METHANE EMISSION FACTORS FOR COAL MINING AND HANDLING ACTIVITIES

DR PATITAPABAN SAHU

ASSOCIATE PROFESSOR

DEPARTMENT OF MINING ENGINEERING

METHANE EMISSION FACTORS

- Coal mining and handling activities have a substantial contribution to Indian greenhouse gas (GHG) emissions. The larger share of emissions from such activities is fugitive methane emissions, which are released from the coal matrix when coal extraction takes place.
- Fugitive methane emissions from fossil fuel extraction account for significant contribution towards greenhouse gas (GHG) emissions in India. Out of total all-India GHG emissions of 1.88 million Gg-CO2 equivalent in 2010 ((with Land use, land-use change, and forestry (LULUCF)), 48928.66 Gg-CO2equivalent belonged to fugitive emissions from fossil fuel extraction.
- Methane emission from coal mining and handling activities has increased from 0.555 Tg (teragram: 10^12 grams.) in 1991 to 0.765 Tg in 2012, as per national emission factors developed by CSIR-CIMFR. These estimates have been prepared as part of India's Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) and the Biennial Update Report (BUR).

BUR: Contains updates of national GHG inventories including a national inventory report and information on mitigation actions, needs and support received.

- Underground coal mining is extremely important as regards to the fugitive methane emissions. The emission factor for Indian underground coal mining activities is 2.5-20 times higher than opencast mines. Similarly, emissions for coal handling is 6.5-21 times higher (MOEF, 2010).

- Moreover, machinery use in underground coal mining is also higher, which means CO2 emissions from diesel combustion are also likely to be higher for the usage of HEMMs.

- Coal mining processes have significant use of heavy machinery and other infrastructure and it is pertinent to discuss the relative carbon footprint of each of these processes.

- Preliminary studies have been conducted at two opencast mines of the Central Coalfields Limited (CCL) – Ashoka and Piparwar (CIMFR & IIMA, 2014). The outcomes of the above studies reveal that while fugitive methane emissions did account for more than 3/4th of the total carbon footprint of the coal mining process. Around 22.5% emissions also resulted from diesel combustion of the auxiliary processes.

- Currently, room-and-pillar method of mining is the most popular method of underground mining in India. This method uses the continuous miner technology, which is a high energy consuming machinery.

- Similarly, significant energy is consumed for ventilation of underground mines, which can be optimized using control settings of ventilation equipment and flow (Panigrahi & Mishra, 2014).

- Another popular method of mining is the longwall method. This process is also a highly mechanized process. But, the energy consumption of the machinery can itself be influenced by the cuttability (and other factors of ease of mining) of the seams, which can be influenced by a variety of factors including the origin and depth of mining. As a result, estimating overall GHG emissions for underground mines is an extremely challenging task and opens up an interesting research question for the future.

- Moreover, studying underground mines for this purpose is also important because most of the opportunities for methane mitigation through CMM or VAM exist mostly in underground coal mines.

- Therefore, it is important to have a scientific study which will refine the fugitive methane emission factor, and reduce the uncertainty levels in the inventory of fugitive methane from coal mining activities and provide annual methane emission estimates for opencast and underground coal mining in India.

- In the last four decades, a substantial growth has been recorded in commercial primary energy consumption in India. Energy usage in India is expected to grow significantly due to India's developmental goals.
- Though renewable energy consumption has grown from 9.2 MTOE (Million tonnes of oil equivalent) in the year 2011 to 13.9 MTOE in the year 2014, coal is likely to remain the main source of energy in India in the foreseeable future. It has been reported that over 70% of electricity generated in India is from thermal power plants. Coal is considered as vital to India's energy security.
- The Geological Survey of India has estimated proven coal reserves of the country at 131.61 billion tonnes. Estimates of total coal resources are much higher at 306.60 billion tonnes up to a depth of 1200 metres as on 1st April 2015. The coal resources reported above are coal in-situ and all of them are not extractable at the present status of economics and technology.
- The proved recoverable reserves of 60.6 billion tonnes are capable to supply coal for over 100 years at current level of production and more than 50 years at double the existing rate of production. This appears to be a very comfortable situation and should enable the coal mining industry in India to meet increasing demand despite some technological and financial barriers.

- Methane is invariably found within coal seams and associated rocks. Coal normally stores substantial quantities of methane within its micro pores.

- Underground coal mining was plagued by the gas hazards and had been a continual source of anxiety and inconvenience to the miners throughout the long history of the industry.

- The ventilation air along with the mine gases is released into the atmosphere. Although, the levels of methane in the vented air is frequently less than 0.02% in the Indian context, a significant amount of the gas is added to the atmosphere every year, as the quantity of vented air is quite large.

- Methane present in coal is not a safety problem in the case of surface mining. However, a considerable amount of the gas is emitted to the atmosphere during surface mining of coal also as the share of coal production from surface mines is more than 90% in India.

- Besides the emission during mining, coal still contains some remnant gas that is released slowly with time during handling activities such as processing in washeries and coal handling plants and subsequent utilization.

- Current methane emissions from Indian coal mining and handling activities are required to be estimated. The basic calculations for estimating emissions need to be carried out following methodologies very similar to those recommended by the Intergovernmental Panel on Climate Change (IPCC).

- Methane emission factors during mining and post-mining for different categories of coal mines are required to be determined.

- Annual coal production data for different categories of mine is collected, which is multiplied by the corresponding methane emission factor and the conversion coefficient of $0.67 \times 10\text{-}6$ Gg m-3 to obtain estimates of methane emission from coal mining.

- Estimates based on IPCC emission factors are obtained and are compared with the present results.

GASSINESS OF COAL SEAMS IN INDIA

- Based on mine specific measurement of rate of emission, all the underground coal mines in India have been categorized into Degree I, Degree II and Degree III by the Directorate General of Mines Safety.

❖ "Degree I Seams" refer to a coal seam in which the percentage of methane in the general body of air does not exceed 0.1 and the rate of emission of methane does not exceed one cubic meter per tonne of coal produced.

❖ "Degree II Seam" means a coal seam in which the percentage of methane in the general body of air at any place in the workings of the seam is more than 0.1 or rate of emission of methane per tonne of coal produced exceeds one cubic metre but does not exceed ten cubic metres.

❖ "Degree III Seams" correspond to a coal seam in which the rate of emission of methane per tonne of coal produced exceeds ten cubic metres.

Distribution of underground working mines having different degree of gassy seams in different states in India is shown in Table 1.

Table 1.Underground working mines having different degree of gassy seam – 2012. [18]

State	Degree I	Degree II	Degree III	Total
Andhra Pradesh	41	...	…	41
Assam	…	….	02	02
Chhatisgarh	42	...	01	43
Jharkhand	61	26	07	94
Jammu and Kashmir	01	02	…	03
Madhya Pradesh	39	16	…	55
Maharashtra	22	…	…	22
Orissa	07	03	…	10
West Bengal	24	56	03	83
All India	237	103	13	353

METHODOLOGY TO ESTIMATE METHANE EMISSION FROM COAL MINING AND HANDLING ACTIVITIES

- ❖ Compilation of available data on coal production, air quantity and methane and CO2 percentages in the intake and return airways of underground coal mines
- ❖ Emission of methane or CO_2 from coal depends upon the method of mining i.e underground or surface. In India there are more than 400 coal mines in different basins. Relevant data may be available only for 25-30 coal mines. Field study is necessary to obtain the information about the method of mining, depth, air quantity etc. at different locations.

Following mine specific data will be collected for the investigation:

- Name of the mine
- Owner of the mine
- District/Province
- Available coal reserve
- Year coal production started
- Mine plans
- Ventilation arrangement of mine
- Degree of gassiness of coal seams for underground mines
- Composition of mine air

- Air quantity is measured in the intake and return airways of the underground mines by standard procedure. Mine air samples are also collected at the air measuring stations. Chambers are fabricated for collection of mine air samples at opencast mines.

- Mine samples are analysed by portable gas analysers and also by gas chromatography. Concentration of methane, CO_2 and other gases, if any, are measured.

- Air quantity, gas concentration and coal production at different opencast and underground mine are compiled and analysed for arriving at national emission factors for fugitive methane and CO_2 emission. Activity data are collected from Statistics of Mines in India. Estimates of annual fugitive methane and CO_2 emission are prepared in line with IPCC 2006 guidelines.

The simple methodology defined in [8, 9] is represented in equation (1). Coal production data is considered as Activity data (A) which is multiplied by methane emission factor (EF) of respective category and the conversion factor of 0.67×10^{-6} Gg m^{-3} of methane to obtain estimates of methane emission from coal mining.

$$Emission\ (GgCH4) = A \times EF \times Conversion\ Factor \tag{1}$$

In order to obtain the methane emission factor, the following measurements were made in the underground mines of three different degrees of gassiness:

- The velocity of air passing through the return airways separately in each ventilating districts and in the main return of the mine with the help of Anemometer.
- Cross sectional area of each return airway of the mine by multiplying the average width and height of the airway.
- Percentage of methane in the air samples collected in the return airway of the mine by gas chromatography.

Quantity of air was calculated by multiplying the air velocity and cross sectional area of the return airway. This was further multiplied by the percentage of methane in the return airways to obtain daily make of methane in the mine. Daily coal production data was collected from the mine authority during the period of investigation. Methane emission factor was calculated by dividing the daily make of methane by the daily coal production [19].

For surface mines a rectangular chamber (Fig.2) with internal dimensions of 50 × 40 × 15 cubic cm, closed from five sides but open floor and fitted with a nozzle for gas collection were used to measure methane flux. These chambers were placed on the benches of surface mines for a known period of time. Methane percentage inside the chamber was determined by gas chromatograph (Chemito, model number GC 1000). Area of freshly exposed coal face was also measured in the surface mines to calculate methane flux. Daily coal production data was collected during the period of investigation.

Fig. 2. Plastic rectangular chamber for methane flux measurement.

Activity data on coal production from surface and underground mines was collected (See Table 2) [18][1].

Table 2.National coal production by type of mine workings in years 1990–2012 (in Million tonnes). Source: Ref 18[1].

Year	Surface	Underground (u/g)				Total Coal
		Degree I	Degree II	Degree III	Total u/g	Production
1990	143.21	46.80	20.06	2.67	69.53	212.74
1991	167.03	44.92	22.56	3.25	70.73	237.76
1992	178.88	45.78	21.99	3.30	71.07	249.95
1993	186.94	49.62	20.48	3.58	73.68	260.62
1994	196.88	48.41	19.13	3.10	70.64	267.52
1995	216.07	46.59	18.95	2.97	68.51	284.58
1996	233.97	48.92	18.59	2.62	70.13	304.10
1997	247.62	48.53	17.98	2.55	69.06	316.68
1998	251.32	48.00	18.17	2.40	68.57	319.89
1999	247.09	47.22	18.61	2.26	68.09	315.18
2000	268.09	46.17	17.36	2.69	66.22	334.31
2001	277.38	45.97	15.73	2.43	64.13	341.51
2002	297.98	46.65	16.34	2.33	65.32	363.30
2003	315.56	45.64	16.13	1.86	63.63	379.19
2004	347.35	44.46	15.42	2.03	61.91	409.26
2005	356.76	44.03	18.18	1.88	64.09	420.85
2006	369.12	43.57	16.00	1.65	61.22	430.34
2007	387.33	44.87	17.43	1.86	64.16	451.49

[1] Coal production data in respect of the underground mines are available from different categories of Degree I, Degree II and Degree III seams from the year 1980 onwards in the Directorate General of Mines Safety, Government of India publications for various years. Ref. [18] gives the reference of the statistics for year 2012. It may be noted that similar data has been used from the year 1990 onwards for this study.

Year	Surface	Underground (u/g)				Total Coal Production
		Degree I	Degree II	Degree III	Total u/g	
2008	440.00	49.77	15.37	1.13	66.27	506.27
2009	491.98	53.76	12.17	0.89	66.82	558.80
2010	531.88	55.31	13.82	0.85	69.98	601.86
2011	538.24	55.40	11.54	2.08	69.031	607.27
2012	553.62	51.36	12.28	0.68	64.34	617.96

Emission factor for surface mining and also from underground mining for different degrees of gassiness are evaluated based on field measurement. These national methane emission factors for different categories of mines in India are presented in Table 3. These are also referred to as CSIR-CIMFR emission factors. These emission factors have been used for quantifying fugitive methane emission estimates, which has been reported in India's Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) and the Biennial Update Report (BUR) [20, 21].

Table 3. National emission factors for coal mining and handling activities in India. [20, 21]

Operation (Mining/ Post Mining)	Methane Emission factor (m^3/tonne)			
	Surface Mining	Underground Mining		
		Degree–I	Degree–II	Degree–III
Mining	1.18	2.91	13.08	23.68
Post Mining (Handling)	0.15	0.98	2.15	3.12

However, the Intergovernmental Panel on Climate Change (IPCC) [8] has provided methane emission factors for low, average and high cases. These emission factors are the same as those described in [9] and are presented in Table 4.

Table 4. IPCC emission factors for coal mining and handling activities. Source: Ref. 9.

Operation (Mining/ Post Mining)	Methane Emission factor (m^3/tonne)					
	Surface Mining			Underground Mining		
	Low	Average	High	Low	Average	High
Mining	0.3	1.2	2.0	10.0	18.0	25.0
Post Mining (Handling)	0.0	0.1	0.2	0.9	2.5	4.0

It may be observed from Tables 3 and 4 that national methane emission factors for surface coal mining and handling activities are comparable to those of the average value of IPCC but the difference is significant, when we compare the national emission factors for underground coal mines with the values of IPCC default emission factors.

- Earlier estimates of methane emission reported a value of 0.4 Tg for the year 1990. Later, measurements were made in 25 surface and 67 underground mines of different degrees of gassiness.
- Estimates for methane emission to the atmosphere were prepared for the years 1990 to 2012 shown in Fig.3. These estimates were prepared using new emission factors determined in Indian context and also using the IPCC emission factors for low, average and high cases. Coal production for the year 2012, emission factors and estimates of methane emission have been presented in the Table 5.

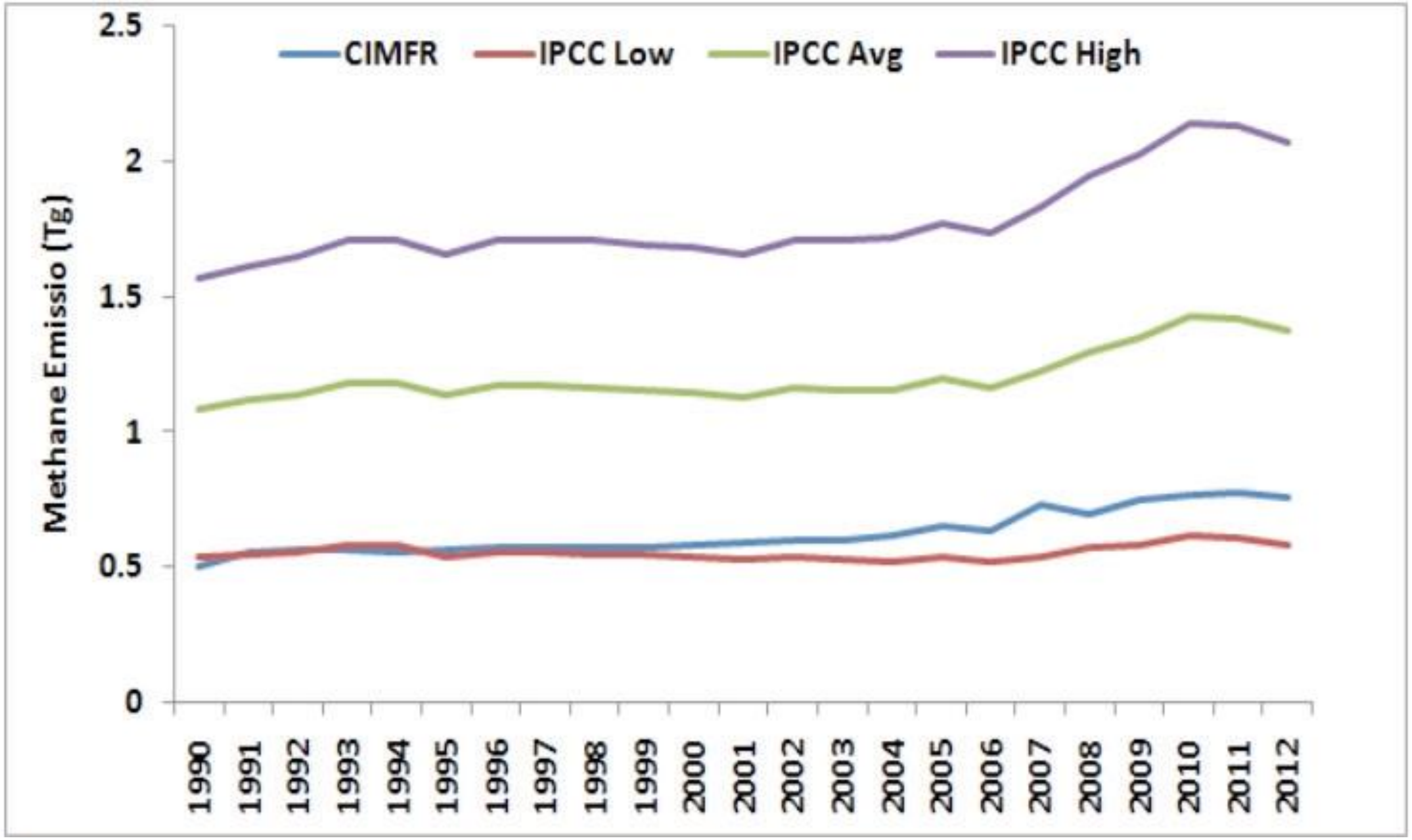

Fig. 3. Trend of methane emission from coal mining and handling activities in India.

Table 5. Methane emission from Indian coal mining and handling activities for the Year 2012.

		STEP 1				STEP 2	
			A	**B**	**C**	**D**	**E**
			Amount of Coal Produced (Million tonnes)	Emission Factor (m^3 CH_4/t)	Methane Emissions (million m^3)	Conversion Factors	Methane Emissions (Tg CH_4)
CIMFR EMISSION FACTORS					**C = (A× B)**		**E=(C × D)**
Underground Mines	Mining	Deg. I	51.36	2.91	149.457	0.67×10^{-6}	0.100
		Deg. II	12.28	13.08	160.622	0.67×10^{-6}	0.107
		Deg.III	0.68	23.64	16.075	0.67×10^{-6}	0.010
	Post-Mining	Deg. I	51.36	0.98	50.332	0.67×10^{-6}	0.033
		Deg. II	12.28	2.15	26.402	0.67×10^{-6}	0.0177
		Deg.III	0.68	3.12	2.121	0.67×10^{-6}	0.001
Surface Mines	Mining		553.62	1.18	653.271	0.67×10^{-6}	0.438
	Post-Mining		553.62	0.15	83.043	0.67×10^{-6}	0.0555
						Total	**0.765**
IPCC EMISSION FACTORS							
Underground Mines	Mining	Low	64.34	10	634.4	0.67×10^{-6}	0.431
		Average	64.34	18	1158.12	0.67×10^{-6}	0.777
		High	64.34	25	1608.5	0.67×10^{-6}	1.079
	Post-Mining	Low	64.34	0.9	57.960	0.67×10^{-6}	0.0388
		Average	64.34	2.5	160.85	$0.67 \times 10^{-6})$	0.107
		High	64.34	4	257.36	0.67×10^{-6}	0.172
Surface Mines	Mining	Low	553.62	0.3	166.086	0.67×10^{-6}	0.111
		Average	553.62	1.2	664.344	0.67×10^{-6}	0.445
		High	553.62	2	1107.24	0.67×10^{-6}	0.743
	Post-Mining	Low	553.62	0	0	0.67×10^{-6}	0.00
		Average	553.62	0.1	55.362	0.67×10^{-6}	0.0371
		High	553.62	0.2	110.724	$0.67 \times 10^{-6})$	0.07431
Low Emission	**0.618**		**Average Emission**	**1.425**		**High Emission**	**2.069**

MITIGATION STRATEGIES

From mitigation perspective, methane in coal may be recovered for its utilization. It has been identified as a clean fuel resource. The extraction technology of methane from coal mines is classified into the following three categories.

- Coal Mine Methane (CMM) or Degasification of working seams: When methane is recovered simultaneously during mining of coal with an objective of reducing the methane concentration in the mine workings and for its utilization, it is known as coal mine methane. Various mine degasification techniques are followed to recover CMM [23].

- Ventilation Air Methane (VAM): Methane present in the ventilation air is known as the ventilation air methane. Although, the concentration of methane in the ventilation air is generally very low, new oxidation technologies have come up which burn the VAM and produce useful energy from it [24]. Ventilation air typically contains low and variable methane concentration and large quantity of the ventilation air make it difficult to handle and process it into useable forms of energy.

- Abandoned Mine Methane (AMM): Methane that continues to be emitted from the left over coal and the adjoining strata and is accumulated in the mine voids even after the abandonment of an underground mine, is known as AMM. The abandoned mines emit gas to the atmosphere through mine openings or factures that connect the mine void to the surface and through leaking or vented seals that are placed over ventilation shafts and other openings [25].