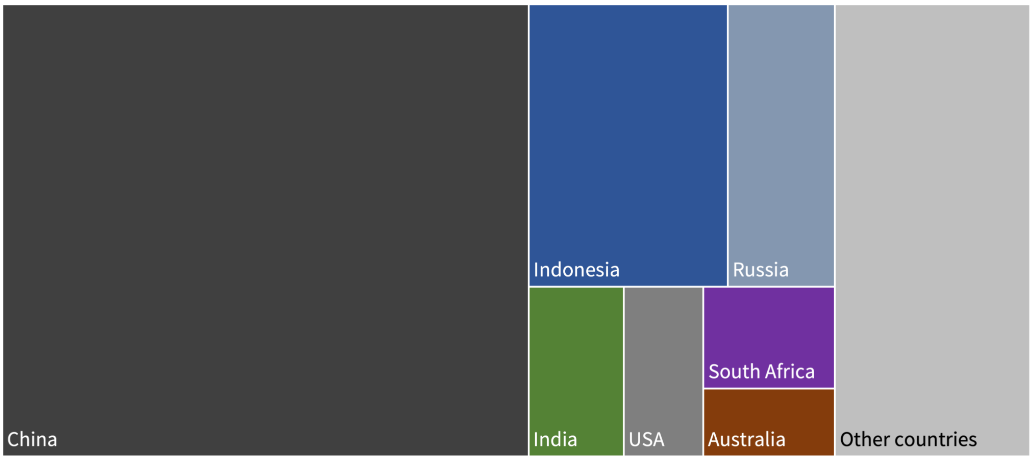

Figure 4: Proportion of reported coal mine methane emissions by country in 2020. Data source: PRIMAP-hist.[9]

    - **The energy sector released 1.4 million tonnes of methane (31% of the national total).** The very vast majority of this is in the form of fugitive emissions from fuel production and processing - here described as both operational and unintentional releases of methane - at 1.29 million tonnes, or 94% of energy related methane emissions.
      Australia is a globally significant fossil fuel producer. More than half (56%) of the world's internationally traded metallurgical coal, one-fifth (20%) of the world's

internationally traded thermal coal and around one-fifth (21%) of the world's liquefied gas is produced in Australia.[27]

        - **Coal mining:** 1 million tonnes of methane (23% of the national total).
            - While precise figures are difficult to obtain from official Australian government data, roughly half of all Australia's reported coal mine methane emissions come from thermal coal and half from metallurgical coal. This estimate accords with IEA estimates for Australia where 50% of coal mine methane is from metallurgical coal, 46% is thermal black coal, and the remainder is other coals, including brown coal.[17]
        - **Oil and gas:** 280 thousand tonnes of methane (6% of the national total).
    - **2.8 million tonnes (47% of the national total) of Australia's annual methane emission came from agriculture.** Three quarters of this (1.8 Mt) is from enteric fermentation in livestock, with over half of that (1.1 Mt) being from pasture-fed or free-range beef. While there are several promising options under development, there are no viable options available to reduce methane emissions of these sectors in the short-term. This figure does not include methane from land use change (see below) or from fertiliser manufacture (included under industrial processes).
    - **Other sectors are responsible for a remaining 960 thousand tonnes (21%).** This is made up of land use (510 thousand tonnes; 12% of the national total), waste (440 thousand tonnes; 10%) and industrial processes (3 thousand tonnes; 0.07%)
- **Reported fugitive methane emissions by state in 2020.**[25]
    - Percentages shown in brackets are as a share of the total methane emissions from Australia. Percentages not in brackets are the share of reported Australian fugitive emissions.

Qld	NSW	WA	Vic	SA	NT	Tas & ACT
720 kt 55.8% (16.3%)	**396 kt** 30.7% (9.0%)	**89 kt** 6.9% (2.0%)	**34 kt** 2.7% (0.8%)	**26 kt** 2.0% (0.6%)	**24 kt** 1.8% (0.5%)	**3 kt** 0.2% (0.1%)

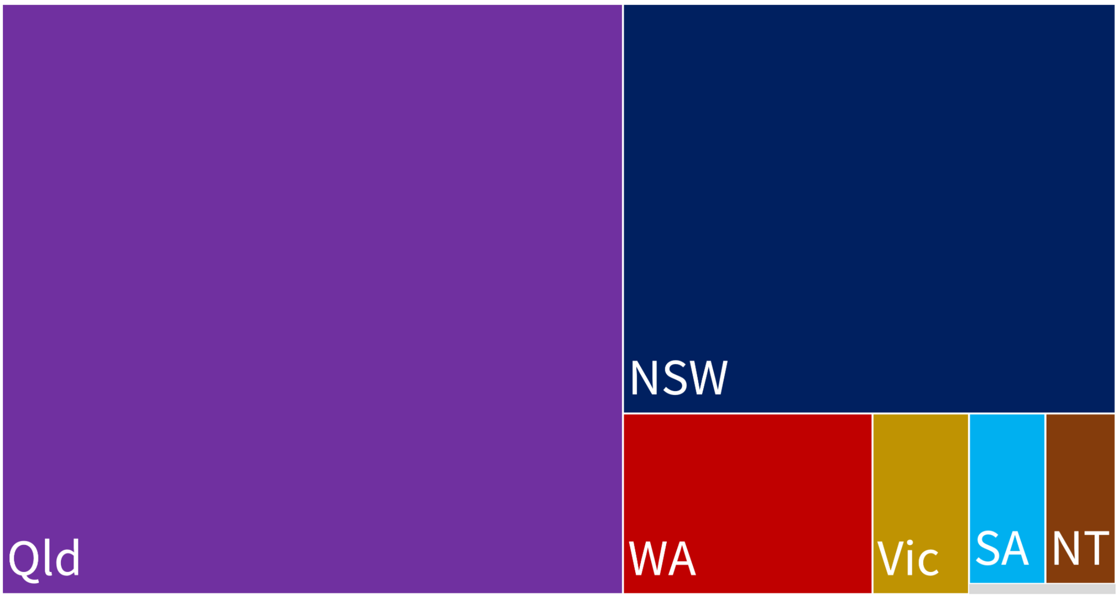

Figure 5: Proportion of reported fugitive methane emissions by state in 2020. Data source: AGEIS.[25]

- **Reported fugitive methane emissions by state and fuel in 2020.**[25]
    - 52% of Australia's reported fugitive methane comes from underground coal mining, 26% comes from open cut coal mining and 22% from gas extraction.
    - Per state data broken down by fuel is withheld in official government sources for all except for NSW and Queensland.
    - Percentages shown in brackets are as a share of the total methane emissions from Australia. Percentages not in brackets are the share of reported Australian fugitive methane emissions.

QLD coal	QLD gas	NSW coal	NSW gas	Other coal	Other gas
629 kt 48.7% (14.3%)	**91 kt** 7% (2.1%)	**377 kt** 29.2% (8.6%)	**19 kt** 1.5% (0.4%)	**0.5 kt** 0.04% (0.01%)	**174 kt** 13.5% (4.0%)

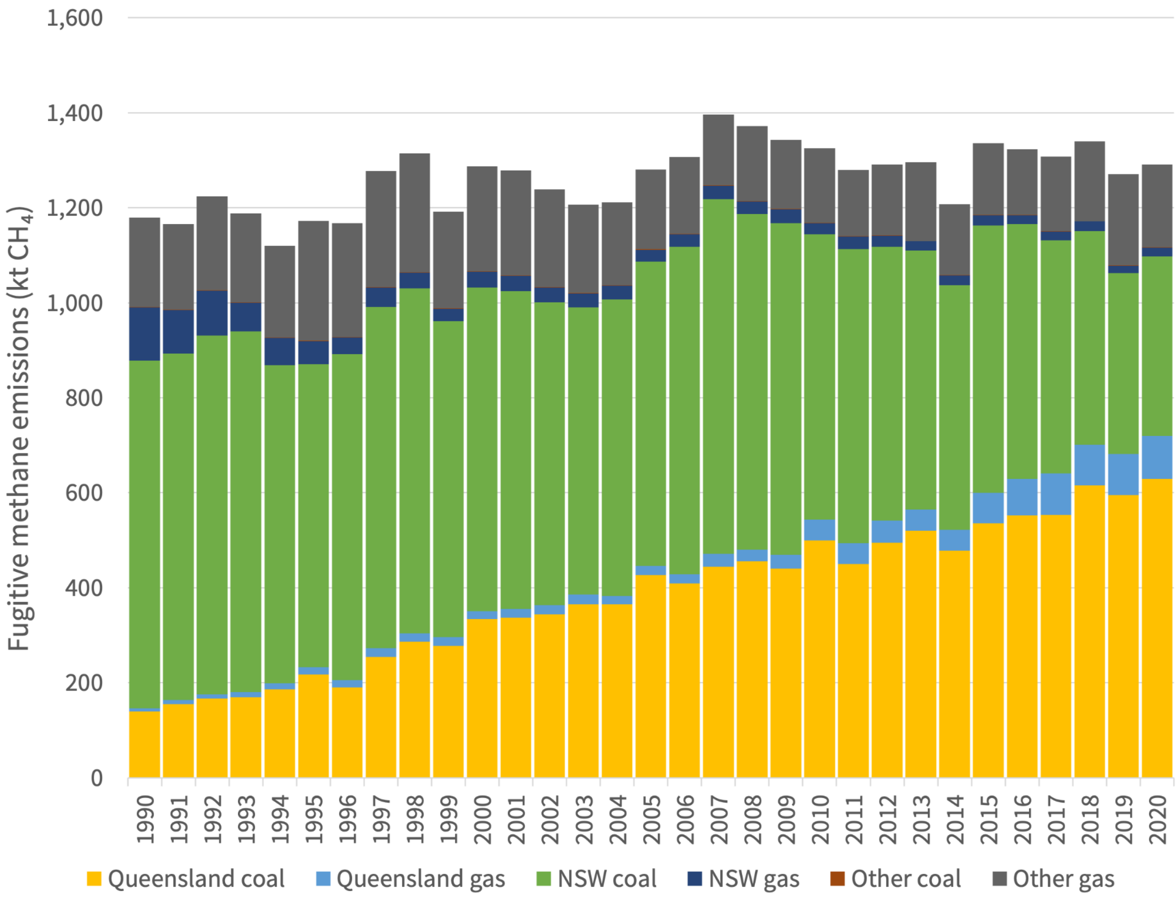

Figure 6: Reported fugitive methane emissions by state and fuel over time. Data source: AGEIS.[25]

- **Most of Australia's reported coal mine methane (58.9%) is released from the Bowen Basin.** While emissions data is not routinely reported by the government at a per basin resolution, a one-off coverage of the topic in a 2021 quarterly report[28] shows that in Bowen Basin two-thirds (67.1%) of reported methane emissions from the basin are attributable to coal mine methane. On these figures, the Bowen Basin accounts for 96.6% of Queensland's coal mine methane and 45.2% of Australia's total fugitive methane emissions.

- **Share of reported coal mine methane emissions from underground and open cut coal mines in Queensland and New South Wales.**[25]
  - **Queensland.** Underground: 58% (363 kt); Open cut: 42% (264 kt)
  - **New South Wales.** Underground: 83% (311 kt); Open cut: 17% (65 kt)

Future projections of Australia's reported fossil methane emissions

- **Australia is a long way from meeting its share of the Global Methane Pledge's overarching goal.**
  - **Australia would miss the target if historical trends continued.** To meet its share of the Global Methane Pledge, Australia's methane emissions in 2030 would need to be 3.08 million tonnes (30% below 2020 levels in 2030).

- While Australia's reported methane emissions have been falling very slowly over time (see above), even if this were accurate and continued for the remainder of the decade, this would result in only an 8.5% decrease in emissions by 2030.

- **Australia's methane emissions are expected to increase this decade.** On official government projections, methane emissions are expected to increase slightly this decade, from 4.4 million tonnes in 2020[25] to 4.6 million tonnes in 2030.[29]

- The success or failure of the Global Methane Pledge depends on big methane emitters like Australia doing their share. Of the more than 130 nations to have signed the Pledge, Australia has the eighth highest reported annual methane emissions.[9]

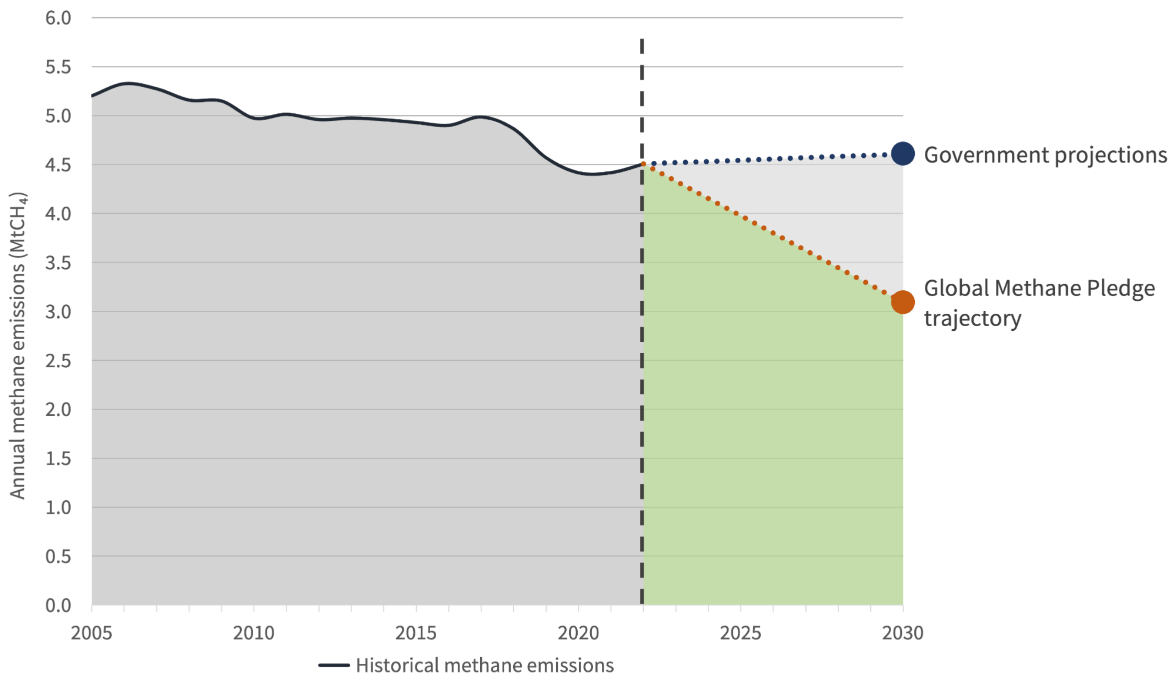

Figure 7: Australia's total historical and projected methane emissions compared to a trajectory that would see Australia reduce emissions in line with the Global Methane Pledge. Data sources: Australia's quarterly emissions[29]; Australia's emissions projections[29]

- **Fugitive emissions are expected to increase overall between now and 2030 and stay at that level until 2035.**[29] Methane-specific figures are not available for at the sector or sub-sector level in Australia's projections. On a carbon dioxide equivalent basis - which combines all gases into a single metric - overall fugitive emissions are projected to increase by 10% on today's levels between now and 2030.

	2020	2022	2030	2035
Domestic natural gas (non-LNG)	10.07 $MtCO_2e$	11.1 $MtCO_2e$	10.89 $MtCO_2e$ (-1.9%)	11.81 $MtCO_2e$ (+17.3%)
LNG	11.84 $MtCO_2e$	10.57 $MtCO_2e$	14.89 $MtCO_2e$ (+40.9%)	14.83 $MtCO_2e$ (+25.3%)
Oil	0.99 $MtCO_2e$	0.67 $MtCO_2e$	0.65 $MtCO_2e$ (-3%)	0.65 $MtCO_2e$ (-34.3%)
Open cut mines	9.39 $MtCO_2e$	9.49 $MtCO_2e$	9.36 $MtCO_2e$ (-1.4%)	9.7 $MtCO_2e$ (+3.3%)
Underground coal mines	21.19 $MtCO_2e$	18.45 $MtCO_2e$	19.58 $MtCO_2e$ (+6.1%)	18.26 $MtCO_2e$ (-13.8%)

- ○ **Both coal and gas methane emissions are projected to increase on today's levels between now and 2030.** While official projections are exclusively on a carbon dioxide equivalent basis at the sub-sector level, on these numbers, it can be estimated that fugitive methane emissions from gas would increase by approximately 50 thousand tonnes between now and 2030 (roughly a 15-20% increase on that sector's historical emissions), and fugitive methane emissions from coal by approximately 35 thousand tonnes (roughly 3-4% increase).

Australia's reported fugitive methane emissions are low compared to all independent estimates

For more information, see Methane reporting methodologies in Australia below.

- **Australia's reported methane emissions are substantially lower than most third party estimates.** This includes work undertaken under the auspices of the International Energy Agency and World Resources Institute, among others.[9,12,30,31]
  - The gap between Australia's reported fossil methane emissions and Australia's fossil methane emissions as they are estimated by the International Energy Agency is greater than the fossil methane emissions of the United Kingdom, Germany and France combined.
- **Third party efforts to quantify methane emissions at the basin[32,33] and mine[34] scale have found major discrepancies.** Emissions figures derived from Australia's national reporting schemes are universally substantially lower than what is seen from satellite and aerial measurement. Recent analysis has shown that Australia's gassiest emitters - such as Glencore's Hail Creek mine - could single-handedly be emitting up to 230 thousand tonnes of methane per year.[34] On this assessment, this one Queesnland open cut mine would be

emitting almost as much as the amount of methane that is reported to come from all of Queensland's open cut coal mines combined. In carbon dioxide equivalent terms - using the federal government's preferred conversion factor - over a dozen times more was emitted from that mine in fugitive methane alone than the mine's entire reported scope 1 emissions.

- **The Australian government acknowledges that its emissions estimates are low compared to similar countries.** For example, Australia's most recent report to the UNFCCC stated that the implied emissions factor for Australian underground coal was 5.68 kilograms of methane for each tonne of coal.[35] According to the same report, the average of like countries is 69.13 kilograms of methane per tonne. On these figures, Australia is claiming that its underground coal mining releases methane at less than one tenth of the average rate in like countries.
  However, the average given in the report is affected by two very significant outliers [personal correspondence with the department]. Once these outliers are disregarded, a more reliable average for countries other than these outliers - and other than Australia - is 17.1 kgCH_4/t. While this is a considerable step down from the figure above, this is nonetheless almost three times higher than Australia's reported rate of methane release from underground coal.

Methane reporting methodologies in Australia

Coal

The estimation of coal mine methane emissions in Australia is performed very differently between underground and open cut coal mines. A summary of the methodologies used in Australia's National Greenhouse and Energy Reporting scheme (NGERs) is described below.

- **Underground coal emissions at the mine.** Underground coal operators must estimate methane emissions using direct measurement, either periodic or constant monitoring. This involves measurement of the ventilated air that is removed from the mine for safety reasons. Based on publicly available data and the NGERs Measurement Determination, it is unclear what share of mines rely on periodic measurement rather than continuous monitoring and how much inaccuracy - if any - may be introduced through the choice of periodic measurement over continuous monitoring.

- **Underground coal post-mining emissions.** Methane emissions from coal continue long after the coal has left the mine, as the greenhouse gas continues to desorb from the coal. According to IPCC guidance, between 10-40% of all methane released from underground coal occurs after it has been extracted, with the difference being determined by whether pre-drainage of the methane occurs and to what degree.[36] Given that underground coal mining is Australia's largest source of fossil methane accurate assumptions about post-ming emissions are critically important. Australia's country specific emissions factor is low compared to the IPCC's recommended Tier 1 values.[36]
  Australia currently reports only the post mining emissions from its most gassy underground coal mines, with other mines assumed not to contribute methane.[35] IPCC guidelines suggest that in the absence of better information countries should presume that 10% and 30% of methane is released from post mining activities, for mines that are and are not pre-drained respectively.[36] Rather than being somewhere in the range of between 10%

and 30% - which it should be if values are an average of mines that would be at either extreme - only 5.9% of Australia's reported underground coal methane occurs as post mining emissions.[25]
Based on publicly available information, it is unclear to what degree Australian underground mines pre-drain their seams, and so unclear whether the national average should be closer to either 10% or 30%. And so, while on these numbers there is some indication that significant underreporting is occurring, if the amount of pre-draining that occurs in Australian mines is low, then the scale of the under-reporting problem becomes very large.

- **Open cut black coal emissions at the mine.** When reporting under NGERs, mine operators can choose between state-specific emissions factors or modelling based on in situ sampling. In practice - according to the latest National Inventory Report - New South Wales and Western Australian miners model their emissions, while Queensland miners - especially in Bowen Basin - most use the state-specific values.[35]
    - **Direct measurement of open cut mines is available today in some circumstances and availability will dramatically improve in coming years.** According to the most recent update to IPCC emissions reporting guidelines there is limited potential for on-the-ground direct measurement of open cut mines.[36] There have long been means by which local methane concentrations can be monitored, but these readings can often be confounded by other local sources.[37] That said, these IPCC guidelines are now several years old and based on science that is even older.
    Recent developments in satellite technology and aerial monitoring mean that there are now multiple means through which lower order methods can be validated with direct measurement. High quality measurement techniques are available today and can be complemented by satellite and aerial measurement. The quality and capability of these complementary technologies will increase considerably over coming years.
    - **There is significant room for improvement to existing, lower tier estimation methods.** The state-specific emissions factors that most Queensland open cut mines use when reporting under NGERs have their evidentiary basis in small-scale studies conducted in the early 1990s.[37,38] In the first of these studies, just 26 coal samples were taken, and only 4 of these produced measurable quantities of methane at the time of testing. This is not a solid foundation for our national emissions reporting three decades on.
    - **In early 2022, the Australian government began applying a higher emissions factor to Queensland's open cut coal mines for the purposes of reporting to the UNFCCC, but this is not applied to NGERs reporting.** This revision to the emissions factors used for Queensland's open cut mines - which was informed by petroleum borehole data that was obtained by the federal government - saw emissions from Queensland's open cut coal mines increased by 44% from 0.8 $kgCH_4/t$ to 1.1 $kgCH_4/t$. This revision was incorporated into Australia's National Inventory Report, but there has not been a revision to the NGERs measurement determination. This means that there are two different emissions factors used for these mines: one for mine operators reporting to the government, and another for Australia reporting to the international community.

- Many important aspects of the process for in situ sampling were created by the Australian Coal Association, with the NGERs measurement determination directing users to follow separately available ACA-produced methodologies in order to calculate their emissions. This process allows for employees of the mine operator to conduct the required sampling and modelling. The method does require a second person to peer review the original work, but peer review by a fellow employee of the same company is expressly permitted.[39]
  Recent evidence of systematic fraud occurring in the closely related, though separate, domain of coal quality testing - that has gone largely unpunished[40] - is sufficient to suggest a need for increased probity measures above what is currently accepted by the regulations. It also raises the need for increased compliance activity in this area. There is no publicly available information to indicate that the Clean Energy Regulator - the body that oversees the NGER regime - has taken any steps to increase compliance activity.

- **Open cut black coal post-mining emissions.** Around 10% of methane released from surface mines occurs after the coal has left the mine.[36] Under NGERs open cut mine operators does not report post-mining emissions from surface mines at all.[35] Presuming that 10% of methane from surface mines is emitted post-mining and unaccounted for, then around 37 kilotonnes of methane - or 2.8% of Australia's reported fugitive methane emissions in 2020 - has been missed as a result of this under-reporting.

- **Open cut brown coal.** State-wide emissions factors are applied to all mines. There are only three operating open cut brown coal mines in Australia, and only two are large. Brown coal contains far less methane than black coal (see below Why does methane content vary by mine?) - in the order of 99% less than black coal. While consumption of brown coal leads is an emissions intensive process - leading to more carbon dioxide emissions per unit of energy delivered than black coal - its methane intensity is much lower.

- **Decommissioned coal mines.** Australia only reports emissions for decommissioned underground mines. Mine operators have a choice between continuing their constant emissions reporting, or determining emissions based on historical emissions with a simple decline rate applied. It is assumed that decommissioned surface mines release very little methane.[35]

- **Coal exploration.** Australia does not report emissions for coal exploration. The latest National Inventory Report indicates that there is a methodology under development.

- **Coal mine waste gas flaring.** 98% of methane sent to flare is presumed to be combusted in all circumstances. Even under the most ideal conditions, a small amount of methane that is sent to a flare will always be emitted as a result of incomplete combustion and a rate of 98% combustion effectively presumes that all flares operate almost perfectly. Recent analysis in the US oil and gas sector demonstrates that in the real world flare efficiency is more like 90%.[41] Such evidence elevates a need to re-examine assumed efficiency rates in the Australian coal sector.

Gas

The estimation of methane emissions from gas is largely based on emissions factors derived from studies conducted by the US EPA in the early 1990s,[42] at a time when - even there - the unconventional gas industry was in its infancy. These have been inherited into the Australian reporting scheme through the NGER regime's reliance on the American Petroleum Institute's 2009 Compendium.[43] Periodically, efforts are made to reconfirm these values, but justifiable doubt exists over the integrity of these studies.[44]

- **Gas exploration, production, processing, transmission and storage - other than venting and flaring.** Emissions are estimated based on a combination of US EPA, and nation-wide emissions factors based on industry-provided data. In many instances, there is no option available in national reporting schemes for direct monitoring and reporting of emissions even when known emissions deviate from the simple emissions factors. This means that - for example - substantial known leaks or blow-outs would be unaccounted for at both the company and country level. Gas exploration includes flaring within default emissions calculations.

- **LNG processing and storage other than venting and flaring.** Emissions are estimated based on rudimentary emissions factors that do not account for the size of the LNG facility. Methane emissions are set at a flat 1,109 tCH4 per terminal per year, and 921 tCH4 per storage station per year. This figure is taken from US EPA studies. In the case of terminals, this factor applies evenly across the board, so Karratha Gas Plant, which has five LNG trains, is presumed to leak the same amount as Darwin LNG Plant, which has only one.

- **Gas distribution other than flaring.** Emissions are estimated using a nation-wide emissions factor based on unaccounted for gas after making certain assumptions regarding theft and meter inaccuracy.

- **Gas flaring.** A simple emissions factor approach is used, similar to that used in coal mine waste gas flaring. There is some ability to account for different methane contributions in the gas being sent to the flare.

- **Gas venting.** Gas venting in most sectors is reported using basic, country-wide emissions factors derived from the API Compendium. The major exception to this is gas production, where constant and periodic measurement is an option. Based on publicly available data it is not possible to know to what extent gas producers rely on emissions factor based estimates over direct measurement.

- **Abandoned gas and oil wells.** Australia's more than 24 thousand abandoned oil and gas wells have a default emissions factor applied that is mostly based on a single US study (see below).[45] These distinguish between whether the well is on- or offshore and whether the well is plugged, unplugged or of unknown status.

  The majority of offshore wells are known to be plugged, but of Australia's 21,416 onshore gas and oil wells in 2020,[35] only 4,726 were known to be plugged. Of the remainder, the majority (13,187, or 62% of all abandoned onshore wells) are of unknown status. Using the default emissions factors, if most abandoned wells of unknown status are in fact unplugged, then this could see estimates of emissions from abandoned wells triple. Even presuming that Australia has several sites emitting at a rate that is at or near the highest ever observed rate of methane seepage from an abandoned well,[46] the total emissions from all abandoned onshore oil and gas wells would nonetheless be small relative to other sectors. At its highest, the national total could plausibly be in excess of one thousand tonnes of methane per year - roughly equivalent to the assumed rate of methane leakage occurring at one LNG terminal - though not very substantially higher than this.

That said, it is also worth noting that of the 138 US wells examined in the study that ultimately forms the basis of Australia's abandoned well emissions factors, only 19 were unplugged, and only 8 were emitting methane at all.[45] This means that while this study represents the best available evidence we have, there is a good reason to improve domestic monitoring to provide robust, Australia-specific factors.

- **Behind-the-meter leakage.** Emissions from this sector are estimated using assumed emissions factors based on the number and type of each appliance thought to exist.

Oil

Australia produces a very small amount of oil and emissions are estimated on similar terms as from gas. The total reported methane emissions from Australian oil production, including venting and flaring, was 10 thousand tonnes in 2020. This is less than 4% of the total released from gas, and 1% of the total released from coal. For the most part, the methodologies used to estimate oil sector emissions mirror those used in gas.

How does methane content vary by coal mine?

- **The methane content of coal varies by depth.** Deeper coal seams generally bear more gas than shallow seams. Depths of less than 200 m will generally result in relatively low methane emissions, while depths in excess of 400 m will be relatively high. Following that, underground coal mines generally release more methane than open cut mines.

- **The methane content of coal varies by basin.** Different basins have significantly higher and lower methane emissions content, with the Southern basin (in the Illawarra region of NSW) reporting methane emissions at a rate that is more than double that of the Hunter and Newcastle basins.[35]

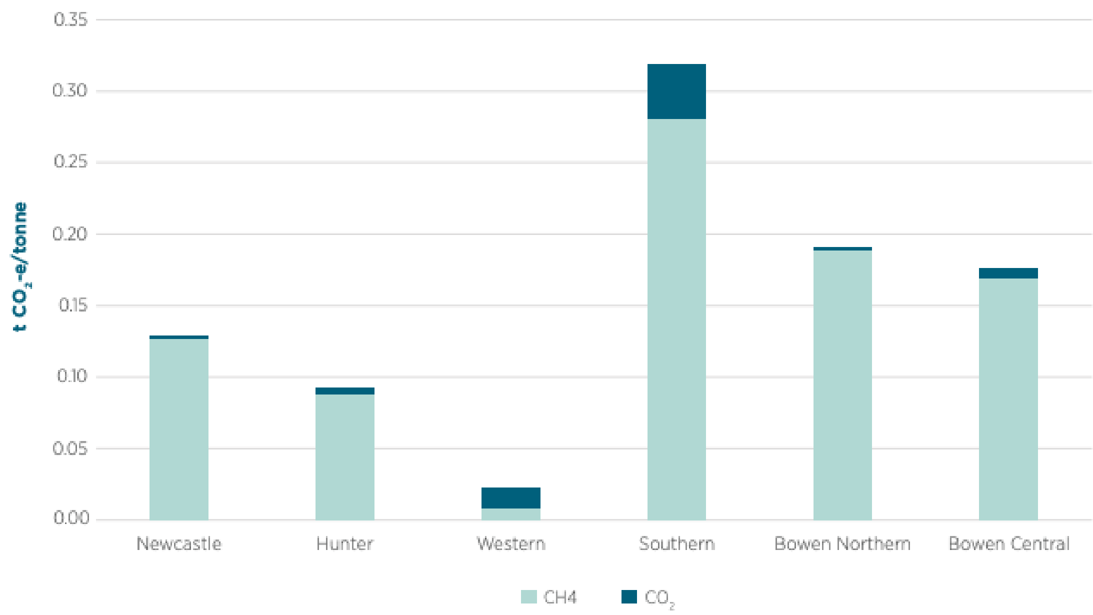

Figure 8: The gas content profile of Australian underground production by coal field. Chart source: Australia's 2020 National Inventory Report.

- **The methane content of coal varies by coal rank.** Geologically older, higher rank coals (e.g. anthracite which is a form of metallurgical coal) generally have a higher methane content than lower rank coals. This can lead to significant variation. For example anthracite contains in the order of five times more methane per tonne than sub-bituminous coals.[47]

Identifying super-emitting coal mines

- Recently, greater attention has been given to so-called 'super-emitting' coal mines. These mines are a promising target for early action to reduce fossil methane emissions. Globally, it is estimated that a small number of mines are responsible for a very significant share of all coal mine methane emissions, with half of all emissions being released from a little over 10% of the mines.[48] Assessments of satellite data reveals that during 2018-19, six Australian mines in the Bowen Basin are responsible for 7% of Australia's national coal production, but more than half of Australia's coal mine methane.[34]

- Based on the previous two sections, we can identify a few core traits which make it more likely that a mine will super-emit. For reference, these factors generally apply to Hail Creek which has been confirmed as a super-emitter.[34]

    - **Absent fraud or other substantial integrity issues, it is less likely that emissions from underground mines will be underreported.** The NGER regime requires underground mines to use continuous or periodic monitoring when reporting their emissions. It is less likely that these mines will emit more than is reported.

    - **Similarly, mines that use *in situ* sampling and modelling of methane emissions are more likely to accurately report extraordinary methane emissions.** If the

ACA/NGERs methodology for determining emissions is sound then it can be assumed that reported emissions from these mines will be more accurate than state-based emissions factors. However, as noted elsewhere in this note, recent revelations of alleged systematic fraud in coal quality testing elevates the urgency of proving that the emissions reporting is robust.[40]
Under NGERs, open cut mine operators can choose whether to base their emissions estimates on state-based emissions factors or sampling. Super-emitting mines are incentivised to use the state-based emissions factors, leading to underreporting.

   - **Mines producing geologically older, deeper coals will on average bear more methane, meaning those that super emit, super emit more.** A shallow, sub-bituminous deposit that contains ten times as much methane as is average for its rank and depth, would nonetheless still only emit just as much methane as a marginally deeper anthracite. The biggest outliers will be those mines producing older, deeper coals.
   - **There are fewer outliers among shallower coals.** Petroleum borehole data from Queensland shows a greater deviation between the mean and median amount of methane contained in coal seams the deeper the seam.[49] This indicates that there is a greater breadth of values, with a small number of extraordinarily high values driving up the mean.

- Based on the above, it can be assumed that **the most dramatically super emitting coal mines are likely to be metallurgical coal mines producing from relatively deep seams in Queensland.**

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