ISSN: 0973-4929, Vol. 19, No. (**2**) 2024, Pg. 634-650

Current World Environment

www.cwejournal.org

Environmental Implications of Fly Ash Management and Utilization: A Review of Laws, Policies, and Practices

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Abstract

In the environmental realm, 'fly-ash' refers to the byproduct of burning pulverized coal in thermal power stations. One of India's most resource-intensive and polluting industries, coal-fired power generation, contributes considerably to atmospheric pollution. Public power stations that use coal or lignite to generate energy account for 77% of the nation's total electricity production. This sector is responsible for over 65% of India's total coal use. This study employs a multifaceted approach combining theological, exploratory, analytical, and descriptive methods. It relies on secondary sources from diverse web resources to analyze fly ash's ecological and health impacts, explore utilization methods, and discuss potential legislation to prevent careless disposal. The coal-based power industry has added 32 GW, or over 64% of the new massive capacity, to its operations in the last decade, leading to a rise in coal consumption. There was a greater than 71% increase in annual coal usage, from 367 million tonnes in 2009–10 to almost 629 million tonnes in 2018–19.[1] The increasing usage of coal in India has led to fly ash being one of the country's most significant industrial solid wastes. Fly ash is a residue or byproduct made when coal is burned, it is harmful to both humans and the environment. The problem is particularly acute in India because of the poor calorific value, high ash content, and low grade of the coal used there.

Article History
Received: 07 February 2024
Accepted: 13 August 2024

Keywords
Characterization; Energy; Environmental - Assessment; Energy; Fly Ash; Utilization.

Introduction

The most minute particles of coal ash are known as fly-ash. Because fly-ash is carried out of the combustion chamber by exhaust gases, it is so called. A micron-sized dust composed of non-combustible mineral debris and trace quantities of carbon residues from incomplete combustion, fly ash is a byproduct of coal's mineral composition. Clay and silt-sized crystalline particles make up the bulk of fly ash, which is often a light tan

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Doi: https://dx.doi.org/10.12944/CWE.19.2.10

color.[2] One can find fly ash in the cementations or pozzolanic categories. Consolidation occurs when a cementation ingredient is 3 combined with water. The addition of an alkaline component, such as lime, is necessary for the hardening of pozzolanic materials by water. The cementations and pozzolanic properties of certain fly ashes make them useful in construction for a wide variety of purposes, including replacing cement in concrete.[3]

In an industrial setting, the byproduct of combustion known as the microscopic, heterogeneous particles that make up fly ash rise along flue gases. Currently, 77 percent of the nation's electricity is produced by utility power plants using coal and lignite. In terms of energy production, fly-ash is considered an unusable material; but, in terms of coal consumption, fly ash is an under-utilised resource. For this reason, thermal electricity producers are searching for new applications for fly ash.[4] In the cement business, it might be a raw ingredient for concrete. The fly ash that is produced by power plants has multiple uses, including as a byproduct and as a resource for farming and engineering.[5,6]

The chief chemical substances found in the fly-ash were as follows:

- *Calcium oxide*
- *Aluminum oxide*
- *Silicon dioxide*
- *Ferric oxide*

Fly ash is a remarkable material that bears a striking resemblance to Portland cement, though it differs significantly in its chemical composition. While Portland cement is a binding agent produced by burning and finely grinding a mixture of limestone and clay, resulting in a powder rich in calcium silicates, calcium aluminate, and calcium alumino-ferrite, fly ash has its own unique chemical profile. Despite these differences, fly ash exhibits cementitious properties, meaning it hardens when mixed with water, much like traditional cement.[7]

The versatility of fly ash is evident in its wide range of applications across various industries. In the construction sector, it plays a crucial role as an ingredient in concrete and cement products, enhancing their properties and sustainability. Beyond construction, fly ash finds use in road-based materials, contributing to the durability and stability of transportation infrastructure. In the realm of industrial processes, it serves a valuable function in metal recovery operations. Additionally, fly ash is utilized as a mineral filler in various products, showcasing its adaptability and importance in modern manufacturing and construction practices.[8]

Fly ash presents significant environmental and health risks. Classified as a toxic air pollutant, it has been linked through epidemiological studies to increased rates of serious health conditions including heart disease, cancer, respiratory problems, and stroke.[9] Its hazards extend beyond air pollution; when in contact with water, fly ash can cause heavy metals to leach into groundwater, potentially contaminating drinking water and aquatic ecosystems. Additionally, it negatively impacts soil quality, interfering with tree root development and potentially disrupting entire ecosystems. These multifaceted risks underscore the need for careful scientific study and stringent regulatory oversight.[10]

The NGT’s Joint Committee's 2020-2021 report reveals a critical environmental issue: 1,670 million tonnes of fly ash have accumulated due to under-utilization. This vast quantity poses significant waste management challenges and risks to public health and the environment. The situation urgently requires comprehensive strategies from policymakers, industry, and environmental agencies to manage and utilize fly ash responsibly.[11]

The Indian government and various organizations have implemented comprehensive measures to promote fly ash utilization, addressing environmental concerns and fostering sustainable industrial practices. These initiatives include the National Thermal Power Corporation's efforts to sell fly ash and collaborate with cement manufacturers, the incorporation of fly ash bricks in the Pradhan Mantri Awas Yojana (Urban) housing program, and Maharashtra's pioneering fly ash utilization policy. To enhance efficiency and transparency, the government has launched digital tools such as a web portal and the "ASHTRACK" mobile application for monitoring fly ash generation and utilization.[12] Furthermore, the reduction of Goods and Services Tax (GST) rates on fly ash products to 5% serves as an economic incentive for increased adoption. This multifaceted approach demonstrates a concerted effort to manage industrial waste effectively while promoting sustainable construction practices across India.

Research Questions

So, here in this paper, the following are the research questions that would likely be verified in further research or study

- *Whether Fly ash is a public health hazard and how far it has the capacity to endanger human health and the environment.*
- *Whether there are any other new possibilities besides traditional use, where fly ash can be utilized.*

An increase in fly ash production is anticipated in the next years due to the anticipated growth in coal-based electricity generation in developing nations such as India, which is driving the global demand for energy. Consequently, there is a risk to the environment and a challenge to proper scientific processing and disposal associated with fly ash production.

Research Methodology

This study employs a comprehensive methodology incorporating theological, exploratory, analytical, and descriptive research approaches, with a primary focus on secondary data from credible sources such as academic publications, industry surveys, government reports, and relevant websites. The research is structured around three core objectives: (1) analyzing the ecological and human health impacts of fly ash as an industrial solid waste, (2) evaluating potential methods for fly ash utilization across various industries and applications, and (3) initiating a dialogue on effective legislation to mitigate careless disposal practices by coal-fired thermal power stations. The methodology encompasses a thorough review of existing literature and practices related to fly ash management in India, addressing both its detrimental effects on health and the environment, as well as potential avenues for beneficial reuse. Recent studies have highlighted the toxicity of coal fly ash and its leachate,[13] emphasizing associated health risks including respiratory issues and cancer, while also discussing the significant hazards posed by heavy metals in fly ash.[14] Additionally, recent government initiatives in India, such as the Ash-track portal, reflect a shift towards sustainable practices in the coal power sector.[15] This research aims to contribute valuable insights into sustainable management strategies for fly ash, promoting environmentally responsible practices in coal-based power generation.

Scope of Study

This research investigated methods for dealing with fly-ash, a substantial industrial solid waste byproduct of India's coal-fired power plants. This research examines the present state and future prospects of fly ash production, use, and disposal in India using data that is currently available from various sources. It also assesses the regulatory frameworks that are currently in place and those that are being considered for fly ash management in India, including the notifications that have been issued since 1999 by the *"Ministry of Environment, Forests, and Climate Change"*, the draft notification for fly-ash that will be issued in 2021, and the National Green Tribunal's directive to establish a Fly Ash Management and Utilization Mission. The report also discusses the problems with implementing and enforcing fly ash regulations, as well as the harmful effects of ineffective fly ash management on society and the environment, and the subsequent legal disputes that have ensued. Lastly, this study delves into the possibilities and ideal approaches to enhance fly ash management in India. These include developing new technologies and products based on fly ash, advertising its usage in various industries like construction, agriculture, and road building, involving local communities and civil society organizations in fly ash governance, and adopting international standards and policies for fly ash management.

Here is a graph that shows the yearly production and utilization of fly-ash from 2010-2011 to 2021-2022. This paper is urgently needed, since the graph clearly illustrates that fly-ash is being wasted at a considerably higher rate than it is being produced.

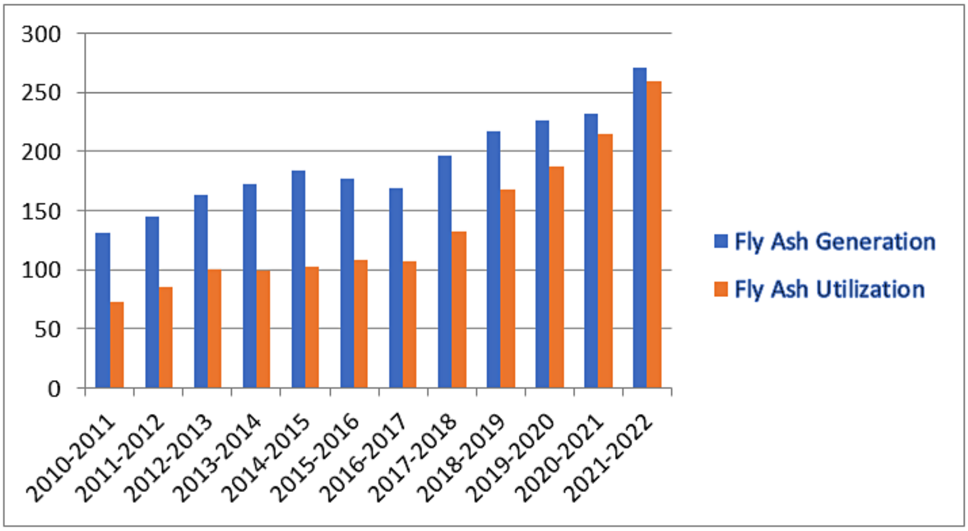

Fig. 1: Comparative analysis of annual production and usage of fly ash from 2010-11 to 2021-22.

Where does fly-ash originate?

A residue of coal-fired energy stations and steam production facilities is fly ash. Often, crushed coa is added to the boiler's combustion chamber together with air, where it burns quickly to produce molten mineral waste and heat.

The following are the major Thermal Power Plants listed here.

Table 1: List of all Public Utility-specific Fly Ash Production and Usage in 2021–2022.[17] 95.95% of India's fly ash production is put to use in numerous manners.[18]

S. No.	Name of Power Utility	Number of Thermal Power Station	Fly-Ash Production [million tonnes]	Fly-Ash Usage [million tonnes]	Percentage (%) Usage
01	Aarti Steels Limited, Odisha	1	0.2612	0.2612	100.00
02	Andhra Pradesh Power Generation Corporation (APGENCO)	2	6.3033	5.7316	90.93
03	APPDCL (Andhra Pradesh)	1	1.2329	0.8031	65.14
04	ARAVALI POWER COMPANY PRIVATE LIMITED (Haryana)	1	1.6420	2.6160	159.32
05	ACB (INDIA) Ltd. (Chhattisgarh)	5	1.5135	1.5133	99.99
06	ADANI POWER (MUNDRA) LTD	1	0.3448	0.3566	103.41
07	Adani Power Ltd. (Maharashtra)	1	4.5451	3.5557	78.23
08	ABHIJEET MADC NAGPUR ENERGY PVT. LTD.	1	0.0000	0.0370	-
09	Adani Power Rajasthan Ltd. (Rajasthan)	1	1.5625	1.5648	100.15
10	ADANI ELECTRICITY MUMBAI LIMITED (Maharashtra)	1	0.6346	0.6710	105.74

11	ADHUNIK POWER & NATURAL RESOURCES LTD.	1	1.1199	0.9762	87.17
12	BAJAJ ENERGY LTD	5	0.3005	0.3005	100.00
13	BHADRESHWAR VIDYUT PVT LTD (GUJRARAT)	1	0.0215	0.0215	100.41
14	"Bhartiya Rail Bijlee Company Ltd." [BIHAR]	1	1.6124	0.9127	56.60
15	Bharat Aluminium Company Ltd. (Balco) (Chhattisgarh)	2	3.1346	4.0345	128.71
16	"C.E.S.C. Ltd." [W.B]	3	1.1135	1.1135	100.00
17	Chhattisgarh State Power Generation Company Ltd.	4	5.5878	2.4636	44.09
18	C.G.P.L (Gujarat)	1	0.0360	0.0420	116.67
19	CHEMPLAST LTD TPS (TAMIL NADU)	1	0.0192	0.0192	100.26
20	"Coastal Energen Pvt. Ltd" [T.N]	1	0.0674	0.0704	104.47
21	DB POWER LTD	1	2.9851	3.4076	114.15
22	Damodar Valley Corporation (D.V.C.)	7	12.4280	9.5306	76.69
23	DB POWER Ltd.	1	2.9851	3.4076	114.15
24	Dhariwal Infrastructure Ltd. (Maharashtra)	1	0.9511	0.9511	100.00
25	ESSAR POWER (GUJARAT) LTD	1	0.0000	0.0000	-
26	MAHAN ENERGEN LTD.	1	0.8359	0.2128	25.46
27	"Gujarat Industries Power Corporation Ltd."	1	0.4719	0.4719	100.00
28	"Gujarat Mineral Development Corporation Ltd."	1	0.1158	0.2246	193.91
29	G.S.E.C.L. (Gujarat)	6	5.1738	6.1721	119.30
30	GMR Kamalanga Energy Ltd (Odisha)	1	2.3240	3.1018	133.47
31	"G.M.R. Warora Energy Ltd." [Maharashtra]	1	0.8208	1.0294	125.41
32	"Haryana Power Generation Cor. Ltd."	3	2.2545	10.6771	473.60
33	HALDIA ENERGY LIMITED (W.B.)	1	1.0940	1.0940	100.00
34	Hinduja National Power Corporation Ltd (Andhra Pradesh)	1	0.0845	0.4047	478.97
35	"Ideal Energy Projects Ltd."	1	NIL	NIL	-
36	"IL & FS Tamil Nadu Power Company Ltd" [T.N]	1	0.0766	0.0766	100.00
37	Indian Metals & Ferro Alloys Ltd. (Odisha)	1	0.5201	0.5201	100.00
38	India Power Corporation Limited (West Bengal)	1	0.0166	0.0166	100.00
39	JK Cement Works Muddapur	1	0.0141	0.0141	100.00
40	Jindal Power Ltd.	2	5.4037	4.7499	87.90
41	JSW Energy Ltd.	2	0.6145	0.6145	100.01
42	"JSW Energy (Barmer) Ltd."	2	0.8972	0.8468	94.38
43	JSW Steel Ltd (Tamil Nadu)	1	0.0094	0.0094	100.30
44	Jaiprakash Power Ventures Limited (Madhya Pradesh)	1	2.2667	1.9754	87.15
45	Jindal India Thermal Power Limited	2	2.4016	1.2906	53.74
46	Jindal Steel and Power Limited (Chhattisgarh)	1	2.5680	1.7397	67.74
47	Jhabua Power Ltd (MP)	3	1.0217	0.5690	55.69
48	Jhajjar Power Ltd (Haryana)	1	1.8045	1.8045	100.00

49	"Karnataka Power Corporation Ltd."	1	3.7161	3.2506	87.47
50	Kanti Bijlee Utpadan Nigam Ltd [Bihar]	2	0.7890	1.3230	167.68
51	Lalitpur Power Generation Company Ltd (UP)	1	2.0943	1.8855	90.03
52	Lanco Amarkantak Power Ltd (Chhattisgarh)	1	1.1070	0.8297	74.95
53	Lanco Anpara Power Ltd (UP)	1	1.7101	0.2191	12.81
54	"Maruti Clean Coal & Power Ltd." [Chhattisgarh]	1	0.6756	0.6756	100.00
55	M.P.L (Jharkhand)	1	1.8518	1.6577	89.52
56	"M/s KSK Mahanadi Power Company Ltd." [Chhattisgarh]	1	2.0586	2.2392	108.77
57	Meenakshi Energy Ltd. (A.P)	1	0.0172	0.0016	9.51
58	MB Power Ltd (MP)	1	2.1848	2.1894	100.21
59	Meja Urja Nigam Pvt. Ltd. (UP)	1	1.8226	1.3207	72.47
60	"Madhya Pradesh Power Generating Company Ltd."	4	5.8844	3.3801	57.44
61	"Maharashtra State Power Generation Corporation Ltd."	7	14.2085	32.7349	230.39
62	NPGC (NTPC-JV)	1	1.6838	0.8596	51.06
63	Nabha Power Ltd, Punjab	1	1.9556	1.9570	100.07
64	NTPC – SAIL Power Company Ltd. (NTPC-JV)	4	2.0264	1.4130	69.73
65	N.L.C India Ltd (Rajasthan)	5	1.2904	2.2134	171.53
66	NLC Tamilnadu Power Limited (Tamil Nadu)	1	1.1385	1.1385	100.00
67	NTECL (Tamil Nadu)	1	2.4466	1.9107	78.10
68	N.T.P.C.LTD.	23	71.0290	57.1382	80.44
69	National Aluminium Company Ltd (NALCO) (Odisha)	1	2.6936	2.3066	85.63
70	"Orissa Power Generation Corporation Ltd."	1	3.5855	0.9812	27.37
71	"OPG Power Generation Pvt Ltd"	1	0.1030	0.1030	100.00
72	"Punjab State Power Corporation Ltd."	4	1.3577	2.3617	173.94
73	Prayagraj Power Generation Company Ltd.	1	2.4194	2.1075	87.11
74	"Rajasthan Rajya Vidyut Utpadan Nigam Ltd."	6	6.0498	6.7646	111.81
75	Rashtriya Ispat Nigam Ltd (AP)	1	0.5111	0.4667	91.31
76	Rattan India Power Ltd	1	2.3922	1.9421	81.19
77	RPSCL (UP)	1	1.3284	1.0491	78.98
78	Raichur Power Corporation Ltd (Karnataka)	1	1.3131	1.1415	86.93
79	Raigarh Energy Generation Ltd	1	1.0950	0.4100	37.44
80	Raipur Energen Limited (Chhattisgarh)	1	2.0409	2.0013	98.06
81	"R K M Powergen Pvt. Ltd" [Chhattisgarh]	1	2.4624	2.4602	99.91
82	Reliance Power Ltd., Madhya Pradesh	1	5.3475	2.7994	52.35
83	"Sai Lilagarh Power Generation Ltd." [Chhattisgarh]	1	0.0041	0.0041	-
84	SEMBCORP Energy India Ltd. (Andhra Pradesh)	1	1.6994	1.6999	100.03
85	"Swastik Power & Minerals Resources Pvt. Ltd."	1	NIL	NIL	-

86	SKS Power Generation (CHHATTISGARH)	1	0.5571	0.5317	95.43
87	SAI Wardha Power Generation Pvt LTD	1	0.4221	0.4221	100.00
88	Tenughat Vidhyut Nigam Ltd. (Jharkhand)	1	0.3973	0.4478	112.70
89	Talwandi Sabo Power Ltd	1	2.4013	2.1702	90.38
90	“Taqa Neyveli Power Company Pvt. Ltd.”	1	0.0761	0.0639	83.98
91	Durgapur Projects Ltd.	1	0.7238	0.4812	66.48
92	Singareni Collieries Company Ltd (Telangana)	1	1.9320	2.2660	117.29
93	Tata Power Company (T.P.CO.) Ltd	2	1.0590	1.0688	100.92
94	Torrent Power Ltd. (Gujarat)	1	0.3739	0.3739	100.00
95	TSGENCO (Telangana)	6	4.4217	3.1596	71.46
96	“T.N.G & D Corporation” [T.N]	5	6.1932	5.8409	94.31
97	TRN Energy Pvt. Ltd. (Chhattisgarh)	1	0.2273	0.1139	50.12
98	“Uttar-Pradesh Rajya Vidyut Utpadan Nigam Ltd.”	4	7.0255	2.1171	30.13
99	Udupi Power Corporation Limited (Karnataka)	1	0.0572	0.0587	102.62
100	Vidarbha Industries Power Ltd. (Maharashtra)	1	0.0000	0.0000	-
101	Vedanta Ltd. (Odisha)	2	4.7471	9.4964	200.05
102	VS Lignite Power Pvt. Ltd (Rajasthan)	1	0.2265	0.2265	100.00
103	“W.B Power Development Corporation Limited”	5	7.5790	5.4168	71.47
104	Zuari Cement Ltd.	1	0.1017	0.1017	100.00
	GRAND TOTAL	200	270.8216	259.8628	95.95

Environmental Benefits & Its Adverse Effect

If manufactured cement is substituted with fly ash, there are major environmental benefits. These advantages include: (1) longer-lasting concrete structures and roads because of the material's greater resilience, (2) a reduction in gross consumption of energy, greenhouse gas emissions, and various airborne pollutants; (3) a decrease in the amount of waste from the burning of coal that needs to be dumped off in waste dumps; and (4) the safeguarding of additional natural assets and components.[19]

Since fly ash is bad for the environment and public health, the National Green Tribunal (NGT) wrote in a report that "this Tribunal has noticed repeated and continuous defaults by the TPPs (Thermal Power Plants), leading to damage to the environment and public health." Fly ash contains minute concentrations of metals that can be harmful to humans and plants, including U, Th, Cr, Pb, Hg, Cd, and others.[20] While leached hazardous metals impair deep water sources, thermal pollution caused by discharge in surface water sources disturbs aquatic life.[21] Pneumonitis, allergies, asthma, lung fibrosis, bronchitis, cancer, and silicosis are all brought on by light and persistent inhalation.[22]

Characteristics of Fly-Ash

Fly-ash, an anthropogenic volatile substance, is characterized as a siliceous or aluminosiliceous material exhibiting minimal or no inherent cementitious properties. This substance demonstrates reactivity with calcium hydroxide (Ca(OH)2) under specific conditions, namely when finely particulated and exposed to moisture at ambient temperature. The resultant reaction yields gel-like products. This definition encapsulates the essential attributes and behavior of volatile fly-ash, emphasizing its reactive nature and the conditions necessary for its transformation. The classification and description of fly-ash as presented herein are pertinent to scientific, industrial, and regulatory contexts where precise terminology and understanding of material properties are crucial".[23] The physical and chemical properties of fly ash are significantly influenced by four primary factors: coal type, boiler design, combustion conditions, and post-combustion events. These variables collectively determine the compositional and structural characteristics of the resultant fly ash, which is critical for its classification and potential applications in industrial and regulatory frameworks.[24] Fly ash, a coal combustion residue is subject to comprehensive characterization through the application of multiple sophisticated analytical methodologies.[25] These include, but are not limited to, Fourier Transform Infrared Spectroscopy (FTIR), X-ray fluorescence (XRF), X-ray diffraction (XRD), Magic-Angle Spinning Nuclear Magnetic Resonance (MAS-NMR) spectroscopy, and Scanning Electron Microscopy coupled with Energy Dispersive X-ray Spectroscopy (SEM/EDS).[26] Each of these analytical techniques, when applied individually or in combination, provides distinct and complementary data regarding the compositional, structural, and physicochemical attributes of fly ash. The utilization of this diverse array of analytical tools enables a thorough and multifaceted examination of fly ash properties, which is essential for its accurate classification, quality assessment, and potential utilization in various industrial and environmental applications, as well as for regulatory compliance purposes.

Shape and Size

Fly-ash is usually more delicate than lime and Portland cement. The majority of fly-ash particles are spherical, with diameters ranging from 1 to 100 μm and more than 50% falling beneath 20 μm. The water demand and workability of freshly formed concrete as well as the rate of strength development in hardened concrete are significantly influenced by the fly ash's particle size distribution, morphology, and surface properties.[27] These tiny glass spheres improved the new concrete's workability and fluidity. Fineness is one of the key elements that determines fly ash's pozzolanic reactivity.

Chemistry

Calcium, iron, silicon, and aluminium oxides make up the majority of fly-ash. There are trace levels of sodium, *magnesium, titanium, sulfur and potassium.*[28] The synthetic compositions of Class F and Class C fly ash have been officially established and codified by two authoritative bodies in the field of materials standards and specifications. These are the American Association of State Highway Transportation Officials (AASHTO), through their standard M 295, and the American Society for Testing and Materials (ASTM), via their Specification C 618.[29,30] These standards provide the definitive criteria for the classification and characterization of fly ash types, which are crucial for ensuring consistency and quality in various industrial and construction applications.

- Class-C ash is mostly made up of tricalcium aluminate, free lime, quartz, and calcium alumino-sulfate glass. It is often formed from sub-bituminous coals (CaO). High-calcium fly ash is another name for class C ash.
- Aluminosilicate glass makes up the majority of Class F ashes, with trace amounts of *quartz, mullite,* and magnetite. Typically, bituminous and anthracite coal are used to make them.

Utilization of Fly-Ash

Portland cement, concrete, flowable fills, embankments/highways, and soil improvement are only a few of the typical uses for fly-ash (Association, 2003). A new dimension to the employment of fly ash as an ash-based product outside of its prior applications was introduced by the MoEFCC's latest notification of December 31, 2021. Additionally, regulatory compliance regarding the 100% usage of legacy ash becomes less of a burden if fly ash generators "stabilize".

Although fly ash is viewed as a byproduct of energy generation, it is actually an underutilized resource when it comes to coal usage. That is why thermal power companies are always on the lookout for novel applications for fly ash. The cement industry may use it as a component in concrete. The coal fly ash that is generated by power stations can be transformed into useful goods for farming and engineering, in addition to being utilized as a byproduct.[31,32] The process by which fly ash is converted into zeolite has also been the subject of numerous investigations.[33]

The idea that it could be used as a cheap adsorbent to purify gas and water is also intriguing. Extensive studies have been conducted by academics investigating the binding of certain pollutants to water-based solutions or flue gas using fly ash. The results indicate that there is potential for reducing organic compounds and heavy metals in industrial effluent.[34]

Fly ash, a coal power byproduct, serves as a resource for cement, construction, and infrastructure industries, aiding in soil conservation. NTPC prioritizes sustainable fly ash utilization, establishing dedicated groups at all coal-based plants since 1991. These units aim for 100% sustainable ash utilization, demonstrating NTPC's commitment to resource efficiency and environmental responsibility in power generation.[35]

There also have been efforts made by NTPC in maximizing Fly Ash Utilization, which are as follows

i) Supply of Fly Ash to Cement Industry - NTPC has implemented dry fly ash extraction and storage systems at all coal-based thermal power plants, with rail loading facilities at key locations. Through an agreement with Indian Railways, NTPC utilizes BTAP wagons for bulk, environmentally-friendly fly ash transportation to cement plants nationwide. This systematic approach optimizes resource utilization and adheres to environmental standards, showcasing NTPC's commitment to efficient fly ash management and distribution.

ii) Use of Fly Ash Bricks - NTPC operates fly ash brick plants at its thermal power stations, producing 60 million bricks annually for internal use. Adhering to MoEF&CC guidelines, NTPC reserves 20% of its fly ash for free distribution to brick, block, and tile manufacturers. This initiative results in 9% of NTPC's total fly ash being utilized by these manufacturers yearly, showcasing NTPC's commitment to sustainable construction and regulatory compliance.

iii) Supply of pond Ash for Road/Flyover construction projects - As per MoEF&CC's 2016 notification, NTPC bears ash transportation costs for road projects within specified radii. NTPC supplies ash to NHAI and state government projects through MoUs and transparent bidding. In 2019-20, NTPC supplied 12.9 million tons of ash to road projects. For 2020-21, 15 NTPC stations are supplying ash, with expected utilization exceeding 20 million tons, showcasing NTPC's regulatory compliance and commitment to sustainable infrastructure development.

iv) Use of Ash in reclamation of Mine Voids: NTPC employs ash for mine void reclamation across multiple sites, notably at Talcher since 2005, with regulatory approvals from state and central authorities. This practice, validated through environmental studies, extends to Korba, Ramagundam, Talcher-Kaniha, and Vindhyachal. These initiatives demonstrate NTPC's commitment to sustainable ash utilization, land reclamation, and regulatory compliance while supporting efficient coal extraction in underground mines.

Laws Governing Fly Ash in India & Global Scenario

Indian Perspective

So far, no concrete statute has been enacted in India that addresses the scientific processing and environmentally suitable disposal of fly ash. The MoEFCC[36] is the main body in the governing framework of the Central Government and is responsible for the scheduling, advancement, collaboration, and inspection of the country's ecological and forestry initiatives and activities. As part of its efforts to meet the 100% utilization requirement, the National Green Tribunal has ordered the MoEFCC, CPCB, IIT Roorkee, and any other parties deemed necessary by the MoEFCC to ensure the scientific disposal of fly-ash and to calculate the amount of damages to be paid for environmental restoration in the Shantanu Sharma case,[37] which involved a violation of statutory norms. Damages like these might also be attributed to Thermal Power Plants that have disregarded regulations.

Although there isn't a specific law that governs how fly ash is handled, there is a general law, the Environment Protection Act, that governs all environmental issues that have an adverse effect on both humans and the ecology. The central government has the authority to take action to safeguard and enhance the environment under Section 3 Subsection (2) of the same Act.

By amending the relevant section of the Environment (Protection) Act, 1986 (i.e. Sec. 3(2)), the MoEFCC attempts to control the scientific treatment of fly ash and issues notifications in the form of regulations in the official gazette of India. It can be inferred from the fact that the court in a particular case viz., Occupational Health case stressed adherence to this main statute and noted that adherence to the Environment (Protection) Act, 1986 and its amendments applicable for Power Plants with regard to emission and discharge, ash utilization, and hazardous waste management to protect the surrounding environment as well as maintain a healthy and secure environment for the workers.

Recently, the MoEFCC issued a notification dated December 31, 2021, discussing the application of fly ash, that expanded its potential applications beyond the areas in which it had previously been used. Furthermore, if fly ash generators "stabilize," the burden of regulatory compliance on the 100% usage of legacy ash is reduced."

Another institution, the National Green Tribunal (NGT), has been empowered to monitor the unregulated pollutants that exist and emerge from the industrial or non-industrial sectors. The National Green Tribunal works to provide prompt and effective remedies when protecting the environment, protecting forestry and other natural assets, or enforcing any environmental legal action needed.[38]

Global Perspective

Moreover, half of the world's energy demand will likely occur between 2016 and 2040. As the world's population, industrialization, and rising middle-class increase the need for coal and energy in general, much of this development will persist in developing nations, especially China and India. The large ash percentage of 30%-45% in Indian coal causes thermal power plants that rely on coal or lignite to produce a considerable quantity of fly ash.

Coal is the most abundant fossil fuel and a relatively inexpensive fuel source; politically stable countries like China, India, and the US have some of the world's largest coal deposits. For the past fifty years (Figure 2), coal has been the main player in the world's energy generation, and that trend is likely to continue for the foreseeable future.

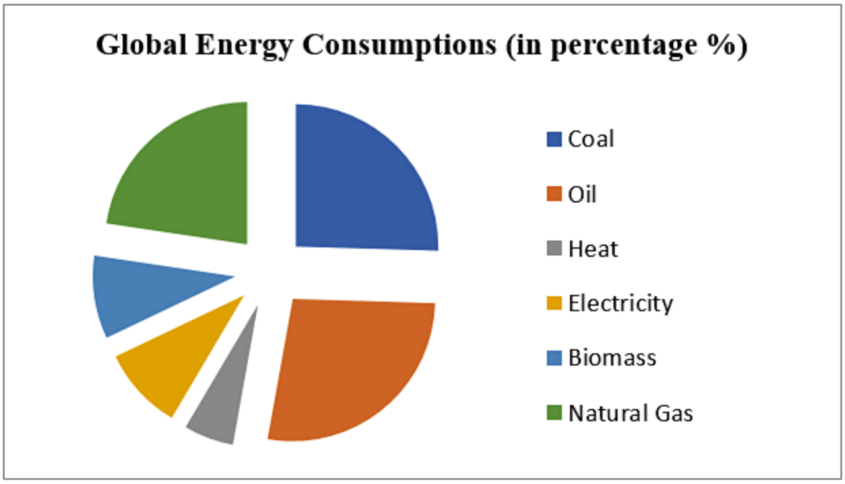

Fig. 2: Breakdown by Energy (2021) – Mtoe (millions of tonnes of oil equivalent)39

In the midst of a worldwide epidemic, global energy consumption has risen by 5% in 2021, following a 4.5% fall the previous year. This recovery was three percentage points faster than the 2% per year average from 2000 to 2019. Global energy consumption in 2021 will be greater than in 2019.[40]

Most countries experienced an increase in energy consumption: the US (+4.7% after -8.6% fall in 2020), Russia (+9% after -4% in 2020), China (+5.2% after +2.2% in 2020), India (+4.7% after -5.6% in 2020), and the EU (+4.5% after -6.8% in 2020).[41]

China, India, and Indonesia accounted for three-quarters of worldwide energy consumption growth. The biggest drops were seen in Germany and the United States. The generation of coal has climbed by 1.5% worldwide, with China and Indonesia leading the way. Nonetheless, the amount of coal used worldwide decreased by 0.6%, and coal's proportion of primary energy reached its lowest point in sixteen years. The OECD countries' coal usage has dropped to its lowest level since the assessment's inception in 1965.

Global output of coal ash has increased dramatically in recent decades due to the increased electricity generated by coal-fired power stations.

Figure 3 presents substantial data on the worldwide picture, encompassing industrialized and emerging countries that rely on coal for energy use. The need for coal is rising in nations like India and China that are rapidly industrializing.

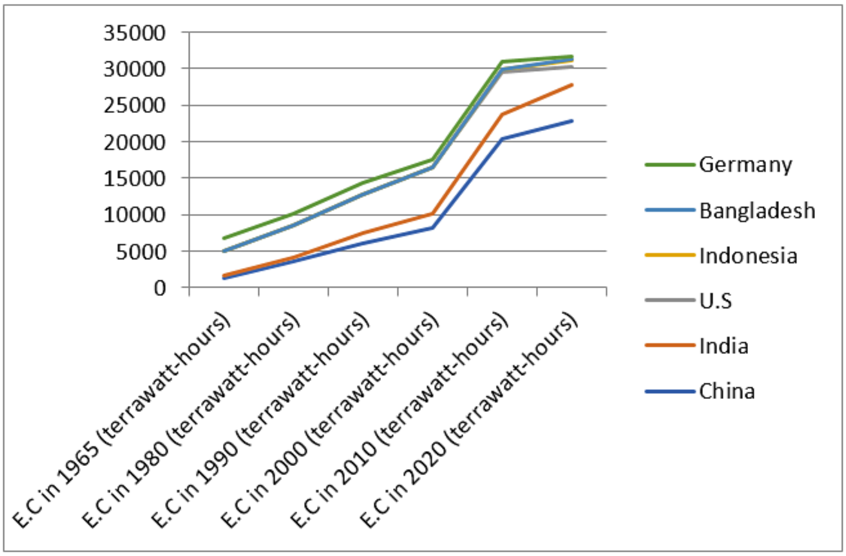

Fig. 3: Progressive Analysis of E.C (Energy Consumption through Coal) in (terawatt-hours) of Developed & Developing Countries.

The energy industry is one of the world's most consequential and ever-changing sectors because of its far-reaching effects on economies, societies, and ecosystems. Various rules and regulations control energy generation, consumption, and trade in different countries due to differences in energy resources, demands, and goals. Within the scope of this essay, we examine the energy laws of 71 countries hailing from different continents and regions. Following is a table with the name of the country, the main law that regulates its energy sector, and the year it was passed. The following table displays:

Table 2: Comparative Analysis of Energy Laws across 71 Nations: A Global Study of Regulatory Frameworks (1910-2023)[42]

S. No.	NAME OF COUNTRY	CONCERNED LAWS	YEAR
01	ALGERIA	Law No. 19-13	2019
02	ARGENTINA	Law No. 15,336	1960
03	AUSTRALIA	National Electricity Law, National Electricity Rules	1st July 2005
04	AUSTRIA	"Federal Electricity Management and Organisation Act 2010 (Electricity Act 2010)"	2010

05	AZERBAIJAN	Electrical and Thermal Power Plants Law	28 Dec, 1999
06	BANGLADESH	"The Electricity Act of 1910" "Bangladesh Energy Regulatory Commission Act, 2003 (Act No. 13 of 2003)"	1910, 2003
07	BELGIUM	The Act of 29 April 1999	1999
08	BULGARIA	Renewable and Alternative Energy Sources and Biofuels Act	2007
09	CANADA	"Canadian Energy Regulator Act (S.C. 2019, c. 28, s. 10)"	2019
10	CHILE	Energy Efficiency Law of 2021 (Law 21305) (Law 20698)	2021
11	CHINA	The National Energy Conservation Law	1997
12	COLOMBIA	Energy Transition Law (Law No. 2099 of 2021).	2021
13	CROATIA	"Energy Act [Zakon o energiji (Narodne Novine, br.N 120/12, 14/14)]"	08.11. 2012
14	CYPRUS	CERA - Law 130(I)/2021	2021
15	"DENMARK"	"Promotion of Renewable Energy Act [Act no. 1392 of 27 December 2008]"	2008
16	EASTERN AFRICA	The Energy Act No 1 of 2019	2019
17	ECUADOR	Public Electric Power Service in 2015	2015
18	EGYPT	Electricity Law No. 87 of 2015	2015
19	ESTONIA	Energy Sector Organisation Act	16th June 2016
20	EUROPE	European Energy Security and Diversification Act of 2019	2019
21	EUROPIAN UNION	EU regulation 2016/1952. EU regulation 1099/2008	2016, 2008
22	FINLAND	Act (1050/2021)	2021
23	FRANCE	Law on Energy and Climate	(Dec. 4, 2019)
24	GERMANY	The Renewable Energy Sources Act	2023
25	HUNGARY	Electricity Act (LXXXVI of 2007)	2007
26	ICELAND	The Electricity Act, No. 65/2003	2003
27	INDIA	The Electricity Act	2003
28	INDONESIA	Electricity Law [No. 30/2009]	2009
29	IRAN	Law on Energy Consumption Pattern Reform [Law No. 1770 of 2011]	2011
30	IRAQ	No Energy Law	
31	IRELAND	The Electricity Act, No. 65/2003 The Electricity Regulation Act 1999	2003, 1999
32	ISRAEL	The Energy Resources Act 1989	1989
33	ITALY	Energy Laws and Regulation	2023
34	JAPAN	The Energy Conservation Act	1979
35	KUWAIT	"Energy Conservation Program Code of Practice (MEW/R-6/2014)"	2014
36	LATVIA	Enerģētikas likums	06th October 1998
37	LITHUANIA	Law on Energy From Renewable Sources No XI-1375	12th May 2011

38	MALAYSIA	Energy Commission Act 2001 (Act 610)	1st Dec 2011
39	MEXICO	Ley de transicion energetica	24th December 2015
40	MOROCCO	Dahir No 1-63-226	
41	NETHERLANDS	The Electricity Act	1998
42	NEW ZEALAND	“Energy Efficiency and Conservation Act”	2000
43	NORWAY	“The Energy Act, No. 50 of 1990”	1990
44	PAKISTAN	The Electricity Act	1910
45	PERU	“Law for the Promotion of Energy Efficiency (Law No. 27345)”	2000
46	PHILIPHINES	“The Renewable Energy Act of 2008”	2008
47	POLAND	Polish Energy Act	2019
48	PORTUGAL	“Decree-Law No. 29/2006” “Decree-Law No. 172/2006”	2006
49	QATAR	Emiri Decision No. 35 of 2014 Law No. 4 of 2018	2014, 2018
50	ROMANIA	Romanian Electricity and Gas Law no. 123/2012	2012
51	RUSSIA	Federal Law No. 261-FZ	2007
52	SAUDI ARABIA	National Energy Act	2008
53	SINGAPORE	Energy Conservation Act	2012
54	SLOVAKIA	Energetická politika National Energy and Climate Plan	2019
55	SLOVENIA	The Energy Act	2014
56	SOUTH AFRICA	The National Energy Act, 2008	2008
57	SOUTH KOREA	Rational Energy Utilisation Act in 1979. Energy Act [Act no. 7860]	1979, 2006
58	SPAIN	The Energy Act read with Royal Decree 1955/2000	2000
59	“SRI LANKA”	“Sri Lanka Sustainable Energy Authority Act [Act no. 35 of 2007]”	2007
60	SWEDEN	The Swedish Fuel Quality Act (Drivmedelslag (2011:319)	2011
61	SWITZERLAND	The Energy Act	2016
62	TAIWAN	The Electricity Act	2017
63	“THAILAND”	“Energy Conservation Promotion Act, B.E. 2535 (1992)”	1992
64	TRINIDAD & TOBAGO	Trinidad and Tobago Electricity Commission Act [Act 42 of 1945]	1945
65	TURKEY	Energy Market Regulatory Authority (EMRA)	
66	TURKMENISTAN	Law No. 104-V of 2014 on Electricity	2014
67	“UNITED ARAB EMIRATES”	“Federal Law No. 24 of 1999 on the Protection and Developmesnt of the Environment”	1999
68	UNITED KINGDOM	The Energy Act	2013
69	UNITED STATES OF AMERICA	The Energy Policy Act	2005
70	UZBEKISTAN	Power Sector No. LRU-225 Rational Energy Use No. LRU-412-I	2009, 1997
71	VIETNAM	Electricity Law No. 28/2004/QH11 of 2004	2004

The chief objective of this table is to furnish a concise overview of the energy industry laws of each country so that comparisons and contrasts can be more easily accomplished. In view of the fact that every country has its own energy situation and set of objectives, the chart might serve as a jumping off point for more discussion and analysis of the merits and shortcomings of specific energy laws.

Results

The research findings reveal critical insights into the ecological and human health impacts of fly ash, its potential for utilization, and the legislative framework governing its management in India.

Ecological and Health Impacts of Fly Ash

The study highlights that fly ash, a byproduct of coal combustion in thermal power stations, poses significant environmental and health risks. Epidemiological studies have established a correlation between fly ash exposure and various serious health conditions, including respiratory diseases, cardiovascular issues, and cancer. The toxic nature of fly ash is attributed to its composition, which includes heavy metals such as arsenic, lead, and mercury. These contaminants can leach into groundwater, posing a risk to drinking water supplies and aquatic ecosystems. The National Green Tribunal (NGT) has reported an alarming accumulation of approximately 1,670 million tonnes of fly ash due to under-utilization, indicating substantial waste management challenges. This accumulation not only threatens public health but also exacerbates environmental degradation, necessitating immediate and effective strategies for management and utilization.

Utilization Potential

The research identifies various avenues for the beneficial utilization of fly ash, emphasizing its cementitious properties, which allow it to be used as a partial substitute for cement in concrete production. This dual functionality enhances the sustainability of construction practices while reducing the environmental footprint of cement manufacturing. Fly ash is also applicable in road construction, soil stabilization, and as a mineral filler in various industrial applications, showcasing its versatility as a resource. The study underscores the importance of promoting innovative technologies and practices that leverage fly ash in construction and other industries. The potential for fly ash utilization is further supported by recent government initiatives, including the incorporation of fly ash bricks in housing projects under the Pradhan Mantri Awas Yojana (Urban) and the establishment of the ASHTRACK portal for monitoring fly ash generation and utilization.

Discussion

The findings of this research underscore the urgent need for comprehensive legislative and regulatory frameworks to manage fly ash effectively.

Legislative Framework

The current regulatory landscape in India includes various policies and notifications aimed at promoting fly ash utilization and mitigating its environmental impacts. However, the enforcement of these regulations remains inadequate, leading to ongoing challenges in effective fly ash management. The study reveals that while initiatives such as the reduction of Goods and Services Tax (GST) on fly ash products serve as economic incentives, there is a pressing need for stricter enforcement mechanisms to ensure compliance among coal-fired thermal power stations. Moreover, the research advocates for the establishment of a dedicated Fly Ash Management and Utilization Mission to oversee the implementation of best practices and facilitate collaboration among stakeholders, including government agencies, industry players, and civil society organizations. Such a mission could play a pivotal role in addressing the legal disputes arising from ineffective fly ash management and ensuring that the health and environmental risks associated with fly ash are adequately addressed.

Recommendations for Future Research and Practice

The study calls for further research to explore innovative technologies that can enhance the utilization of fly ash, particularly in construction and infrastructure development. Engaging local communities in fly ash governance and raising awareness about its potential benefits are also crucial for fostering sustainable practices. In conclusion, the research highlights the multifaceted challenges posed by fly ash in India, emphasizing the need for a concerted effort to develop sustainable management strategies. By addressing the ecological and health impacts, promoting beneficial utilization, and strengthening the legislative framework, India can move towards a more environmentally responsible approach in managing fly ash and its associated risks.

Conclusion

Due to the continued need for coal-fired power generation, coal fly-ash usage is expected to rise for the foreseeable future. Gaining a grasp of the production and classification of fly ash lays the groundwork for its alternative usage. This research examined fly ash generation in India and around the world, as well as its various applications, in order to understand the current state of fly-ash consumption.

The building industry relies on fly ash recycling, but only if it meets specific physical and technological standards. Governments at the state and local levels should enact recycling legislation to promote the use of fly ash. This could include measures like lowering the total effective tax and offering preference purchasing to products derived from recycled fly ash. This can be condensed into the following

1) In 2021-2022, roughly 95.95 percent of total fly ash generated in India will be utilized in a variety of applications, which is significantly less than the required aim. Furthermore, while this percentage is cumulative, many Thermal Power Plants perform poorly when it comes to the usage of Fly Ash.
2) Fly ash collection, storage, and disposal facilities require technological improvement to make dry fly ash available to customers.
3) Encouraging the usage of fly-ASH ash in building flyovers, roads, buildings, and other infrastructure projects in the districts and states where TPPs are located.
4) According to the MoEFCC announcement dated January 25, 2016, fly ash utilization in operations within a 300-kilometer vicinity of any TPP must be guaranteed right away from the project development stage.
5) Fly ash is used less in agriculture than expected since it contains radioactive components and toxic metals. Increasing the usage of fly ash requires addressing these problems.
6) Increased industry-institute contact is necessary to carry out seminars, awareness-raising, and entrepreneurial development.

Acknowledgement

First and foremost, we extend our heartfelt appreciation to Dr. M.Z.M. Nomani from the Faculty of Law at Aligarh Muslim University for his unwavering guidance, insightful suggestions, and continuous assistance during the research. His knowledge and guidance were very helpful in determining the course of our research. I would also like to acknowledge the contributions of my co-author, Dr. Ajaz Afzal Lone for his valuable discussions and feedback during our weekly research meetings. His insights and constructive criticism helped refine our ideas and strengthen our findings.

Funding Sources

For the research, writing, and/or publication of this work, the author(s) did not receive any funding.

Conflict of Interest

The author(s) declares no conflict of interest.

Authors' Contribution

All the authors have collectively contributed in this paper.

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