ASEAN Centre for Energy
One Community for Sustainable Energy

Coal Mine Methane Emissions Largely Overlooked in ASEAN

September 2024

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Published by:
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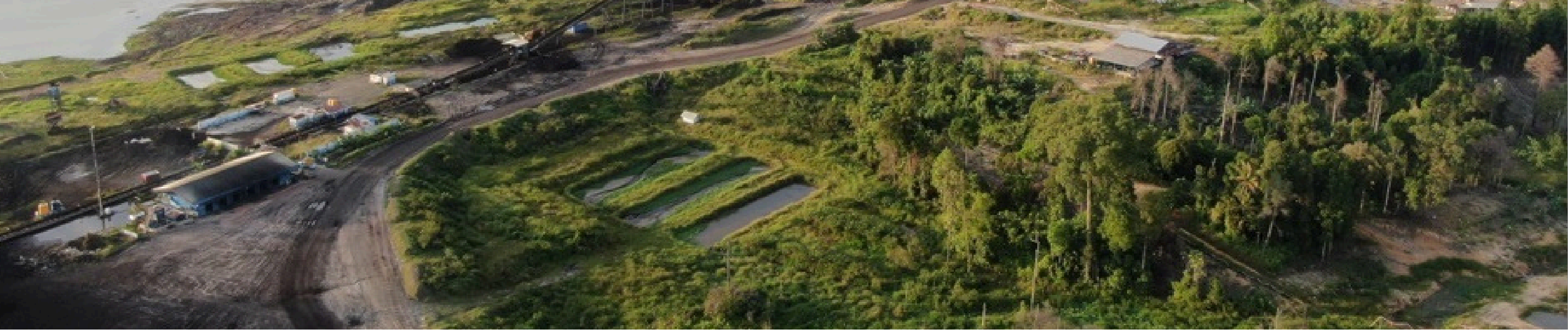


AMS	ASEAN Member States
ASEAN	Association of Southeast Asian Nations
ATS	ASEAN Member States (AMS) Targets Scenario
BAU	Business-As-Usual
BUR	Biennial Update Report
CH_4	Methane
CMM	Coal Mine Methane
CO_2	Carbon Dioxide
COP26	26th Conference of the Parties
COP28	28th Conference of the Parties
CFPP	Coal-Fired Power Plant
CFPPs	Coal-Fired Power Plants
DC	Direct Current
EIA	Energy Information Administration
GHG	Greenhouse Gases
GWP	Global Warming Potential
H_2O	Water
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kt	Kiloton
kWh	Kilowatt-hour
LNG	Liquefied Natural Gas
md	Millidarcy
MMcf	Million Cubic Feet
MRV	Monitoring, Reporting, and Verification
$MtCO_2e$	Million Tons of CO_2 Equivalent
$MtCO_2$-eq	Million Tons of CO_2 Equivalent
Mtoe	Million Tons of Oil Equivalent
NZE	Net Zero Emissions
NO_x	Nitrogen Oxides
Nm^3/hr	Normal Cubic Meters per Hour
OGDC	Oil and Gas Development Company
OGMP	Oil and Gas Methane Partnership
RCOs	Regenerative Catalytic Oxidisers
RTOs	Regenerative Thermal Oxidisers
SCFM	standard cubic feet per minute
SCM	Surface Coal Mining
SIS	Surface to In-seam
SMR	Steam Methane Reforming
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
VAM	Ventilation Air Methane
VS.	Versus
˚C	Degrees Celsius

Highlights

28x Warming Effect

Methane has a warming effect of **28 times** that of **carbon dioxide,** over 100-year time scale. The potential of methane emissions abatement to yield quick reductions whilst delivering air quality benefits has pushed global leaders to catalyse efforts in abating methane emissions.

6,700 $MtCO_2e$ by 2050

ASEAN would still continue to rely on **fossil fuels**, including coal, up to 2050 as a means to achieve energy security. Energy-related GHG emissions is therefore projected to reach **6,700 $MtCO_2e$ by 2050**, with methane accounting for 15.2% or up to **1,100 $MtCO_2e$.**

Oil & Gas vs. Coal

Methane emissions abatement efforts and commitment in the energy (fossil fuel) sector is more **intense** and **advanced** in the **oil and gas sector**, compared to coal, despite studies showing that the latter emits as much methane emissions as oil and gas.

Challenges

The lag behind coal mine methane abatement efforts can be attributed to several challenges, including, the lack of transparency and **absence** of a robust **Monitoring, Reporting, and Verification (MRV) system** for coal mine methane emissions, **lack of knowledge** on the types and availability of abatement technologies, **limited financing**, and the **lack of awareness** and **political commitment.**

Introduction

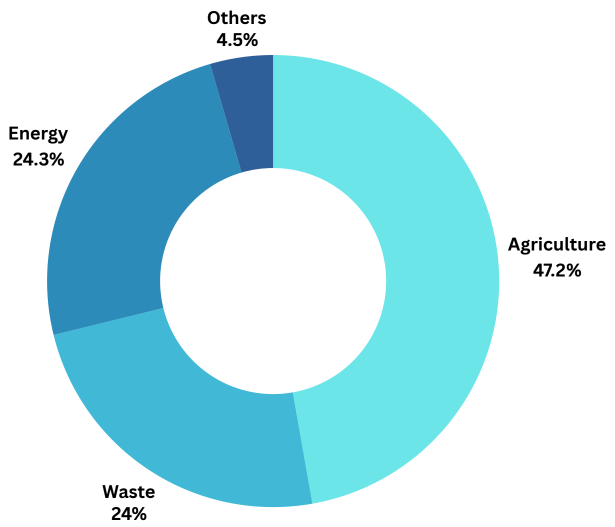
Introduction

Compared to CO_2 emissions, methane (CH_4) emissions have until recently received much less attention in the global net-zero movement. Awareness is now rapidly spreading about how this short-lived climate pollutant takes only 10 years to break down from the atmosphere but has a warming effect which is 28 times more potent than that of carbon dioxide over a 100-year time horizon [1].

According to the United Nations Environment Programme (UNEP), reducing 45% of anthropogenic methane emissions could reduce global warming by nearly 0.3°C in 2045, helping to limit the global temperature rise to 1.5˚C as mandated under the Paris Agreement targets.

The potential of methane emissions abatement to yield quick reductions whilst delivering air quality benefits has pushed global leaders to catalyse efforts aimed at abating methane emissions, including, the Global Methane Pledge launched at COP26 in 2021, where participating countries agreed to take voluntary actions to contribute to a collective effort to reduce global methane emissions by at least 30% from 2020 levels by 2030 [2].

Figure 1 : Source of Methane Emissions in ASEAN as of 2021



Source: IEA Methane Tracker

Of the total methane emissions from the Association of Southeast Asia Nations (ASEAN), 24.33% come from the energy sector, following the agriculture sector's share of 47.22% (see Figure 1) [3]. In response to the rapid economic and population growth occurring in the region, energy demand continues to increase. Based on the Baseline Scenario, energy demand will triple the 2020 levels to reach approximately 1,282 Mtoe in 2050 and will be dominated by oil, gas and coal [4].

Energy-related GHG emissions are projected to reach 6,700 $MtCO_2e$ by 2050, with methane accounting for 15.2% or up to 1,100 $MtCO_2e$ from 2020 level [4]. The International Energy Agency (IEA) estimates that 47% of the methane emissions in ASEAN come from the offshore oil and gas sector, specifically gas pipelines, liquefied natural gas (LNG) facilities and from steam and coking coal at 44% [5].

Abating the methane emissions from the oil and gas sector is perceived as highly cost-effective. As the abatement measures cost less than the market value of the additional gas that is captured, approximately 40% of these emissions from the oil and gas operations could be avoided at no net cost [5].

Due to the experts' confidence in the abatement measures, many global commitments and initiatives on methane abatement in the oil and gas sector are emerging, including the Oil and Gas Methane Partnership 2.0 (OGMP 2.0) which is a flagship oil and gas reporting and mitigation programme of the UNEP that establishes a comprehensive, measurement-based international reporting framework for the sector.

The Oil and Gas Decarbonization Charter (OGDC) launched during COP28 in 2023 under which 50 oil and gas companies have pledged to align with the net-zero movement by or before 2050.

Other important steps include zero-out methane emissions defined as achieving a "**near-zero**" methane intensity target of 0.2 percent and eradicating routine flaring by 2030, while also improving the measurement, monitoring, reporting, and independent verification of greenhouse gas emissions [6].

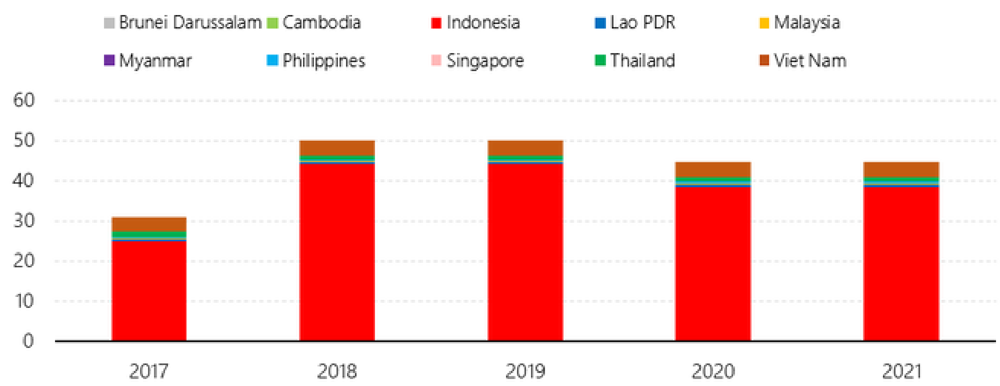
However, in the ASEAN region, the initiatives on coal methane emissions abatement are lagging behind, even completely overlooked in some places despite the large reduction potential and proven cost-effective technologies to mitigate them from existing coal mines. Hence, **this short report aims to take a deep dive into the status of coal mine methane (CMM) in ASEAN** by *first* **examining the current challenges and opportunities associated with its management and utilisation**, and *then* **making recommendations to address these challenges** and **leverage the opportunities for improved cross-sectoral outcomes**.

Coal Status in ASEAN

Coal Production and Reserves Status in ASEAN

Almost 80% of the coal reserves in ASEAN are found in Indonesia. As shown in Figure 2, between 2018 and 2020, there was a fluctuation in the coal reserves: a major increase in 2018 from 25 billion short tons to 44 billion short tons, and a decline in 2020, with reserves dropping to 38 billion short tons [10].

Figure 2: Coal reserves by country in ASEAN in billion short tons



Source: US Energy Information Administration (EIA).

Table 1: Classification of Coal Mines in ASEAN

Country	Mining Classification		
	Surface	Underground	Surface & Underground
Brunei Darussalam	0	0	0
Cambodia	0	1	0
Indonesia	511	6	2
Lao PDR	2	0	1
Malaysia	1	1	0
Myanmar	8	0	2
Philippines	6	3	0
Singapore	0	0	0
Thailand	1	0	1
Viet Nam	9	14	4

Source: US Energy Information Administration (EIA).

Table 1 provides the coal mine classifications in the 10 ASEAN countries. **Indonesia leads with 511 surface mines, six underground and two combining both methods**. It is the only country in the region that consistently discloses its reserve estimates. Viet Nam follows with nine surface mines, 14 underground and four using both techniques.

Myanmar and the Philippines also show notable activity, with Myanmar having eight surface and two combined mines, while the Philippines has six surface and three underground mines. Cambodia has a single underground mine. Lao PDR, Malaysia, and Thailand have minimal mining activities, and Brunei Darussalam and Singapore report no mining operations [11].

Understanding Coal Mine Methane

Coal mine methane (CMM) is a commonly used term to describe all methane that is released during the mining of coal and in post-mining operations.

According to the IEA's Net Zero analysis, **global CMM must be reduced to 75% by 2030**, if the planet is to be on track with the 1.5-degree target set under the Paris Agreement [7]. Given that 24% of CMM emissions are currently coming from metallurgical coal (coal used by the steel industry) and that 76% are from thermal coal (coal used in the power sector), the steel industry and power sector must play significant roles in reducing their methane emissions [8].

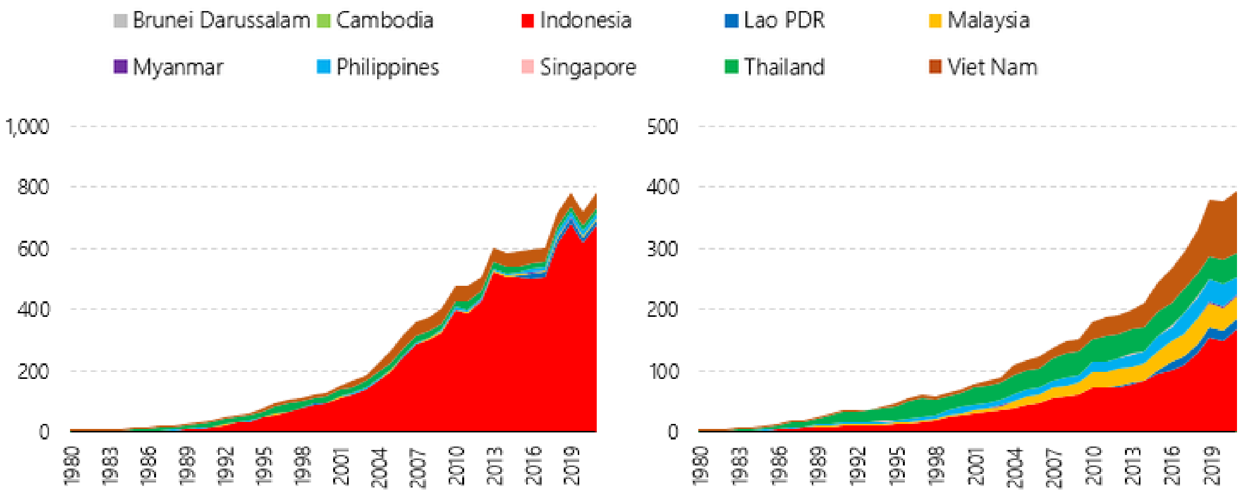
Methane is produced during coalification, or the process of coal formation. Some of it is trapped under pressure in the coal seam and surrounding rock. Hence, when the coal seams are fractured during the mining process, especially in long wall mining, the trapped methane is released. It escapes into the mine and eventually into the atmosphere [9]. The amount released is actually more than what was trapped in the coal itself because mining reduces the pressure, pulling in extra gas from nearby rocks. Methane can also leak over time from shallow coal layers through natural cracks in the rocks above them.

The amount of methane emitted depends on a variety of factors, but basically, underground coal mining releases more methane compared to surface mining due to deeper coal seams and higher coal rank [8]. **It is estimated that approximately 84% of global CMM comes from underground mining.**

In terms of production in recent years, Indonesia, Myanmar, the Philippines and Viet Nam have had consistent or even growing trends in coal production. Given Indonesia's massive share of coal reserves, it is not surprising that it is the largest coal producer in ASEAN (see Figure 3). Between 2010 and 2021, it contributed 86% of the region's cumulative production [10].

As previously indicated, the higher the coal rank, the higher the methane emissions. Between 2010 and 2021, the production of anthracite, the highest-ranking coal, stagnated and grew at an annual average rate of only 7% due to limited availability - with Viet Nam being the main producer [10]. Bituminous and sub-bituminous coal, as second- and third-ranking coal, output grew by more than 50%, while lignite as the lowest-ranking coal grew the fastest, increasing by more than 170%- with Indonesia as the main producer [10].

Figure 3: Coal production (left) and consumption (right) by country in ASEAN in million short tons



Source: US Energy Information Administration (EIA).

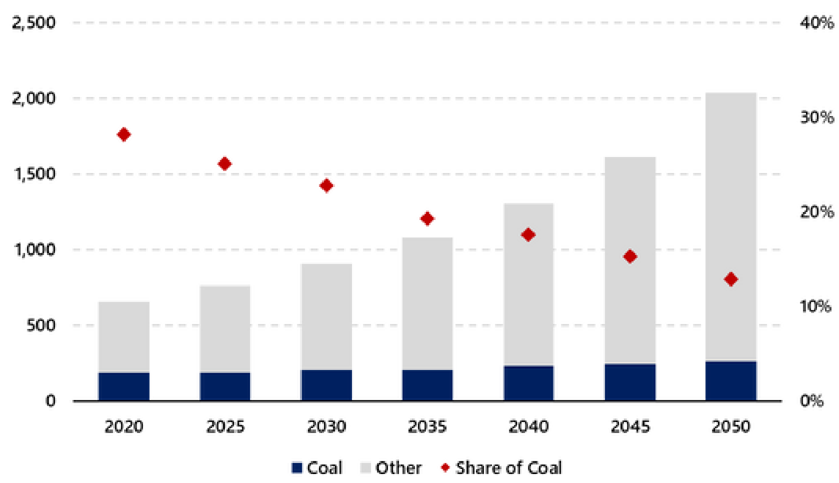
Meanwhile, the consumption pattern of these different coal ranks has been opposite to that of production, with the use of lignite stagnating and expanding by less than 30% over the same period, while the use of other coal ranks grew more than 100% [10].

The coal trade landscape extends beyond the region. India, Japan and South Korea are the key importers of coal from ASEAN, while Australia and the Russian Federation are the main coal exporters to the region.

Coal in ASEAN's Energy Mix

Coal contributed about 28% to the AMS' energy supply in 2020 [4]. However, its share is expected to decline to below 13% by 2050 (see Figure 4), reflecting the broader global shift towards cleaner energy sources and sustainability. Nonetheless, in the ASEAN Member States (AMS) Targets Scenario (ATS),

Figure 4: Outlook of coal in the primary energy supply mix (Mtoe) in the APS Scenario



Source: 7th ASEAN Energy Outlook

The absolute growth of coal supply will continue, expanding from 184 Mtoe in 2020 to 261 Mtoe by 2050, or 42% [4].

Coal will still be used primarily for industrial heat, power generation and other transformations (including the industry's own use and losses). The industrial sector's demand for coal is expected to grow 66% from 2020 to 2050. Conversely, the share of coal in electricity generation will decline by 60% over the same period as it is increasingly replaced with natural gas and renewables [4].

However, even with the sustained demand growth for bioenergy and other renewables, coal will continue to dominate ASEAN's final energy consumption for at least the next decade, accounting for 42% in 2025 and 22% in 2035. However, by 2050 its share is expected to drop to less than 9% [4]. Even so, this 9% is still equivalent to 133 Mtoe. Consequently, with the rising energy demand relying heavily on fossil fuels, it is predicted in the ATS Scenario that energy-related GHG emissions will reach 4,503 $MtCO_2$-eq by 2050, 15% of which will be methane [4].

The IEA estimates that as of 2023, methane emissions from coal (seam coal and coking coal) account for 44% of the total in ASEAN's energy sector, whereas oil and gas (onshore, offshore, gas pipelines, and LNG facilities) account for 47% [5]. Setiawan and Wright even claims that the CMM emissions from six Indonesian companies could be similar, or larger than the currently reported mining emissions from fossil fuel combustion with purchased electricity [12].

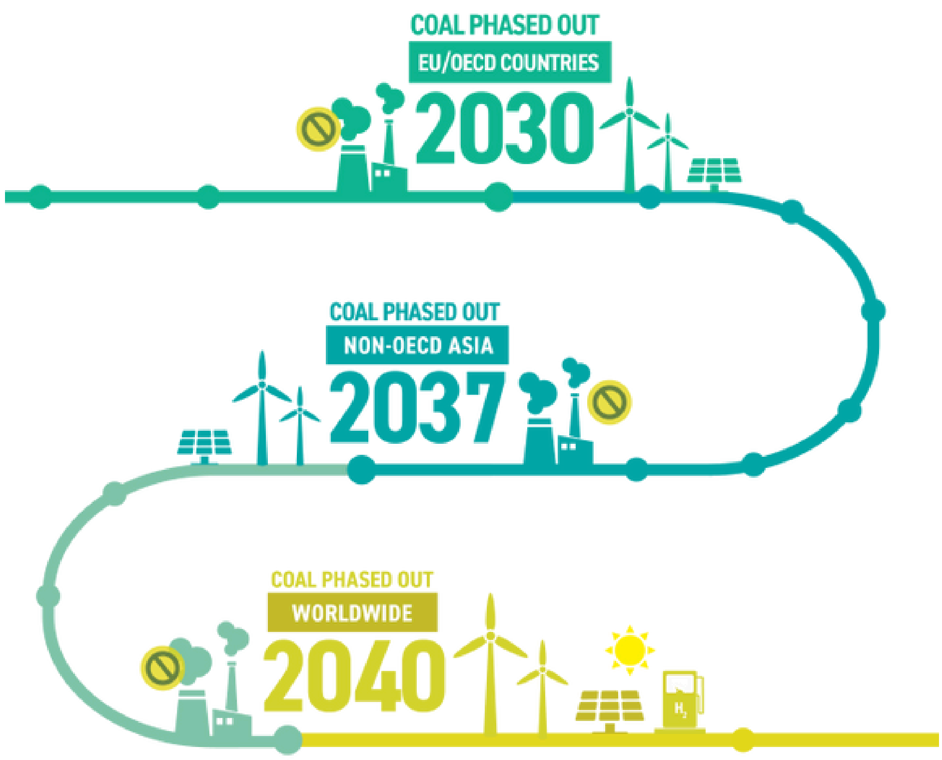
The Possibility and Implications of A Coal Phase-Out

Due to the large amounts of emissions associated with coal mining, a global movement is emerging that is advocating a “coal phase-out”.

Globally, during COP26 in Glasgow in 2021, the Global Coal to Clean Power Transition Statement, which called for a shift away from unabated coal power generation by 2040 or as soon as possible after that, was signed by more than 40 nations. Half of the AMS signed the Statement, namely Brunei Darussalam, Indonesia, the Philippines, Singapore and Viet Nam [13].

Nationally, nine out of 10 AMS have announced their commitment to reducing their emissions to a certain level, mainly relative to the Business-As-Usual (BAU) Scenario, with most of them also setting carbon neutrality and net zero emission (NZE) goals with target years ranging from 2050 to 2065. Concurrently, the commitments on coal phase-down vary across the AMS.

Figure 5: Coal Phase-Out Scenario



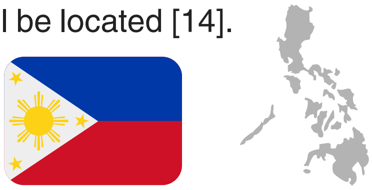
Source: Climate Transparancy - 12 INSIGHTS TO MOVE BEYOND COAL TOWARDS NET-ZERO

To date, Brunei Darussalam, Indonesia, the Philippines and Viet Nam have announced plans to phase-out coal. However, some of these announcements have made little to no progress in terms of being formalised into their respective national policies.

Indonesia, as the largest coal producer, exporter and consumer, and a key shaper of the regional coal transition outlook, enacted Presidential Regulation No. 112/2022 on the Acceleration of Renewable Energy Development for Electricity Supply which outlines a roadmap to cease the operation of coal-fired power plants (CFPPs).

However, licenses for prospective CFPPs are still being granted because coal mining is still legally valid undervalid under the 2020 Mining Law Amendment (to the Law No.4 of 2009 on Mineral and Coal Mining) [13]. The Indonesian government has also recently approved a coal production quota of 922 million tonnes for 2024 [12].

The Philippines, though accounting for much smaller amounts of coal production and use, committed to a moratorium on new coal plants in 2020. Still, the relevant bureau clarified that this policy does not cover existing and operational coal-fired power generation facilities as well as any coal-fired power projects regarded as committed power projects; existing power plant complexes which already have firm expansion plans and existing land site provisions; and indicative power projects with substantial accomplishments, particularly with signed and notarised land acquisition or lease agreements for the projects, and with approved permits or resolution from local government units and the Regional Development Council where the power plants will be located [14].



The degree of commitment to phase-out coal depends on a country's coal availability and current coal dependence, as well as the reliability of alternative energy sources. As coal has been the cornerstone of electricity supply in much of ASEAN for many decades, it must be kept in mind that an abrupt coal phase-out combined with increased use of less secure energy sources could jeopardise energy security, energy affordability and economic growth in the region. Natural gas is often seen as a transitional fuel, but increased dependence on it can expose countries to global market volatility, particularly as domestic production declines.

In terms of affordability, **an early coal phase-out would incur substantial costs**, including buying out existing CFPP contracts, which could cost up to USD 37 billion in Indonesia alone. Additionally, replacing coal plants with new, potentially more expensive power plants and upgrading the grid for renewable energy would also be highly costly. **Most of the CFPPs in ASEAN are relatively young**, averaging around 14.3 years and most still use less efficient subcritical technology, making up 59% of the total generating capacity.

Economically, a rapid coal phase-out could constrain growth. It would reduce revenues from coal-related activities for both private companies and governments. Furthermore, it could lead to job losses, affecting workers across the mining, transport steel and power generation sectors.

In light of the above, as there is no doubt that coal will continue to have a major role in ASEAN's energy mix as a means to ensure energy security and resiliency. **Therefore, the measures to reduce CMM must be bolstered.**

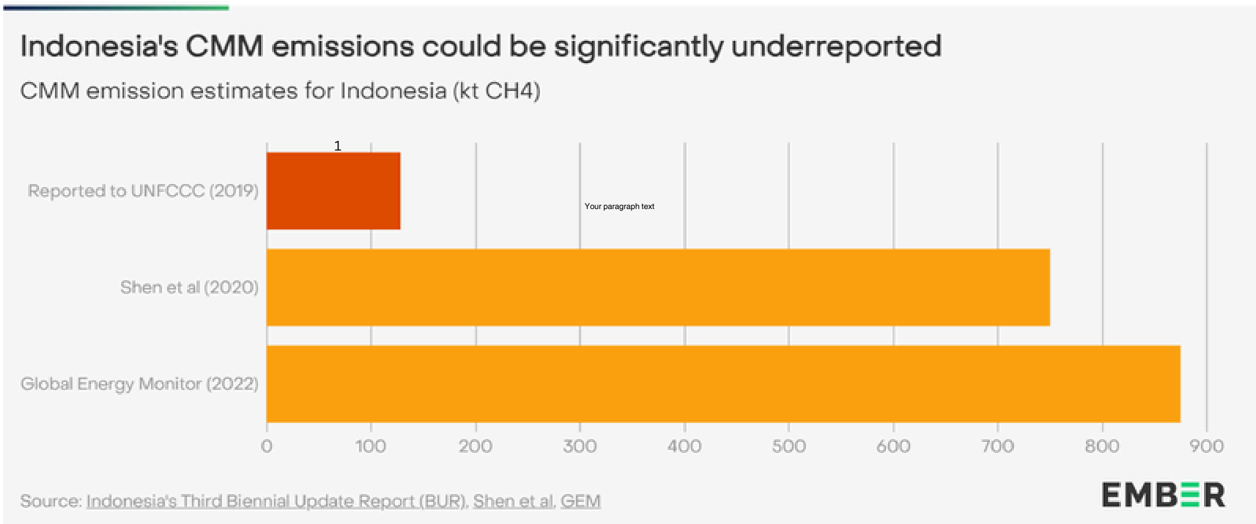
Challenges in Abating Coal Mine Methane Emissions

Challenges in Abating Coal Mine Methane Emissions

In ASEAN, methane emission abatement activities are more focused on oil and gas, despite IEA data showing coal only having 3% less methane emissions than of oil and gas. This maybe be attributed because of the following identified challenges.

The most fundamental challenge is **the lack of transparency and absence of a robust monitoring, reporting and verification (MRV) system for methane emissions.** Independent studies reveal that global CMM emissions could be more than twice what governments report them to be [15]. At present, in ASEAN's "coal giant", Indonesia, only four out of ten big coal mining companies have included CMM in their emissions reporting [12]. Based on independent estimates using satellite and mine-level data, Indonesia's CMM emissions are up to seven times higher than what is currently reported: 128 kt of methane (officially reported by the government), versus 750 kt of methane (as calculated from satellite data) and 875 kt of methane (as calculated from mine-level data)- see Figure 6 [12]. The discrepancy may be a result of the continued use of inaccurate emissions factors, an outdated Global Warming Potential (GWP) reference and the exclusion of underground coal mines.

Figure 6: Indonesia CMM emission estimates from different sources



Source: Ember

Without an accurate MRV system, it is difficult for any country to realise and understand the "hidden" methane problem that the country is experiencing.

1 Indonesia is still using the outdated methane GWP factor of 21 published by the IPCC's second assessment report in 1996. The latest IPCC report indicates that methane's GWP is 30 times that of CO_2.

Some countries are aware of the actual amounts of methane being emitted, **but lack the necessary knowledge relating to the types and availability of abatement technologies**.

Regionally, there is a **scarcity of service providers, project developers and technical specialists** that operate the specialised equipment needed to capture CMM. Compounding the problem is the fact that many coal mines are in remote locations, making the installation and operation of the abatement technologies challenging.

The associated costs of abating CMM are also a barrier, and cause companies to invest instead in other activities with a higher rate of return.

Incentives are needed to persuasively engage mine operators to install CMM abatement technologies. However, the global movement of coal phase-out/down may affect the cost-effectiveness of capital investments in methane abatement, leading to difficulties in obtaining funding and financing for CMM abatement technologies and/or projects.

Latest Finding

A recent finding about how **abandoned underground coal mines also emit high methane emissions may perhaps enable funding and financing amidst coal phase-down movements**. According to analysis by the Global Energy Monitor based on its granular coal mine dataset, methane emissions from abandoned underground coal mines in the European Union that have closed since 2015 could be emitting an estimated 298 million cubic metres of methane per year, equivalent to the amount of potential emissions leaked from the Nordstream pipeline after the 2022 explosion [17].

A **strong commitment and political will from companies and government will affect efforts on methane emissions abatement.**

Regulation, Commitment, Revenue

Awareness on the existing CMM will be irrelevant if not manifested into company's operating practices. Similarly, government must explore and adopt policies that mandates or incentivise the abatement of CMM.

Technological Solutions and Innovation

Surface Coal Mining (SCM)

Options for reducing methane in surface mines are quite limited, but one effective method is pre-mining gas drainage. This technique involves drilling boreholes into the coal seam, either from the surface or using underground rigs, to remove the gas before mining starts. For this method to work well, the coal seam needs to have moderate to high permeability so that the gas can be reduced significantly within a reasonable period. A standpipe is installed at the top of the borehole and connected to a pipeline to carry the captured gas away from the site. There are challenges with this approach, such as high-water pressure in the pipeline, instability of the borehole, and keeping the drilling direction under control. Additionally, there's a risk of encountering active drainage boreholes during the actual mining process [16], [18].

Figure 7: Operational surface coal mine in East Kalimantan

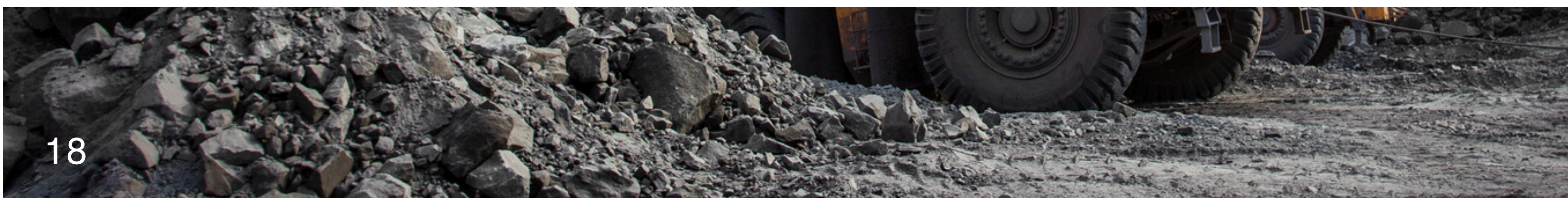
Source: Mongabay

The permeability of the coal is very important because it affects how long it takes to reduce the gas content to safe levels. Lower permeability means that more time is needed for effective gas drainage. Whether pre-drainage is a viable option depends on how much time is available before mining starts and the cost of drilling operations [18].

Modern drilling techniques and carefully planned drilling patterns can help to maximise gas removal. Usually, multiple boreholes are drilled from a single location, apart from one another and located in fan or parallel patterns. These patterns are designed to avoid intersecting with mining activities later on, aiming to remove the gas and drain the coal well in advance, often more than six months before mining begins [18].

The flow rates of gas from drainage boreholes change over time. Initially, high flow rates occur because of gas expansion and desorption near the borehole. This rate may decrease quickly but can increase again as surrounding rock is dewatered, which makes the coal more permeable and allows more gas to flow. Eventually, the flow rate decreases as the gas in the area gets depleted. Geological features, such as faults, can also affect the emission and flow rates of gas [18].

Gas drainage systems influence how productive a mine can be. The efficiency of these systems and the capacity of the ventilation system determine how much coal can be safely extracted from gassy coal seams. Often, it is more cost-effective to improve gas drainage systems than to increase the volume of ventilation air. Investing in effective gas drainage systems can reduce downtime caused by gas issues, make mining safer, and potentially provide financial benefits through emissions trading schemes [18].



Surface to In-seam (SIS) Directional Drilling

SCM is a common mining method in Southeast Asia. Out of the ten largest open-pit mining sites in the Asia-Pacific region, four are in Southeast Asia, especially in Indonesia. In open-pit mining, coal is usually extracted from the top layers first. While methane emissions from SCM are less than those from underground mining, they are still quite significant. Managing these emissions is more difficult because the environment in open-pit mining is more exposed and open [16], [18].

One relatively environmentally friendly method is Surface to In-Seam (SIS) drilling. This technique helps better manage methane emissions from coal mining. SIS drilling involves using directional drilling to set up gas drainage systems and boreholes, which act as main channels for transporting the gas produced during mining [19].

SIS directional drilling has been shown to be effective for pre-draining coal seams with a permeability range under 10 millidarcy (md). Typically, directional drilling is done vertically, but if there are geographical issues, horizontal drilling can be used instead. This can serve as a low-pressure reservoir and help draw gas from areas above it. The gas captured through these boreholes can be used for generating heat and electricity or can be burned off using flaring methods [19].

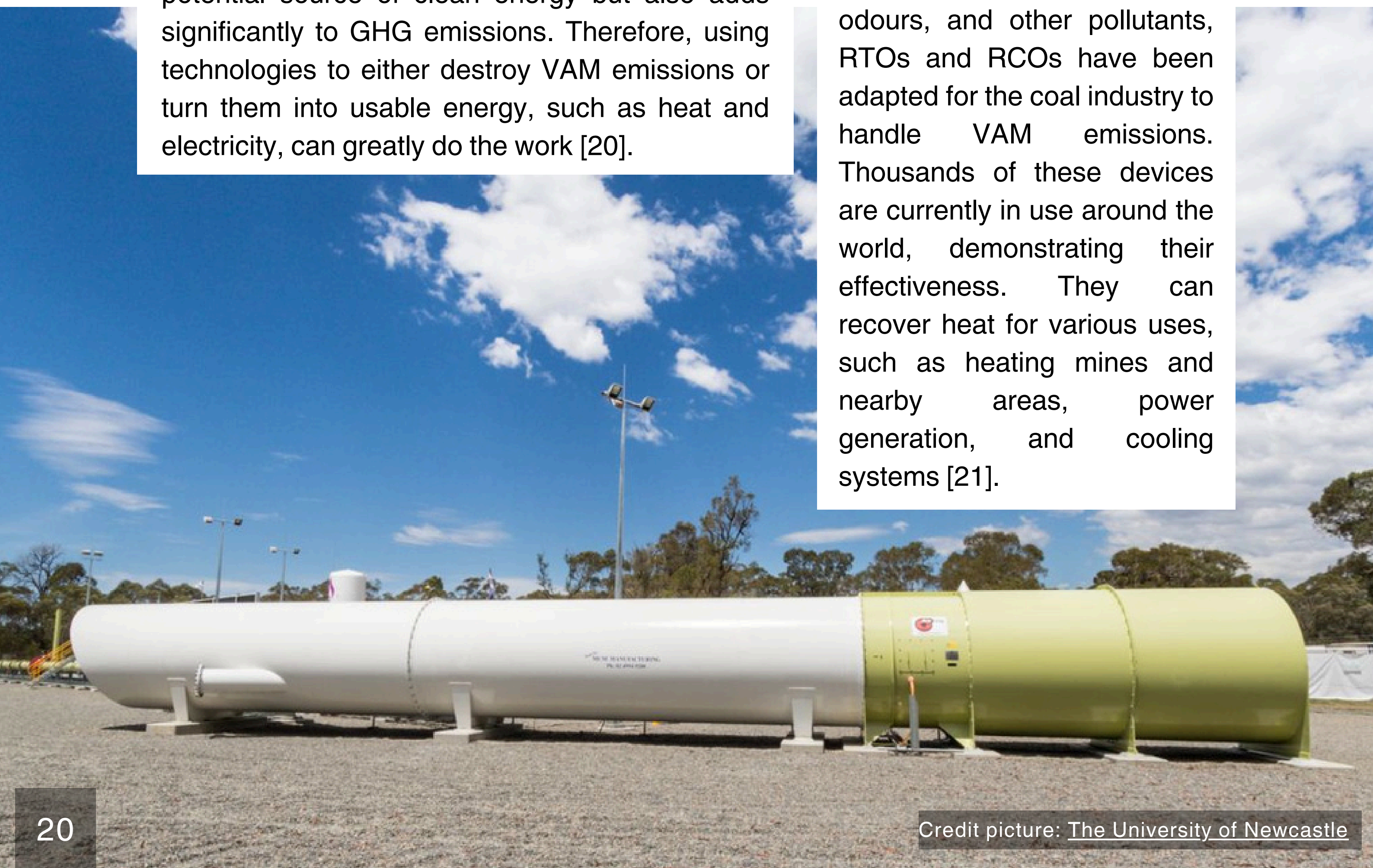
Underground Coal Mining

VAM Capture and Conversion

Ventilation Air Methane (VAM) is a byproduct of underground coal mining and has a very low methane concentration, typically less than 1% [20]. To protect miners, extensive ventilation systems are used to circulate large amounts of fresh air through the mines. This process dilutes the methane levels inside the mine to well below explosive limits. The methane-rich air from these systems is usually released into the atmosphere, making VAM the main source of CMM emissions worldwide, contributing to over half of all such emissions.

The main goal for managing CMM is to find ways to use it. However, because VAM has such a low concentration, using it effectively can be very challenging. Without cost-effective methods for utilisation, destroying the methane becomes a key strategy for reducing greenhouse gas emissions and achieving environmental benefits. Releasing VAM into the atmosphere not only wastes a potential source of clean energy but also adds significantly to GHG emissions. Therefore, using technologies to either destroy VAM emissions or turn them into usable energy, such as heat and electricity, can greatly do the work [20].

Technologies like Regenerative Thermal Oxidisers (RTOs) and Regenerative Catalytic Oxidisers (RCOs) have been developed to tackle this problem. Initially designed for pollution control to remove volatile organic compounds, odours, and other pollutants, RTOs and RCOs have been adapted for the coal industry to handle VAM emissions. Thousands of these devices are currently in use around the world, demonstrating their effectiveness. They can recover heat for various uses, such as heating mines and nearby areas, power generation, and cooling systems [21].



Credit picture: The University of Newcastle

Regenerative Thermal Oxidisers (RTOs) are notable as the only commercially viable technology that can use VAM as a primary fuel at low concentrations. Their adaptation for oxidising methane in mine ventilation air began in the early 2000s, with the first commercial VAM RTO project starting in 2007. Since then, at least six commercial RTO projects have been implemented in countries like China and the United States [21].

Figure 8: 2nd VAMOX® RTO unit
72 m3/sec (152k cfm) Virginia – 2022

Source: UNECE

The process of destroying VAM with an RTO involves directing a portion of exhaust air from the ventilation fan into the oxidiser through ducts. A fan maintains air flow by creating vacuum pressure, ensuring a steady flow of mine ventilation air into the oxidiser without adding back pressure to the fan. Once inside the RTO, the gas passes through a bed or column of heat exchange material, usually ceramic media preheated to 1,000°C, which is the temperature needed for methane oxidation.

In the oxidation chamber, the VAM is oxidised, releasing heat that is absorbed by a secondary bed of heat exchange material. This heat helps sustain the oxidation process without needing extra fuel. Valves and dampers periodically reverse the incoming VAM flow to keep the hot zone in the centre of the oxidiser [21].

Catalytic and thermal systems operate on this principle, though catalysts allow the reaction to occur at lower temperatures and with less pressure drop across the heat exchange bed. When VAM concentrations are high enough, thermal oxidisers can generate additional heat that can be used for applications like heating the mine shaft and generating power [21].

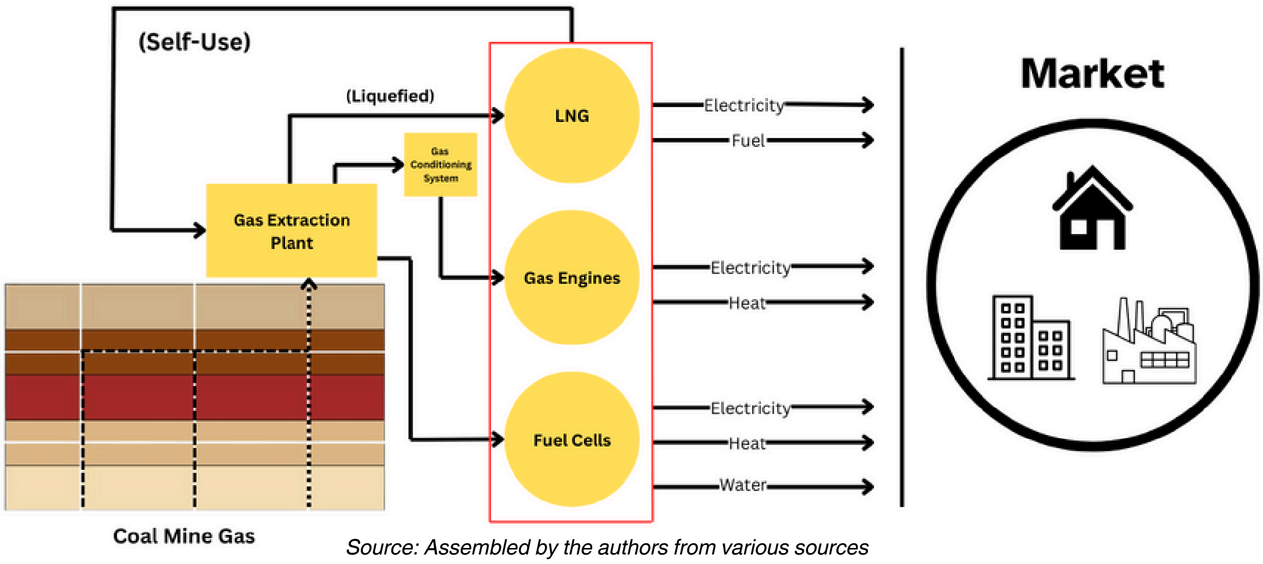
Credit picture: NESTEC

Methane to Energy

Liquefied Natural Gas

LNG is produced by cooling methane lower than -150˚C, which turns it into a liquid and reduces its volume. This process makes it easier to store and transport. Additionally, liquefaction purifies methane, resulting in a high-energy fuel that is over 95% methane. LNG is valuable for power generation and transportation, as it can be delivered to areas that do not have natural gas pipelines. Compared to coal and oil, LNG burns more cleanly, which helps reduce emissions and is important for transitioning to more sustainable energy sources [21]. Setting up an LNG terminal near a coal mine to process CMM into LNG is both feasible and beneficial. This process captures and purifies the methane, which helps cut down emissions, improves safety, and turns waste into a useful resource. Although there are initial costs and technical challenges, the environmental and economic advantages of this approach make it a promising way to lessen the ecological impact of coal mining.

Figure 8: Methane to Energy Chain in Coal Mines



Source: Assembled by the authors from various sources

Co-firing Boilers

Co-firing boilers offer another flexible solution for using CMM. These boilers are fitted with special burners that allow them to use methane from coal to generate heat or steam. They can handle a wide range of methane concentrations, from 25% to 100%. This adaptability is especially useful for CFPPs located near CMM production sites, where CMM can be used as an additional fuel source [22].

Gas Engines

As shown in Figure 6, gas engines can be modified to generate electricity from CMM even when methane concentrations are as low as 25%. However, these engines operate more efficiently when the methane concentration is above 40%. This flexibility enables effective energy recovery from gas streams with lower methane concentrations [22].

Fuel Cells

Fuel cells provide a cutting-edge method for generating electricity by using hydrogen, which is produced through a process called steam methane reforming (SMR).

In this process, methane is combined with water (H_2O) to produce hydrogen. This hydrogen is then used with oxygen to generate electricity, heat, and water, as illustrated in Figure 6. Unlike traditional combustion methods, fuel cells produce direct current (DC) electricity without burning fuel, offering a cleaner energy option and expanding the range of technologies available for utilising methane [23].

In-House Improvements

The in-house improvements referred to in this section are enhancements to the mining infrastructure at each site, which the authors believe are necessary for all mining sites. These improvements include gas drainage and enclosed flaring. Both are significant in providing flexibility in the gas flow to prevent blockages or narrow points that could be hazardous to worker safety and to minimise the large methane emissions released during mining operations. In-house improvements include:

Gas Drainage

Gas drainage in coal mines is a key method to prevent methane explosions. It involves drilling boreholes to remove gas from coal seams before it can accumulate to dangerous levels. The extracted methane can either be vented safely or used as fuel, which not only improves safety but also helps to reduce emissions [24]. This process demands meticulous planning and ongoing monitoring, showcasing both technological progress and a strong commitment to safety and environmental protection.

Enclosed Flaring

Enclosed flaring in coal mines involves capturing methane and burning it in a sealed chamber. This method converts the methane into less harmful carbon dioxide and water vapor. Enclosed flaring improves mine safety, cuts down on emissions, and can even produce usable energy. To maximise the environmental benefits, it is crucial to ensure efficient methane capture and rigorous maintenance of the system. This makes enclosed flaring an important strategy for reducing the ecological impact of coal mining [25].

Best Practices and Case Study

Surface/Open Pit Mining

Pre-mining gas drainage is a highly effective method for managing methane in surface or open-pit mining, particularly in areas with large coal reserves, such as Southeast Asia, China, and Australia. This technique involves extracting methane from coal seams before actual mining starts, which significantly reduces the amount of methane that would otherwise be released during operation. By addressing methane before it reaches the atmosphere, pre-mining gas drainage not only mitigates the risk of methane emissions but also enhances mining safety by lowering the risk of explosive gas concentrations [26].

The process of pre-mining gas drainage typically includes drilling boreholes or wells into the coal seam. These boreholes are strategically positioned to optimise methane capture, with gas being extracted under controlled conditions. In China, for example, extensive networks of boreholes are employed in coal-rich areas to drain methane from deep within the seams. The extracted methane can be stored, transported, or used as a valuable energy resource, converting a potent greenhouse gas into a commercially valuable product. This approach addresses environmental concerns and provides economic incentives for mining companies to invest in methane capture technologies [26].

In Australia, where surface mining is widespread, pre-mining gas drainage is integrated into broader methane management strategies. Australian mining companies often combine this technique with advanced geological surveys to identify areas with high methane concentrations before mining begins. This proactive approach allows for more efficient gas drainage and reduces the risk of methane emissions during mining. Additionally, the captured methane can be used for power generation, helping meet the energy needs of mining operations and reducing reliance on external energy sources [19].

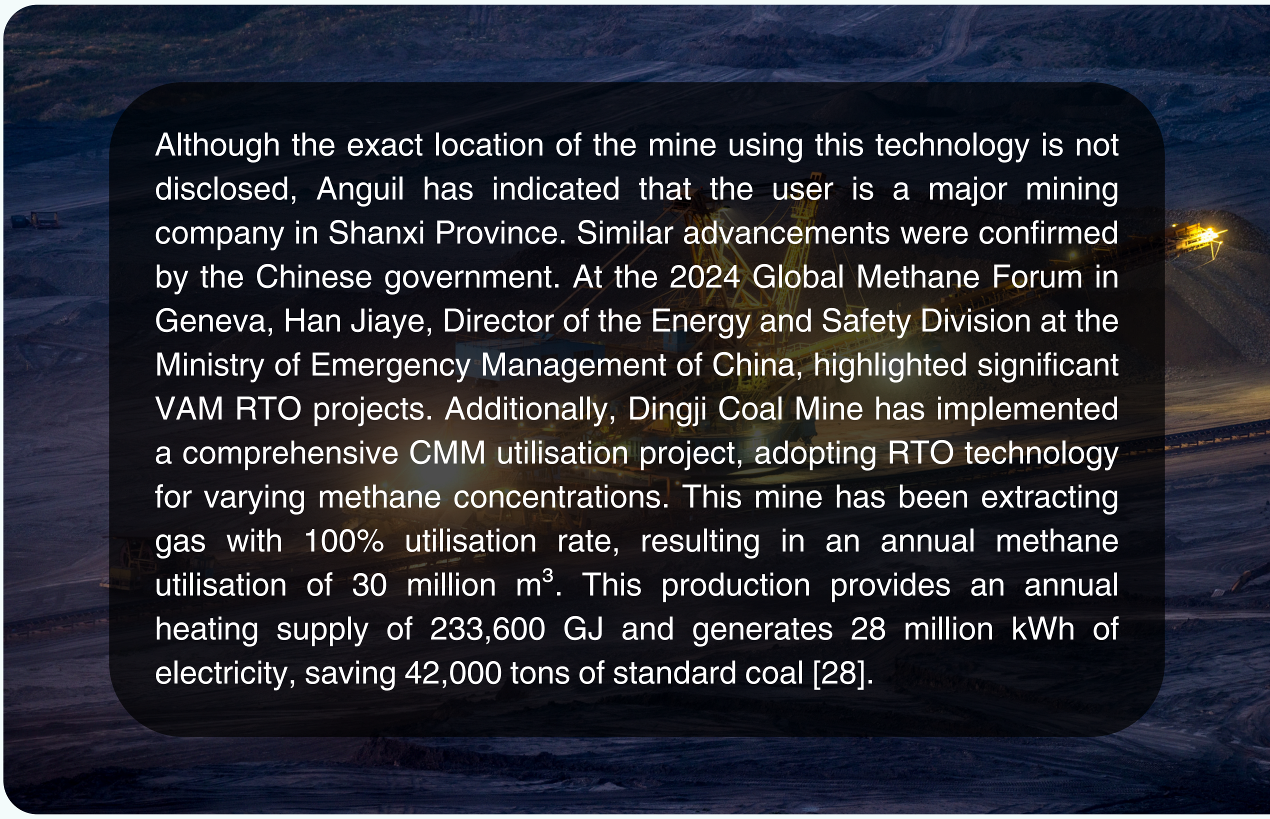
In Southeast Asia, where mining conditions vary due to diverse geology, pre-mining gas drainage is increasingly important. In countries like Indonesia, where coal mining is a major industry, implementing pre-mining gas drainage is becoming a key part of modernising and regulating the mining sector environmentally. By adopting this technique, Southeast Asian countries can better manage methane emissions, align with global environmental standards, and benefit economically from methane utilisation.

Underground Mining

The VAM Abatement Project in Shanxi, China, highlights the advanced use of RTO technology. This project employs RTO systems, enhanced with hot gas bypass, to effectively neutralise VAM emissions and some low-concentration CMM from drainage pipes.

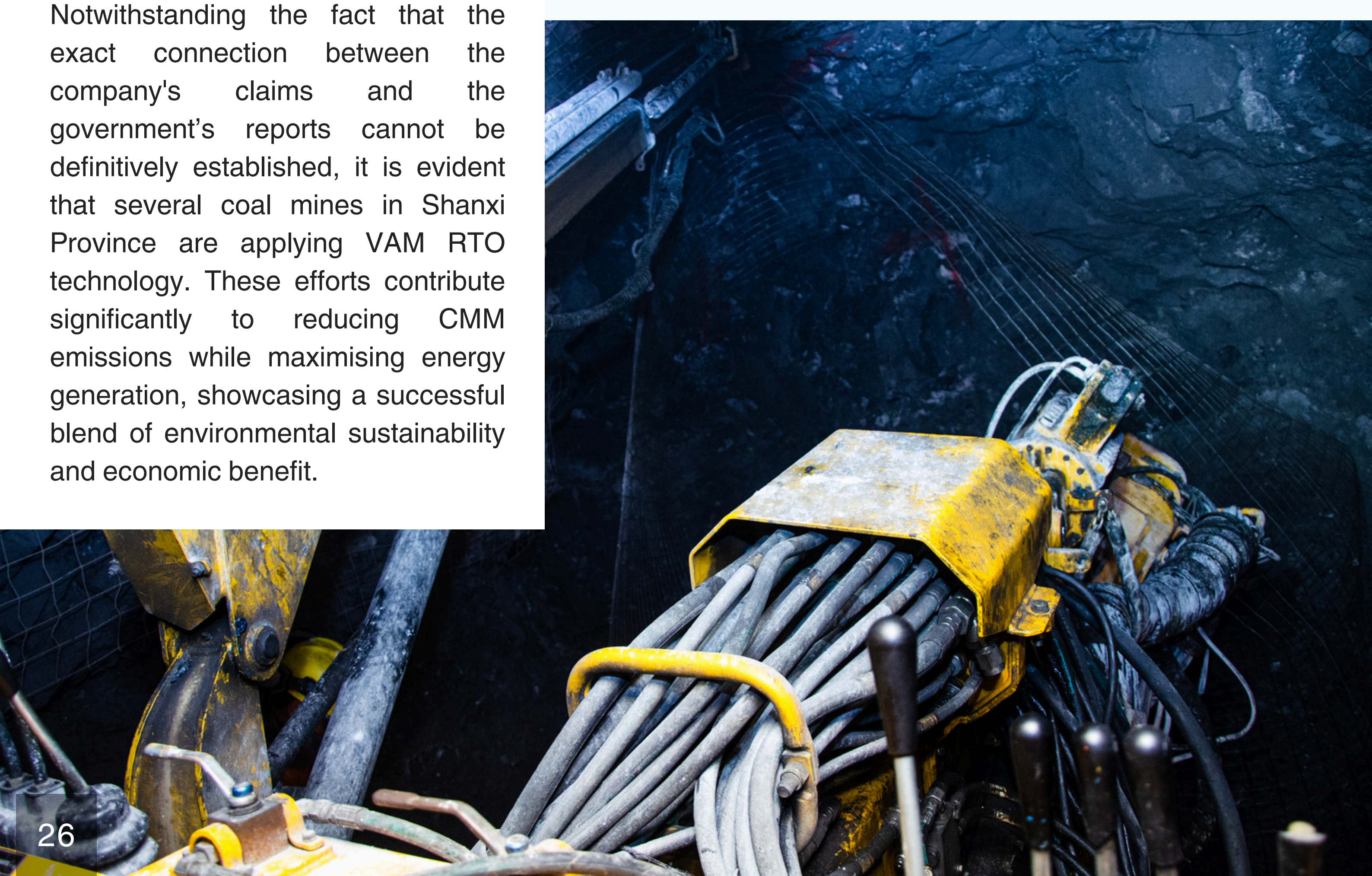
Anguil, a company specialising in engineered environmental equipment and services, is behind one of the key implementations of this technology. It focuses on addressing complex air and water challenges for industrial and manufacturing sectors. A notable feature of Anguil's RTO design is its ability to operate without additional energy if the incoming methane concentrations are above 0.35%. This represents a significant advancement in sustainable technology by minimising the energy required for efficient methane destruction. The RTO system further enhances energy efficiency by directing excess heat generated during the oxidation process through hot gas bypass dampers to a boiler system. The steam produced from this process is then used to power a steam turbine for electricity generation. This method avoids the creation of nitrogen oxides (NO_x), which are typically associated with burning coal or gas, thus maintaining a stable temperature for power generation [27].

The RTO system not only destroys emissions but also turns them into a profitable asset. By converting methane into an energy source, the coal mining company can generate and sell electricity. The project employs six RTO units that process a total of 540,000 Nm^3/hr (336,448 standard cubic feet per minute (SCFM)) of exhaust, with an average methane concentration of 1.2%. When operating at full capacity, the system can produce up to 15 megawatts of electrical power, which is fed back into the national power grid. Independent assessments show that the RTO system has the highest methane destruction efficiency, and it can eliminate more than 50 million cubic feet (MMcf) of methane annually. Moreover, the excess steam generated is used to regulate temperatures, further enhancing the project's overall energy efficiency [27].



Although the exact location of the mine using this technology is not disclosed, Anguil has indicated that the user is a major mining company in Shanxi Province. Similar advancements were confirmed by the Chinese government. At the 2024 Global Methane Forum in Geneva, Han Jiaye, Director of the Energy and Safety Division at the Ministry of Emergency Management of China, highlighted significant VAM RTO projects. Additionally, Dingji Coal Mine has implemented a comprehensive CMM utilisation project, adopting RTO technology for varying methane concentrations. This mine has been extracting gas with 100% utilisation rate, resulting in an annual methane utilisation of 30 million m^3. This production provides an annual heating supply of 233,600 GJ and generates 28 million kWh of electricity, saving 42,000 tons of standard coal [28].

Notwithstanding the fact that the exact connection between the company's claims and the government’s reports cannot be definitively established, it is evident that several coal mines in Shanxi Province are applying VAM RTO technology. These efforts contribute significantly to reducing CMM emissions while maximising energy generation, showcasing a successful blend of environmental sustainability and economic benefit.



Policy Recommendations

Policy Recommendations

1

Improve the **accuracy and transparency** of methane emissions monitoring and reporting. Without accurate data, countries may not realise and understand the underlying “hidden problem”. Currently, the largest coal producing ASEAN country, Indonesia, is using the IPCC Tier 1 Method to estimate its surface CMM emissions.[2] Improvements can be made to using Tier 2[3] and Tier 3[4] approaches to reduce levels of uncertainty, provide superior spatial resolution, enable more detailed inventory categorisation, and enhance the overall quality and accuracy of the inventory data.

2

Deploy **incentives** (and fiscal disincentives) to increase and accelerate the adoption of CMM abatement measures, such as subsidies, royalty relief and carbon taxes. Moreover, it is imperative to increase the number of service providers, project developers and technical specialists who operate specialised equipment for CMM.

3

Increase **awareness** about the importance of addressing CMM at all levels of the coal, steel and power industries, from senior management[3] to the technical level.

4

Continue **research and development** on CMM, including the post-mining emissions and methane emissions from abandoned coal mines.

[2] The IPCC Tier 1 Method uses a simple reference emission factor, which is the multiplier used to estimate the amount of methane gas emitted for every tonne of coal extracted or produced. The IPCC recommends that this is used only when the overburden depth of a coal mine is less than 25m, whereas in the coal mines of East and South Kalimantan it may reach up to 30 – 60m.

[3] The Tier 2 approach uses country- or basin-specific emission factors that represent the average values over the coal mines considered.

[4] The Tier 3 approach requires both local measurements and facility-level data.

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