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Research Article

GEOGRAPHICAL SPREAD OF FLY ASH GENERATION AND RESIDUAL POTENTIAL FOR ITS UTILIZATION IN INDIA

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ABSTRACT
A lot has been done to use fly ash so that the amount generated every year gets utilized in that year irrespective of type of use. Despite vigorous efforts, still more than 40% of fly ash that is generated in a year left unutilized in that year. In this study, efforts have been made to establish the geographical spread of fly ash generated and utilized in India at state level. Based on the volume of fly ash utilized and residual fly ash left in the last four years, a framework is suggested to estimate the quantum of support required for each state. It may help to prepare an action plan for national and state level for increasing the fly ash utilization.

Keywords: *Fly Ash, Generation, Utilization, Residual Potential*

INTRODUCTION
Industrialization and rapid economic growth has raised the electricity demand tremendously. Coal has dominant role for electricity generation in India and primacy of coal usage for power generation would continue in near future.
Use of coal in thermal power stations results in production of fly ash. Engineers are facing greater challenges in containing the degradation of land and atmospheric pollution caused by ever mounting deposits of fly ash at power plants. The solution to this problem lies in gainful utilization of fly ash. Construction of roads and embankments provides an avenue for bulk utilization of fly ash.

Fly Ash
In coal based thermal power plants, fly ash is produced by the combustion of finely ground coal, passing 75 micron sieve size, injected at high speed with a stream of hot air into the combustion chamber where it burns instantaneously (Ahmed *et al.*, 2007).
On entry into the furnace, where the temperatures are usually around 1500^{o}c, the carbonaceous content of coal in suspension is burnt instantaneously. The remaining inorganic matter present in the coal, such as shales and clays essentially consisting of silica, alumina and iron oxide, melt whilst in suspension. Ash particles undergo rapid cooling which causes the formation of fine spherical particles. About 80 per cent of the coal ash is eventually carried out of the furnace with the flue gases and must be removed before flue gases are discharged into the atmosphere.
Fly ash is removed from the flue gases by electrostatic precipitators or bag filters. On an average a 210 mw thermal power station using power grade coal having 40 per cent ash content generates 50 tonne of fly ash per hour (Karim *et al.*, 2011).

Power Sector and Coal
The necessity of providing electric power to rapidly growing industrial and agricultural sectors, has resulted in setting up of a number of thermal power stations all over the country. There has been an impressive increase in power generation capacity in India.
From 1,362 mw in 1947, the total installed power sector capacity has reached 253 gw in 2014 with about 60% power plants are coal-based.

Table 1 states the sector-wise installed capacity (mw) of power plants in India as on Aug. 31, 2014 (sector-wise) (Banerjee, 2014).

However, despite this substantial growth, there still remains a wide gap between demand and supply of power. Economical electricity is the positive side of coal combustion while environmental pollution due to production of waste ash is the negative side of electricity generation (Yeboah and Burns, 2011). The utility thermal power stations in addition to several captive power plants use bituminous or sub-bituminous coal and produce millions of tonne of fly ash annually, occupying acres of land as ash ponds.

Table 1: All India Installed Capacity (MW) as on Aug. 31, 2014 (Sector-wise) (Banerjee, 2014)

	Thermal				Others			
	Coal	**Gas**	**Diesel**	**Total**	**Nuclear**	**Hydro**	**Renew-able**	**Grand Total**
Central	46525.01	7065.53	0.00	53590.54	4780.00	10622.76	0.00	68993.30
State	55290.50	6974.42	602.61	62867.53	0.00	27482.00	3803.67	94153.20
Private	50495.38	8568.00	597.14	59660.52	0.00	2694.00	27888.47	90242.99
All India	152310.89	22607.95	1199.75	176118.59	4780.00	40798.76	31692.14	253389.49

Figure 1 provides the sector-wise total installed capacity for different fuel sources in 2014. Table 2 shows all India yearly coal consumption for power generation. The Indian power sector used about 487 million tonne of coal in 2013-14. The annual coal requirement for the power sector in 2017 is projected to be 730 million tonne (including 180 million tonne of imports) (Cicek and Tanrıverdi, 2007).

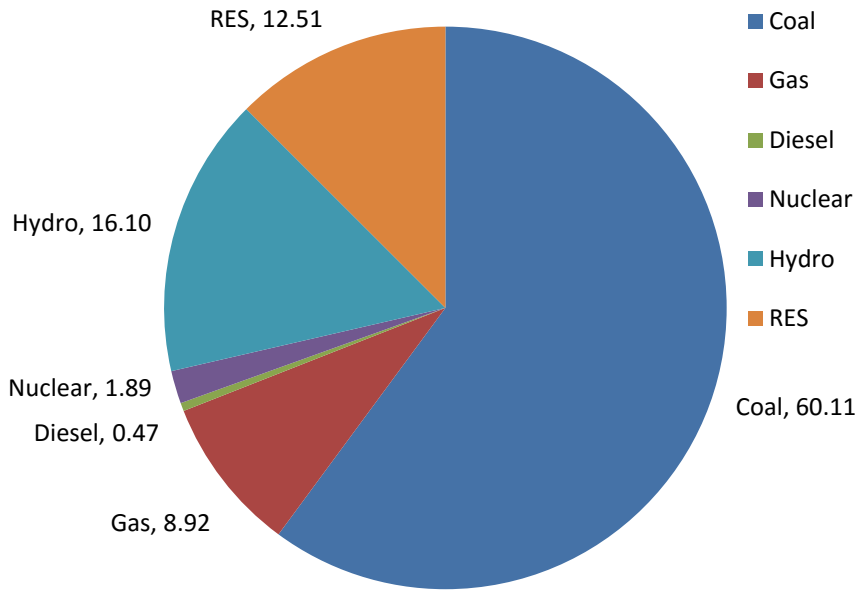

Figure 1: Indian Installed Power Generation Capacity as on Aug. 31, 2014 (Banerjee, 2014)

Table 2: All India Yearly Coal Consumption for Power Generation (Utilities) (Banerjee, 2014)

Year	Coal Consumption (Million Ton)
2004-05	278.00
2005-06	281.00
2006-07	302.00
2007-08	330.00
2008-09	355.00
2009-10	367.00
2010-11	387.00
2011-12	417.56
2012-13	454.60
2013-14	487.90

Table 3 shows the production, consumption, and estimates of India's conventional fossil fuel reserves. The physical units have been converted into energy units by using an assumed average calorific value. It can be seen that coal is India's principal coal reserve.
Even if only the proven fossil fuel reserves are considered, the static reserve-to-consumption ratio is over 100 years.

Table 3: Fossil Fuel Production and Reserves in India (Dhadse *et al.*, 2008)

Source	2011 Production	2011 Consumption	Reserve Estimate	Energy Resource (EJ)
Coal	540 million ton	635 million ton	294 billion ton (118 billion ton proven)	2200-5500
Lignite	42 million ton	42 million ton	41 billion ton	490
Oil	38 million ton	211 million ton	760 million ton	32
Natural Gas	48 billion m3	46 billion m3	1330 billion m3	47

From the above discussion, it can be easily concluded that the operation of coal-based power plants shall not only be continued but also be increasing. The operation of coal-based power plants shall be releasing fly ash after operation.

International Scenario

Globally fly ash generation and utilization scenario is tabulated in Table 4 on the basis of World Wide Coal Combustion Products Network (WWCPN) and secondary sources (Executive Summary: Power Sector, 2014; Heidrich *et al.*, 2013). From various studies, it was found that in year 2010, worldwide production of coal combustion products was approximately 780 million tonne.
The largest CCP producing countries were China (395 MT), North America (118 MT), India (105 MT), Europe (EU15) (52.6 MT), Africa (31.1 MT) and Middle East as a minor contributor. About 53% has been reported as utilized on global level.
Utilization rates are varying widely with Japan having utilized 96.4% of its CCPs and Africa/Middle East with 10.5% as the lowest utilize.

Table 4: Global Fly Ash Generation and Utilization (Executive Summary: Power Sector, 2014)

No.	Country/ Region	CCPs Production (Mt)	CCPs Utilisation (Mt)	Utilisation Rate	CCPs Production/ Person(Mt)	CCPs Utilisation/ Person(Mt)
1	Australia	13.1	6	45.8	0.6	0.27
2	Canada	6.8	2.3	33.8	0.2	0.07
3	China*	395	265	67.1	0.29	0.2
4	Europe[EU15]	52.6**	47.8	90.9	0.11	0.1
5	India*	105	14.5	13.8	0.09	0.01
6	Japan	11.1	10.7	96.4	0.09	0.08
7	Middle East &Africa	32.2	3.4	10.6	0.02	0.01
8	United states of America	118	49.7	42.1	0.37	0.16
9	Other Asia*	16.7	11.1	66.5	0.05	0.03
10	Russian Federation	26.7	5	18.8	0.19	0.04
	Total	777.1	415.5	53.5		

* Non-member of WWCCPN
* * Total production in Europe > 145 Mt. No verified figures on use other than for EU15.

In a study (Lee *et al.*, 2006), total world coal utilization by-products (CUBs) for 2003 have been estimated at 591 Mt of which 25% bottom ash, 5% boiler slag and 70% coal fly ash, and based on an average ash content in bituminous coal (12.0%), the world total FA production for 2003 was estimated at 413.7 Mt of which about 20 Mt enter into the atmosphere.

According to the study of ACAA (2009) (Izidoro *et al.*, 2012), US power plants produce more than 63 million tons of fly ash per year and used only 39.2%. In Asia, more than 100 million tons of fly ash is produced in China per year, with about 40% being recycled. The production feature of fly ash in Europe exceeds 50 million tons per year.

China is the largest producer of coal in the world, with nearly 12% of total proven reserves (114 billion tons). In China the fly ash emitted by the thermal power plants is around 160 million tons in 2002. The comprehensive utilization of coal ash amounted to 51.88 million tons in 1995 increased to 70 million tons in 2000 (Majid *et al.*, 2008).

Over 50% of fly ash produced in China, is used in different purposes such as bricks manufacture which have low economic benefits but also in the construction of dams and cement industry. Large amount of the Chinese fly ash is still emitted into ponds or piled in land.

However, Basu *et al.*, (2009) reported that in China for 2005, about 100 MT (million tons) of coal combustion products was produced each year (Mukherjee *et al.*, 2008). During 2005, the utilization of fly-ash was 100% in Italy, Denmark and Netherlands with an annual production of 2 MT, 50–85% in USA and Germany and 45% in China (Table 5) (Mukherjee *et al.*, 2008).

Table 5: Generation and Utilization of Fly-Ash in Different Countries (Mukherjee *et al.*, 2008; Koukouzas *et al.*, 2006) (2005)

Country	Fly-Ash Production (Million Tons per Year)	Fly-Ash Utilization (%)
India	112	38
China	100	45
USA	75	65
Germany	40	85
UK	15	50
Australia	10	85
Canada	6	75
France	3	85
Denmark	2	100
Italy	2	100
Netherlands	2	100

In 1997, approximately 3.7 million tons of waste fly ash were produced in Korea (Planning Commission, Government of India, 2013). Each year approximately 10 million tons of lignite fly ash is produced in Greece (Majid *et al.*, 2008). In Turkey, over 10 millions of tonnes of fly ash is produced yearly as per the year 2006 [Central Electricity Authority (2014)]. Only a small portion of this waste is utilized as a raw material in the production of cement and concrete.

Brazilian power production is based mainly on hydropower with only 11% electricity (1500 MW) generation through coal based power plants [Central Electricity Authority (2014a)]. These power plants produce approximately 3 Mt of ash per year in 2008 [Central Electricity Authority (2014a)]. Fly ash production in Brazil in 2010 is around 4 Mt per year while the annual utilization for incorporation into cement and concrete accounts only for about 30% of total fly ash production [Central Electricity Authority (2011)].

Fly Ash Utilization in India

According to the reports from Central Electricity Authority, Ministry of Power, Government of India, the generation and utilization of fly ash in India from 1996-97 is shown as Figure 2. The total fly ash generated in last four years viz. 2010-11 till 2013-14 has increased from 131.08 million tonne to 172.87 million tone (Silva *et al.*, 2010; Sridharan and Prakash, 2007; Vittal Guru, 2002).

During the period, the utilization of fly ash has increased from 73.19 million ton to 99.62 million ton. Fly ash utilization in terms of percentage has moved between 55% to 61% with an overall percentage of 58.45%.

On one side, it reflects that all possible actions need to be taken to fully utilize the fly ash generated whereas on the other side, it shows that there is a huge potential of finding ways and means to utilize the fly ash.

With the generation of around 613 million tonne of fly ash during the period of four years, fly ash that is utilized, is around 358 million tonne. The volume of fly ash that remains to be gainfully utilized is around 255 million tonne during these four years. It states that around 64 million tonne of fly ash is accumulated every year.

Such a volume will need an area of around 18 sq. km every year considering covering depth of 3 m, an area that is more than the half of the area of Lakshadweep Island.

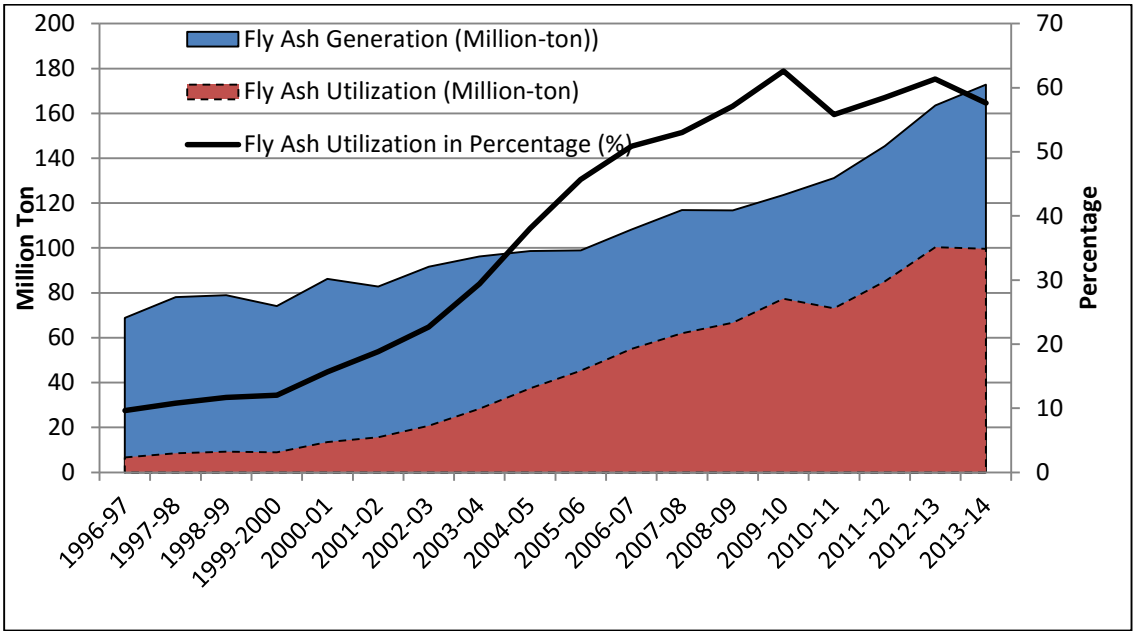

Figure 2: Fly Ash Generation and Utilization

State-Wise Fly Ash Utilization

The state-wise year-wise fly ash generation and fly ash utilization in India has been tabulated in Table 6. State-wise fly ash utilization from 2010-11 to 2013-14 is also shown as Figure 3. The percentage utilization of fly ash every year at state level represents wide range from 22.42% by Bihar in 2013-14 to as high as 115.52% by Tamil Nadu in 2011-12. More than 100% reflects that the fly ash accumulated over the years has been utilized to some extent.

It can be concluded from the information that almost all states have maintained similar percentage utilization over the years. Seven states viz. Delhi, Gujarat, Jharkhand, Punjab, Rajasthan, Tamil Nadu and West Bengal have shown good utilization pattern exceeding 70%. States like Andhra Pradesh, Madhya Pradesh, Maharashtra and Uttar Pradesh have maintained the average range of 50% to 70% which is national average range over these years.

Residual Potential

The volume of fly ash that remains to be gainfully utilized is around 255 million tonne during these four years. It states that around 64 million tonne of fly ash is accumulated every year. Such a volume needs enormous land area. During the period, residual fly ash has been calculated in Table 7. Different states have different patterns of fly ash utilization. The quantum of fly ash utilized and residual left for each state reflects the need of support in terms of technology, awareness, execution potential etc.

Based on the volume utilized by each state and the volume of residual fly ash left with them, a support framework is suggested in terms of:

- High support required – suggesting to take all out efforts as volume utilized is significantly low and/or residual volume is significantly high.
- Sufficient support required – suggesting to take significant efforts as volume utilized is comparable to residual volume and/or the residual volume is itself significant.
- Support required – suggesting to take efforts as residual volume is significant but the states are also utilizing significant proportion of fly ash.
- No support required – suggesting that appropriate framework for fly ash utilization is available, and no special effort is required, though the efforts being made are to be continued.

Table 6: State-Wise Fly Ash Generation and Utilization in India (Silva *et al.*, 2010; Sridharan and Prakash, 2007; Vittal Guru, 2002)

	2010-11			2011-12			2012-13			2013-14			Total		
State	**Generation**	**Utilisation**	**%age**	**Generation**	**Utilisation**	**%age**	**Generation**	**Utilisation**	**%age**	**Generation**	**Utilisation**	**%age**	**Generation**	**Utilisation**	**%age**
Andhra	13.44	6.75	50.22	17.09	9.05	52.97	19.68	10.68	54.24	19.84	10.00	50.37	70.06	36.48	52.06
Bihar	2.98	1.69	56.71	4.09	1.15	28.03	4.56	1.04	22.72	4.86	1.09	22.42	16.49	4.96	30.09
Chhattisgarh	5.66	2.64	46.64	15.75	6.74	42.82	18.82	7.27	38.66	19.68	6.57	33.37	59.90	23.22	38.77
Delhi	7.88	3.99	50.63	1.49	1.27	85.36	1.44	1.24	86.15	1.18	0.91	77.50	11.99	7.42	61.86
Gujarat	6.43	4.94	76.83	7.88	4.85	61.60	8.02	6.02	75.01	6.84	5.70	83.37	29.17	21.51	73.75
Haryana	2.11	0.83	39.34	5.97	2.00	33.53	6.59	2.48	37.57	6.03	2.74	45.52	20.69	8.05	38.90
Jharkhand	5.53	1.77	32.01	4.68	3.78	80.66	6.93	4.73	68.28	7.38	6.76	91.57	24.52	17.03	69.47
Karnataka	4.54	1.45	31.94	2.70	1.45	53.73	3.40	1.63	47.95	4.49	2.03	45.30	15.13	6.57	43.39
Madhya Pradesh	8.05	2.66	33.04	10.62	4.56	42.90	12.15	7.21	59.33	11.97	6.09	50.87	42.79	20.51	47.94
Maharashtra	12.98	6.96	53.62	12.60	7.01	55.62	13.91	8.81	63.37	16.38	10.05	61.35	55.87	32.83	58.76
Odisha	10.42	5.61	53.84	10.66	3.63	34.01	11.70	5.30	45.34	14.15	6.76	47.75	46.93	21.30	45.38
Punjab	2.87	1.59	55.40	3.41	2.82	82.80	3.36	2.78	82.68	3.15	2.80	88.94	12.78	9.99	78.13
Rajasthan	4.26	3.75	88.03	5.22	4.81	92.02	5.59	5.51	98.55	6.35	6.01	94.68	21.42	20.08	93.72
Tamil Nadu	10.19	6.78	66.54	6.67	7.70	115.52	6.88	7.12	103.52	7.29	6.50	89.23	31.02	28.10	90.59
UP	21.64	11.67	53.93	20.45	10.43	51.01	22.03	11.48	52.14	24.22	12.24	50.52	88.34	45.82	51.87
West Bengal	12.10	10.11	83.55	16.14	13.81	85.53	18.51	17.08	92.26	19.07	13.38	70.15	65.82	54.37	82.60
Grand Total	**131.08**	**73.19**	**55.84**	**145.42**	**85.05**	**58.49**	**163.56**	**100.37**	**61.37**	**172.87**	**99.62**	**57.63**	**612.92**	**358.23**	**58.45**

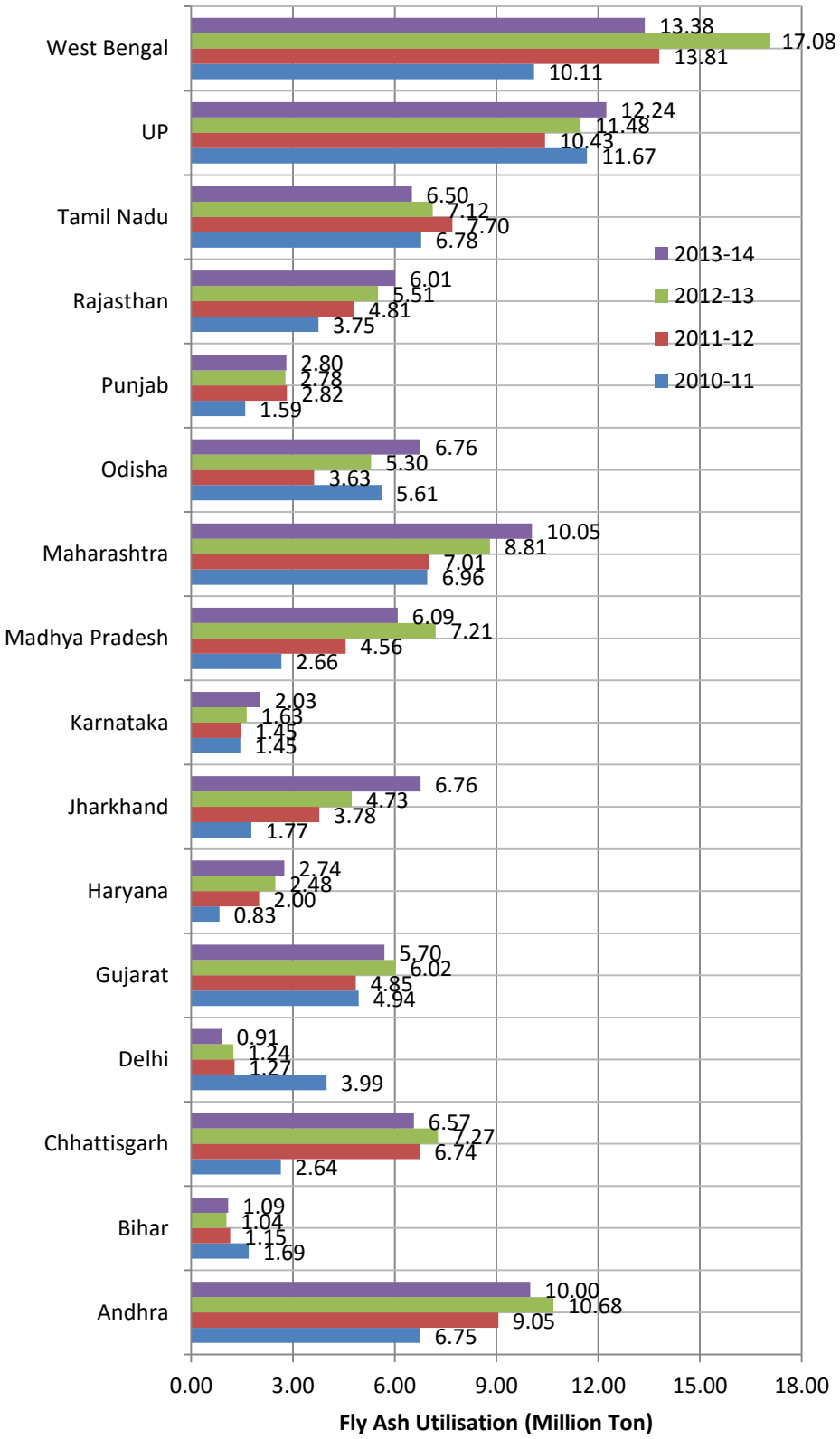

Figure 3: Fly Ash Utilization for Indian States

Table 7: State-Wise Residual Fly Ash during 2010-11 to 2013-14

No	State	Fly Ash Generation (Million-Ton)	Fly Ash Utilization (Million-Ton)	% Utilized	Residual Fly Ash (Million Ton)	Ratio of %Utilized to Residual	Support Framework
1	Chhattisgarh	59.90	23.22	38.77	36.68	1.06	High support required
2	UP	88.34	45.82	51.87	42.52	1.22	High support required
3	Andhra	70.06	36.48	52.06	33.58	1.55	High support required
4	Odisha	46.93	21.30	45.38	25.63	1.77	High support required
5	Madhya Pradesh	42.79	20.51	47.94	22.28	2.15	Sufficient support reqd.
6	Maharashtra	55.87	32.83	58.76	23.04	2.55	Sufficient support reqd.
7	Bihar	16.49	4.96	30.09	11.53	2.61	Sufficient support reqd.
8	Haryana	20.69	8.05	38.90	12.64	3.08	Sufficient support reqd.
9	Karnataka	15.13	6.57	43.39	8.57	5.07	Sufficient support reqd.
10	West Bengal	65.82	54.37	82.60	11.45	7.21	Support required
11	Jharkhand	24.52	17.03	69.47	7.48	9.28	Support required
12	Gujarat	29.17	21.51	73.75	7.66	9.63	Support required
13	Delhi	11.99	7.42	61.86	4.57	13.53	Support required
14	Punjab	12.78	9.99	78.13	2.80	27.95	No support required
15	Tamil Nadu	31.02	28.10	90.59	2.92	31.04	No support required
16	Rajasthan	21.42	20.08	93.72	1.35	69.67	No support required
	Total	612.92	358.23	58.45	254.69		

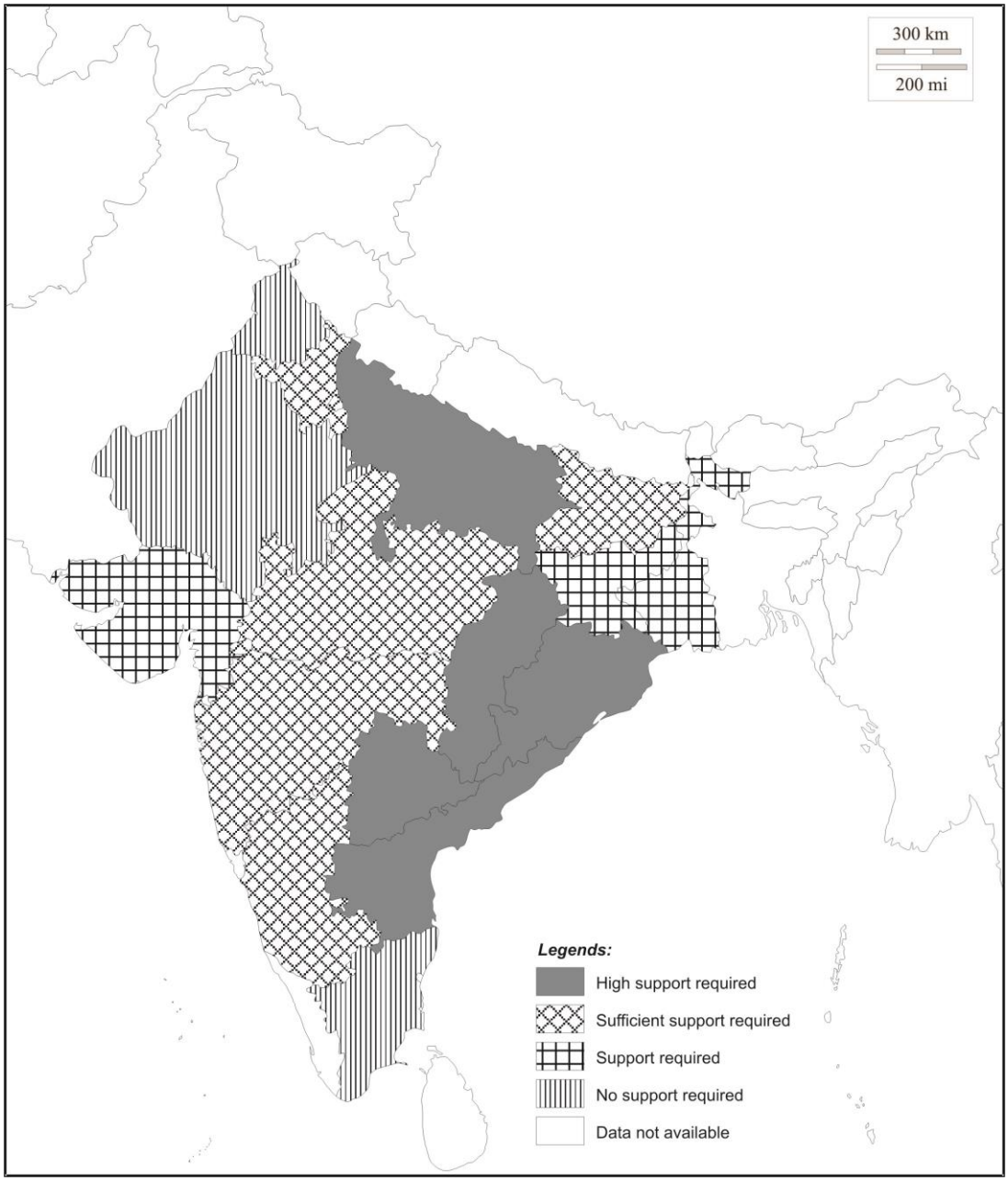

Figure 4: Quantum of Support Required for Enhancing Fly Ash Utilization

Support frameworks are suggested for each states and is depicted as Figure 4. The quantum of fly ash utilized and residual left for each state reflects the need of support in terms of technology, awareness, execution potential etc. For states like north-eastern states, Jammu & Kashmir, Himachal Pradesh and Uttrakhand and Kerala, either the data was not available or they do not have coal-based thermal power plants.

Various factors that may be responsible for under utilization of fly ash are:

1. Availability of fly ash in terms of quality and quantity
2. Economic feasibility of using fly ash particularly due to handling and transportation costs

3. Managerial potential of concerned teams
4. Awareness about various technology options and policy framework
5. Availability of appropriate ecosystem for adopting or implementing each technology options for utilizing fly ash

Conclusion

The global fly ash utilization scenario states a utilization rate upto 96.4% but the average figure is 53.5%. It appears from the data that the higher utilization rate is in those countries which have low amount of fly ash generation since the European countries collectively indicate 90.9% of utilization. Countries like US and China which are producing more fly ash are not able to utilize fly ash significantly, thereby reflecting huge storage or pile up of fly ash.

In India, we have seen utilization rate from 30.09% to 93.72% in different states of the country. Different states have different patterns of fly ash utilization. The quantum of fly ash utilized and residual left for each state reflects the need of support in terms of technology, awareness, execution potential etc. High support is required for those states where volume utilized is significantly low and residual volume is significantly high. Such states need technical support, awareness and appropriate ecosystem so that all stakeholders contribute towards gainful utilization of fly ash. There are states which need sufficient support as volume utilized is either comparable to residual volume or the residual volume is itself significant. Some states have been able to utilize significantly but still the residual volume is significant. Such states need support so that they are able to utilize the remaining fly ash. There are states that do not need any support per se, as appropriate framework for fly ash utilization is available, and no special effort is required, though the efforts being made are to be continued.

Above discussion suggests that attention of policy makers and executive agencies may be drawn to put in required efforts so that fly ash is gainfully utilized to the maximum extent. Focus of state level agencies is expected to result in better utilization of fly ash. Both top-down approach and bottom-up approach is required to speed up the utilization process. There is a need to give renewed thrust to increase the utilization rate. Efforts such as technology awareness, establishing ecosystem involving concerned stakeholders such technology providers, technology implementers, logistics and handling etc., incentivisation for more utilization, and so on are needed for enhancing the utilization rate.

REFERENCES

Ahmed S, Jamil M, Popov V, Ahmed S and Khan ZA (2007). Management of electricity generation using the Taguchi approach, Energy and Sustainability- *WIT Transactions on Ecology and the Environment* 105 13-23.

Karim MR, Zain MFM, Jamil M, Lai FC and Islam MN (2011). Strength development of mortar and concrete containing fly ash: A review, *International Journal of the Physical Sciences* **6**(17) 4137-4153.

Banerjee R (2014). Coal-Based Electricity Generation in India, Cornerstone-*The Official Journal of the World Coal Industry*, Beijing, **2**(1) 37-42.

Basu M, Pande M, Bhadoria PBS and Mahapatra SC (2009). Potential fly-ash utilization in agriculture: A global review, *Progress in Natural Science* **19** 1173–1186.

Cicek T and Tanrıverdi M (2007). Lime based steam autoclaved fly ash bricks, *Construction and Building Materials* **21** 1295–1300.

Dhadse S, Kumari P and Bhagia LJ (2008). Fly ash characterization, utilization and government initiatives in India – A review, *Journal of Scientific and Industrial Research* **67** 11-18.

Executive Summary: Power Sector (2014). Central Electricity Authority, Ministry of Power, Government of India.

Heidrich C, Feuerborn HJ and Weir A (2013). Coal Combustion Products – A Global Perspective, *VGB Power Tech* **12** 46-52.

Lee H, Ha HS, Lee CH, Lee YB and Kim PJ (2006). Fly ash effect on improving soil properties and rice productivity in Korean paddy soils, *Bioresource Technology* **97** 1490–1497.

Izidoro JDC, Fungaro DA, dos Santos FS and Wang S (2012). Characteristics of Brazilian coal fly ashes and their synthesized zeolites, *Fuel Processing Technology* **97** 38–44.
Majid J, Ahmed S and Rizwan M (2008). Feasibility for import of Hydro Power to India from its neighboring Countries and its Environmental Benefits, *Curie Journal* **1**(2) 49-56.
Mukherjee AB, Zevenhoven R, Bhattacharya P, Sajwan KS and Kikuchi R (2008). Mercury flow via coal and coal utilization by-products: A global perspective, *Resources, Conservation and Recycling* **52** 571–591.
Koukouzas NK, Zeng RS, Perdikatsis V, Xu W and Kakaras EK (2006). Mineralogy and geochemistry of Greek and Chinese coal fly ash, *Fuel* **85** 2301-2309.
Planning Commission, Government of India (2013). *Twelfth Five Year Plan (2012–2017)*. Economic sectors, **II,** (New Delhi: Sage Publications, India).
Central Electricity Authority (2014a). Report on Fly Ash Generation at Coal/Lignite Based Thermal Power Stations and its Utilisation in the Country for the Year 2011-12 and 2012-13, Central Electricity Authority, Ministry of Power, Govt. of India, Jan. 2014.
Central Electricity Authority (2014). Report on Fly Ash Generation at Coal/Lignite Based Thermal Power Stations and its Utilisation in the Country for the Year 2013-14, Central Electricity Authority, Ministry of Power, Govt. Of India, Aug. 2014.
Central Electricity Authority (2011). Report on Fly Ash Generation at Coal/Lignite Based Thermal Power Stations and its Utilisation in the Country for the Year 2010-11, Central Electricity Authority, Ministry of Power, Govt. Of India, Dec. 2011.
Silva LFO, Ward CR, Hower JC, Izquierdo M, Waanders F, Oliveira MLS, Li Z, Hatch RS and Querol X (2010). Mineralogy and leaching characteristics of coal ash from a major Brazilian power plant, *Coal Combustion and Gasification Products* **2** 51-65.
Sridharan A and Prakash K (2007). *Geotechnical Engineering Characterisation of Coal Ashes*, (CBS Publishers & Distributors, New Delhi, India).
Vittal Guru UK (2002). *Utilisation of Fly Ash in Roads and Embankment Works*, (CSIR-CRRI Report, New Delhi, India).
Yeboah NNN and Burns SE (2011). Geological Disposal of Energy-Related Waste, *KSCE Journal of Civil Engineering* **15**(4) 697-705.