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REVIEW ON CURRENT SITUATION OF GENERATION AND MANAGEMENT OF COAL ASH IN VIETNAM

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ABSTRACT: Due to rapid industrialization and economic growth, the generation of coal ash from coal-fired thermal power plants is increasing in Vietnam. As of 2020, coal-fired power accounts for 49.3% of the total power supply in the electrical industry and leads to a large generation of coal ash every year. The amount can be expected to increase to up to 30 million tons according to the master plan for electricity development, with 52 coal-fired power plants expected to be in operation by 2030 and more than 422 million tons of coal ash being stored. In recent years, the management and recycling of coal ash have played an important role in economic and social development. Besides protecting the environment, coal ash is also widely used in construction. Based on survey results, thermal plants do not possess sufficient capacity for storage of coal ash, especially from small-scale and old plants (which face the risk of closure). It is recommended to improve the technical standards for handling, reuse, and recycling of coal ash and to establish a collaborative system and framework among enterprises, government, and research institutes to promote the effective reuse and recycling of coal ash in Vietnam.

Keywords: Coal ash, Coal-fired power plant, Reuse and recycling, Treatment and disposal, Vietnam

1. INTRODUCTION

Due to the rapid increase of population and economic growth, urbanization, and industrialization, the electricity demand has increased, and a stable supply of electricity is necessary to provide benefits to the economy and society in Vietnam. In reality, less than half of households used electricity in 1993, and more than 98% have used the by the end of 2015 [1]. According to the Report of the Ministry of Construction (MOC) in 2020, 25 coal-fired thermal power plants under commercial operation generated 18.5 million tons of coal ash [2]. The generation of coal ash is expected to reach 30 million tons from 52 coal-fired thermal power plants, including newly-operated ones, by 2030, resulting in an estimated increase in total electricity production of 27% in Vietnam [3]. Simultaneously, the spread of electricity and the increase of coal-fired power plants has caused social and environmental problems in recent years. One cause of the problems is attributed to improper management of the coal ash generated. Nowadays, most coal ash is disposed of simply in the environment without treatment, i.e., dumped in landfill sites despite overloaded capacity [4].

In developed countries, recycling and reuse of coal ash from coal-fired thermal power plants are encouraged, especially in cement and construction industries, as well as the development of technical standards and guidelines. According to the Japan Coal Frontier Organization (JCOAL), for example, reuse and recycling of coal ash reached approximately 98% (including 64% in cement and concrete and 14% in construction activities) of the annual generation of coal ash of 12.35 million tons in Japan [5]. In Vietnam, on the other hand, the coal ash generated from coal-fired power plants is not yet fully recycled and reused, and the limited amount of coal ash that meets technical standards is used in cement, concrete, and unburnt bricks. As well as the direct disposal at dumping sites, coal ash dust attributed to storage and transportation (from coal-fired power plants to the dumping sites) causes air pollution and impacts human health and the environment [6]. Commonly, the storage areas of coal ash have not met the required environmental protection rules, and trucks used for coal ash transportation have not had suitable equipment installed to prevent coal ash from spreading [7].

This paper, first, introduces the current situation of coal-fired thermal power plants including properties of coal ash, use of recycled coal ash, and effects of improper management of coal ash on environmental pollution and risks to human health in Vietnam. Next, challenges and legal actions to promote the reuse and recycling of coals ash in Vietnam are introduced.

2. COAL ASH FROM COAL-FIRED POWER PLANTS IN VIETNAM

2.1 Current Situation of Coal-Fired Thermal Power Plants and Coal Ash

Currently, Vietnam has various energy sources such as coal, natural gas, petroleum, hydropower, and renewables such as solar and wind energy. Among them, the electricity supplied by coal-fired thermal power plants accounts for nearly 53.2% of total electricity production and will consume about 129 million tons of coal in 2030 [8]. Figure 1 shows the locations of coal-fired thermal power plants in Viet Nam [9]. As shown in the figure, the coal-fired thermal power plants are mostly located in the coastal areas near industrial zones in Vietnam such as Quang Ninh with 10 plants and Hai Phong with three plants. The process of burning coal to operate thermal power plants generates combustion products, the so-called coal ash. Coal ash is also referred to as coal combustion residuals, which include fly ash, bottom ash, boiler slag, and flue gas desulfurization materials [10]. Among the forms of coal ash, in general, the amount of fly ash accounts for about 80-90%, while slag accounts for only about 10–20% [11].

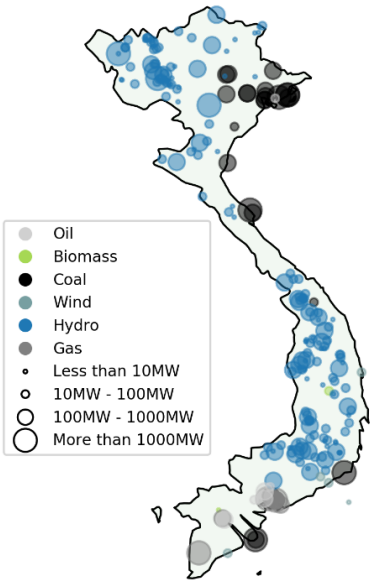

Fig. 1 Locations of coal-fired thermal power plants in Vietnam

As of 2020, the total electrical capacity was 17,999 MW, and the total amount of coal ash generated was reported to be approximately 18,492,000 tons [2]. Coal ash is generated in the North (65% of the total), Central (23% of the total), and South (12% of the total) regions of Vietnam. The plant that generates the largest amount of coal ash is the Vinh Tan I BOT Thermal Power Plant in Binh Thuan Province (1.6 million tons/year). The largest locality that generates coal ash from coal-fired thermal power plants in Quang Ninh Province, and generates approximately 6.7 million tons of coal ash per year (~35% of the total). The total amount of coal ash stored by the end of 2020 is reported to be approximately 47.65 million tons [2]. It is also reported that ~25-30% of operating coal-fired thermal plants consume/reuse the coal ash generated, but other plants do not (i.e., discard it) [12]. Due to economic growth in recent years, the share of coal as a resource for electricity production is estimated to gradually increase from 49.3% in 2020 to 56.4% in 2030, according to the revised Seventh Power Development Plan of Vietnam [13]. Table 1 shows the estimated total amount of coal ash stored if it is not reused in the future [8, 14], suggesting strongly that the reuse and recycling of coal ash (generated and stored) is an urgent issue in Vietnam.

Table 1 Total amounts of coal ash generated and stored [8, 14]

Year	Total generation of coal ash (tons/year)	The total amount of stored coal ash (tons)
2016	15,784,357	22,705,558
2018	20,612,500	61,515,750
2020	27,614,400	78,409,091
2025*	29,371,100*	248,978,800**
2030*	38,314,500*	422,663,000**

** Estimated values; **Total amount of stored coal ash if not reused*

2.2 Current Situation of Disposal Sites of Coal Ash

It is reported that many coal-fired thermal plants are facing insufficient land for coal ash dumping, and the filling rate of operating coal ash disposal yards is high. For example, the fill rate reached 100% in 2019 at Mong Duong I*, 80% at Duyen Hai 1, 60% at Duyen Hai 3, and 70% at Vinh Tan 2 and Vinh Tan 4 [2]. In Quang Ninh Province, there are seven coal-fired thermal power plants with a total capacity of 5,850 MW electricity (32.5% of the total electricity produced in the country). They occupy a large coal ash disposal area: e.g., two plants (Cam Pha thermal power plants 1 & 2) in Cam Pha City of the province (total electricity capacity of 600MW) use 34 ha for dumping coal ash generated at 1 million tons per year. In addition, some disposal sites are used not only for the disposal of coal ash but also other

residues, such as those of cement factories and others, which are dumped together [15]. Photos of coal ash disposal sites are shown in Fig. 2.

Fig. 2. Coal ash disposal sites: Ha Long plant (Upper) and Mong Duong 1 (Middle) in Quang Ninh Province, and (Lower) typical coal ash transportation by a truck in Vietnam

*Note: The Mong Duong 1 coal-fired thermal power plant operated since 2015 is facing possible closure shortly due to the overload of coal ash. The plant with a capacity of 1,080 MW consumes about 3 million tons of coal per year and generates 1 million tons of coal ash annually. At present, only 40% of coal ash generated is being sold to cement and concrete manufacturing factories. The plant, however, meets difficulties in finding a buyer of fly ash among the types of coal ash and finding a treatment company [16]. The dumping site of the plant has a total volume of 2.25 million m^3, but it has been full since 2019. Currently, the plant company has constructed a raised dike covering the coal ash yard to about 3 m according to the technical design and report (Environmental Impact Assessment has been approved; additional store volume of 300,000 m^3 [2]).

2.3 Coal Combustion Technologies in Vietnam

Currently, coal-fired thermal power plants in Vietnam use two types of burning technologies: pulverized combustion (PC) and circulating fluidizing bed (CFB) technologies. Of 25 thermal power plants, 16 plants use PC technology and 9 plants use CFB technology (see also Table 2). In PC technology, coal is finely ground by a crushing machine and dried to a particle size of less than 0.09 mm, then moved to storage tanks. The temperature in the furnace is about 1400–1600^{o}C to create the pressure to feed the power electricity. Burning coal leaves coal ash, with part of the molten superheated coal turning into slag that falls to the bottom of the furnace, where it is cooled by water, and most of the fine coal ash follows the flue wind to filter electric dust and obtain clean gas, which is discharged into the environment [8]. For thermal power plants using PC, ash, slag, and flue gas desulfurization of gypsum (if any) are discharged separately, which is convenient during processing, and they are used as raw materials for the production of building materials.

The CFB technology, on the other hand, is used when the coal is low quality and high in sulfur. Coal and limestone are processed on a hammer crushing machine to particle size are less than 10 mm, stored in tanks for feeding and dosing at the bottom. Coal and limestone are fed into the circulating fluidized bed furnace to generate heat and feed the water in high-pressure steam to create electricity. Fine ash goes into an electrostatic dust filter to collect fly ash, and clean gas is discharged into the environment through the chimney. Large particles of coal ash and limestone, whether reactive or not, will fall to the bottom of the kiln to form bottom ash. For plants using CFB, gypsum and residual limestone are always mixed with fly ash. The mixed discharge leads to difficulty in separating gypsum and handling excess limestone from fly ash, leading to difficulties in its use as raw materials for the production of construction materials [8].

2.4 Properties of Coal Ash at Thermal Power Plants in Vietnam

Fly ash and bottom ash obtained from some coal-fired thermal power plants in Vietnam are shown in Fig. 3. Fly ash is a type of artificial pozzolan, which is the ash of burned coal bran, so it is very fine, and below 10 μm [17]. Fly ash is classified into two types with different characteristics: Type C generally contains more than 10% CaO and type F normally contains less than 10% CaO [18]. The particle size of bottom ash is usually much bigger than that of

Table 2. Selected coal-fired thermal power plants, their electricity production capacity, and components of coal ash in Vietnam [8]

No.	Name of plant	Capacity (MW)	$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	SO_3	CaO	LOI (%)
		PC Technology				
1	Uong Bi 1, Uong Bi 2	735	85	0.58	<0.008	6-8
2	Pha Lai 1, Pha Lai 2	4×110, 2×300	64.5-71.3	0.12-0.06	<0.008	22.6-25
3	Quang Ninh 1, Quang Ninh 2	4×300	83-85.2	0.29	<0.008	6-8
4	Hai Phong 1, Hai Phong 2	4×300	83-87.1	0.32	0.63	10-14
5	Ninh Binh	400	70	0.12-0.06	<0.008	22
6	Duyen Hai 1	2×622	84	0.32	0.63	12
7	Nghi Sơn 1	2×300	76.5			14-17
8	Vung Ang 1	2×600				<6
9	Vinh Tan 2	2×622				12
10	FMS Dong Nai	3×150	88.6	0.68		<6
		CFB Technology				
1	Na Duong	2×55	58.7	10.6	21.7	4-8
2	Cao Ngan	2×57.5	45.61	10.5	13.5	24-27
3	Cam Pha	2×340	78.0	2.4	5.5	8-12
4	Son Dong	2×110	85.6	1.1	1.3	10-14
5	Mao Khe	2×220	84.3	0.7	2.0	6-8
6	Mong Duong 1	2×540	72	1.87	7.42	11.0
7	An Khanh	2×58	83	0.7	1.96	6.6

fly ash. The properties of coal ash depend on the burning technology.

Fly ash and bottom ash obtained from some coal-fired thermal power plants in Vietnam are shown in Fig. 3. Fly ash is a type of artificial pozzolan, which is the ash of burned coal bran, so it is very fine, and about 55% below is 10 µm [17]. Fly ash is classified into two types with different characteristics: Type C generally contains more than 10% CaO and type F normally contains less than 10% CaO [18]. The particle size of bottom ash is usually much bigger than that of fly ash. The properties of coal ash depend on the burning technology.

Fig. 3 Fly ash (upper) and bottom ash (lower) from coal-fired thermal power plants in Vietnam

3. EFFECTS OF COAL ASH ON ENVIRONMENTAL POLLUTION AND POTENTIAL RISKS TO HUMAN HEALTH

Improper management of coal ash generated by coal-fired thermal plants causes serious social and environmental problems, such as spreading of dumping space, the overloaded capacity of disposal yards, and various environmental pollutions. Especially, air pollution due to the improper management of coal ash is a risk to human health. The monitored data from the Ministry of Natural Resources and Environment (MONRE) [21] showed that concentrations of dust in the air at 100% of coal mining and processing facilities exceeded the Vietnamese standard on ambient air quality [22] and rose to 30 to 300 times acceptable [23]. Not only the disposal site of coal ash but storage and transportation of coal ash cause air pollution [7]. Coal ash is transported from coal-fired thermal power plants to dumping sites by trucks, but the coal ash is commonly piled up in the trucks without any cover (see Fig. 2), resulting in severe damage to local people. Moreover, pollutants such as SO_x, NO_x, and $PM_{2.5}/PM_{10}$, as well as CO_2 generated by coal-burning and mining processes, impact human health and the environment greatly [1]. It has been reported that the high concentration of $PM_{2.5}$ was observed commonly in the regions of coal-fired thermal power plants and their surrounding in Southeast Asia, including Vietnam [24].

4. CHALLENGES AND SOLUTIONS FOR SOUND MANAGEMENT AND RECYCLING OF COAL ASH

4.1 Challenges to Promoting Reuse and Recycling of Coal Ash

In the world, the total amount of coal ash generated was estimated to be approximately 480 million tons in 2000 [25], and reuse and recycling of coal ash have been promoted in recent decades. In the European Union, for example, ~95 million tons of coal ash were produced in 2003, 53% of the coal ash was used in construction and underground mining, and 36% was used for the restoration of open cast mines, quarries, and pits. Only 12% of the total was temporarily stored (8%) and disposed of (4%) [26]. In Japan, the generation of coal ash was ~12.35 million tons in 2016, and the rates of reuse and recycling reached 99.3% [27]. Coal ash is used widely in construction (raw material for cement, road pavement materials, ground-leveling materials) and is also used in the fields of agriculture, forestry, and fishery [5, 27]. In Vietnam, Decision No. 1696/2014/QD-TTg [28] was issued to promote the reuse and recycling of coal ash for the production of building materials. According to actual surveys and reports, however, only 31% (approximately 5 million tonnes) of the total coal ash generated is reused and recycled annually [29]. According to the latest report of the Ministry of Construction (MOC) [2], a total of 34.5 million tons of coal ash was reused and recycled in 2020. The most common use was as mineral additives for cement (estimated 24 million tons/year; 70%) and for the production of baked clay bricks and unburnt bricks (estimated 4 million tons/year; 12%), an additive for the production of fresh concrete, concrete for irrigation works, traffic works (cement-concrete roads in rural areas), and civil constructions (large block foundations with low heat generation) (estimated ~3 million tons; 8%), and as materials for leveling and filling roads of all kinds (~3.5 million tons; 9%).

Recently, the Vietnam government launched a program to use coal combustion residuals (CCR), a waste product from thermal power plants, to make building materials [29]. The program directed at least 25% of CCR to be recycled by 2015. Some plants, including the Cao Ngan coal-fired power plant* in Thai Nguyen Province (discharges ~200,000 tons/year) achieved the target recycling % of CCR; however, as a whole, only 18% of CCR was recycled at the end of 2015 according to the survey of the Building Materials Institute [29]. In addition, some new technologies, such as integrated gasification combined cycle (IGCC), pressurized fluidized bed combustion (PFBC), and ultra-clean coal (UCC) technologies, can be expected to be introduced for increasing the energy efficiency rate and minimize the generation of CCR [25, 26].

*The Cao Ngan coal-fired power plant delivered nearly 32,000 tons of fly ash for the testing of cement production at Quan Trieu Cement Plant until the end of 2015. The average monthly amount was around 6500 to 7000 tons [4], resulting in the saving of dumping areas of ~2 ha/year.

4.2 Legal Actions and Strategies to Promote Reusing and Recycling of Coal Ash

The Vietnamese government provides many laws and decisions on the use of reused and recycled coal ash in construction, as shown in Table 3. The first law on environmental management was published in 1993, and in recent years, the Government of Vietnam has issued many policy documents, operating documents, mechanisms that create a favorable legal corridor to promote the treatment and use of ash, slag, and plaster [24, 30-34]. In addition, to encourage and give incentives to treat ash, slag, and gypsum from thermal power plants for use as raw materials in the production of building materials [28,30], the government has introduced stronger measures in sanctioning units that emit, treat, and use ash, slag, and gypsum that do not strictly comply with the regulations of the national law [31]. The laws introduce new regulations to create more favorable conditions for the consumption of ash and slag, to allow the application of foreign standards in case Vietnam does not have established standards, to consider ash and slag that meet the standards as building materials to be products of construction materials and substitutes for natural mineral resources in the production of building materials and to have more favorable regulations in the transportation of ash and slag [34,42].

In cooperation with the direct management agencies, the Ministry of Construction (MOC) has also developed and issued or transferred to competent parties the authority to promulgate 19 standards, 1 regulation, and 7 technical instructions, 3 economic and technical norms, techniques for treatment and use of ash, slag, and gypsum as raw materials for the production of building materials and in construction works according to the tasks set out in Decision No. 452/2017/QD-TTg [2] of the Prime Minister. To promote the processing and consumption of ash, slag, and plaster, the MOC issued Document No. 3314/2018/BXD-VLXD [43] on the use of

Table 3 Acts, regulations, and decisions related to the treatment of recycled coal ash

Year	Type of document	Name of document	Remarks
1993	Law	Law on Environmental Protection [35]	Environmental regulation shall consist in the review of natural and human elements and factors of the environment, observation and recording of their alterations, as well as the supervising of the causes of these alterations. Last amendment in 2020
2005	Law	Law on Protection of the environment [36]	Update from Law in 1993
2007	Decree	No.59/2007/ND-CP. Decree on solid waste management [37]	Initial guideline for managing solid waste
2009	QCVN	QCVN 07: 2009/BTNMT [38]	National Technical Regulation on Hazardous Waste Thresholds
2009	Vietnamese Standard	Fly ash - Methods of chemical analysis [39]	Prescribes chemical analysis methods for fly ash
2014	Decision	Decision No.1696/QD-TTg [28]	Encourages recycling coal ash as building material (guideline, incentive, international cooperation)
2014	Vietnamese Standard	TCVN 10302:2014. Activity admixture - Fly ash for concrete, mortar, and cement [18]	Applies to mineral admixtures of fly ash (hereinafter referred to as fly ash) that have been through dry or wet sorting treatment technology for concrete, mortar, and cement.
2017	Decision	Decision No.452/QD-TTg [2]	Encourages recycling of coal ash as building material (guidelines, incentives, international cooperation)
2018	Vietnamese Standard	TCVN 12249:2018. Coal ash of thermal power plant using as backfill material [40]	Applies to coal ash from coal-fired thermal power plants and is used for leveling for construction and technical infrastructure.
2018	Decision	Decision No. 3986/QĐ-BNN-XD [41]	Instructions for the use of fly ash in irrigation concrete

ash and slag as raw materials in construction and construction works. Then, the Vietnamese government promulgated TCVN 12249 on the use of coal ash of thermal power plants as backfill material - General requirements [40].

The Ministry of Industry and Trade (MOIT), on the other hand, has presided over and coordinated with the MOC to promulgate a sample scheme for treatment and consumption of ash, slag, and flue gas desulfurization of gypsum and phosphogypsum of thermal power plants in chemical fertilizer plants [44]. It has directed state-funded traffic project investors to prioritize using ash, slag, gypsum, or building materials containing ash, slag, and gypsum [45], as backfill materials for construction projects of some expressways on the North-South-East route [46]. These policies are expected to increase the consumption of ash and slag from thermal power plants in the coming years. Most recently, the MOIT released a draft proposal for the national power development plan for the period of 2021–2030 with a vision to 2045 ("PDP8") in May 2021 [47]. This proposal focuses on some structural changes in the power industry, especially the coal power industry. It specified that from 2020 to 2030, there will be no additional development of new coal-fired thermal power plants. The power capacity of coal-fired thermal power plants will be reduced from 43% in 2020 (PDP7) to 27% in 2030 and a further 18% in 2045 [3].

5. CONCLUSIONS

This paper describes the current conditions of coal-fired thermal power plants, including the properties of coal ash and the effects of improper management of coal ash on environmental pollution and risks to human health in Vietnam. In addition, challenges and legal actions to promote the reuse and recycling of coal ash in Vietnam are introduced. The major difficulties can be summarized as i) there are few technical standards for handling, reuse, and recycling of coal ash, and ii) coal-fired thermal plants do not possess sufficient storage capacity of coal ash. Therefore, many challenges and programs, as well as legal actions, to promote the reuse and

recycling of coal ash, are necessary to strengthen a collaborative system and framework among enterprises, governments (central and local), and research institutes to initiate policies for promoting effective reuse and recycling of coal ash in Vietnam. Finally, not only promoting the reuse and recycling of newly generated coal ash but also further research and development are required to treat dumped/stored coals ash in Vietnam.

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7. REFERENCES

[1] Minh, H.D., An, H.T., and Hoang, A.T.N. 2016. Synthesis Report on Socio-environmental Impacts of Coal and Coal-fired Power Plants in Vietnam.

[2] MOC report on Summary of Implementation of Prime Minister Decision No. 452/2017/QD-TTg.

[3] Viet Nam Energy Partnership Group Technical Working Group 5 – Energy Data and Statistics Report of the 5th Meeting. http://vepg.vn/wp-content/uploads/2020/11/VEPG_TWG5_5th_Meeting_Report_fin.pdf

[4] Thriveni, T., Nguyen. T.M.N., Lai, Q.T., Trinh, H.S., Ho, H.H., Dang, T.N.T., Nguyen, T.T.T., Duong, T.T.T., Doan, T.N.H., Tran, T.V., Ramakrishna, C., and Ji, W.A. 2018. Technological solutions for recycling ash slag from the Cao Ngan Coal Power Plant in Vietnam. Energies, 11(8): https://doi.org/10.3390/en11082018.

[5] Japan Coal Frontier Organization (JCOAL). 2021: http://www.jcoal.or.jp/eng/

[6] Le, T. 2015. Live Together with coal ash and dust. LAO DONG: http://nld.com.vn/news20150406215144374.htm (accessed on Dec. 05, 2021).

[7] Hoang, L. 2016. Vinh Tan 2 Coal Power Plant Cause Pollution in Binh Thuan Province. LAO DONG: http://laodong.com.vn/chung-toi-len-tieng/nhiet-dienvinh-tan-2-treu-nguoi-tinh-binh-thuan-511896.bld

[8] Decision No. 428/2016/QD-TTg on the approval of revisions to the national power development plan from 2011 to 2020 with visions extended to 2030.

[9] U.S. Agency for International Development (USAID). 2021. Greening the Grid: https://greeningthegrid.org/

[10] U.S. Environmental Protection Agency (EPA). 2021. Coal Ash (Coal Combustion Residuals, or CCR): https://www.epa.gov/coalash

[11] Dinh, Q.D., Doan, T.T., Do, N.S. 2019. Coal ash of thermal power plant using as backfill material. Construction Science and Technology Magazine - No. 1/2019

[12] Le, V.Q. 2019. Report on analysis technology. Trends of application of coal ash in the production of building materials (in Vietnamese). Compiled by: Statistics and Science and Technology Information of Ho Chi Minh City.

[13] GIZ Energy Support Programme in Viet Nam. 2020. Vietnam Power Development Plan for the period 2011–2020: Highlights of the PDP 7 revised: http://gizenergy.org.vn/media/app/media/legal%20documents/GIZ_PDP%207%20rev_Mar%202016_Highlights_IS.pdf

[14] Jongyeol, L., Taeyoon, K., Mina, S., Vu, H.H.T., Kyung, N.S., and Ji, W.A. 2020. An integrative approach to international technology transfer for recycling Vietnam coal ash with consideration of the technological, legal, and network perspectives. Sustainability, 12(3), 771: https://doi.org/10.3390/su12030771.

[15] VIETNAMNET Bridge. 2017. Ash & slag from thermal power plants threatens Ha Long Bay: http://english.vietnamnet.vn/fms/environment/187712/ash---slag-from-thermal-power-plants-threatensha-long-bay.html

[16] Trang, V. 2017. $1.6-billion thermal power plant faces possible closure over ash problems. Vietnam Investment Review: https://www.vir.com.vn/16-billion-thermal-power-plant-faces-possible-closure-over-ash-problems-51889.html

[17] Duc, D.S. 2014. Properties of fly ash from a thermal power plant in Vietnam. Int. J. Chem. Tech. Res. 6: 2656–2659.

[18] TCVN 10302: 2014. Activity admixture – Fly ash for concrete, mortar, and cement.

[19] TCVN 6882: 2016. Mineral additive for cement.

[20] ASTM C618-19: 2019. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.

[21] Ministry of Natural Resources and Environment (MONRE). 2014. National Environmental Report 2013 - Air Quality (in Vietnamese).

[22] QCVN No. 05/2013/BTNMT on National technical regulation on ambient air quality.

[23] Green Innovation and Development Centre. 2015. Survey on some coal-fired power plants in Vietnam (in Vietnamese).

[24] Koplitz, S.N., D.J. Jacob, M.P. Sulprizio, L. Myllyvirta, and C. Reid. 2017. The burden of disease from rising coal-fired power plant emissions in Southeast Asia. Environ. Sci. Technol., 51(3): 1467–1476. https://doi.org/10.1021/acs.est.6b03731.

[25] Heidrich, C., Feuerborn, J. 2013. Coal combustion products: A global perspective. http://www.mcilvainecompany.com/Decision_Tree/subscriber/Tree/DescriptionTextLinks/International%20flyash%20perspective.pdf.

[26] European Energy Agency. 2006. EN-10. Residues from combustion of coal for energy production: https://www.eea.europa.eu/data-and-maps/indicators/en10-residues-from-combustion-of/residues-from-combustion-of-coal#:~:text=Residues%20from%20the%20combustion%20of,3.5%25%20of%20total%20waste%20generation

[27] Vietnam Electricity. 2018. Japan efficiently reuses over 99% thermal coal ash: https://en.evn.com.vn/d6/news/Japan-efficiently-reuses-over-99-thermal-coal-ash-6-12-1186.aspx

[28] Decision No. 1696/2014/QD-TTg on taking measures to treat ash, slag, and gypsum from thermal power, chemical or fertilizer plants for the production of building materials.

[29] Hong, H.T.V and Ji, W.A. 2018. Overview of coal-fired power plant ash situation and cement industry in Vietnam. J. Energy Engineering, 27(3): 57-62.

[30] Decree 24a/2016/ND-CP on Building material management.

[31] Decree No. 139/2017/ND-CP on Penalties for administrative violations against regulations on investment and construction; extraction, processing, and trading of minerals used in construction, production and trading of building materials; management of infrastructural constructions; real estate business, housing development, management and operation of apartment buildings and office buildings.

[32] Decision No.452/2017/QD-TTg on Approving the proposal to boost treatment and use of ash, slag, and gypsum discharged from thermal power plants, chemical, and fertilizer plants for the production of building materials and use in construction projects.

[33] Decree No.40/2019/ND-CP on Amendments to decrees on guidelines for the law on environmental protection.

[34] Decree No.21/2020/ND-CP on Amendments to government's decree no. 139/2017/ND-CP on penalties for administrative violations against regulations on investment and construction, extraction, processing, and trading of minerals used in construction, production, and trading of building materials, management of infrastructural constructions, real estate business, housing development, management and operation of apartment buildings and office buildings.

[35] Law on Environmental Protection, Vietnam. 1993.

[36] Law on Environmental Protection, Vietnam. 2005.

[37] Decree No.59/2007/ND-CP on Solid waste management.

[38] QCVN No. 07/2009/BTNMT on National technical regulation on hazardous waste thresholds.

[39] TCVN 8262: 2009. Fly ash - Methods of chemical analysis Prescribes chemical analysis methods for fly ash.

[40] TCVN 12249: 2018. Coal ash of thermal power plant using as backfill material - General requirements.

[41] Decision No. 3986/2018/QD-BNN-XD on instructions for the use of fly ash in irrigation concrete.

[42] Decision No. 1266/2020/QD-TTg on Approving the strategy on the development of building materials in Vietnam for the period of 2021 - 2030, with a vision to 2050.

[43] Ministry of Construction (MOC) document No. 3314/2018/BXD-VLXD. Guidelines on the use of ash and slag as raw materials in construction and construction works.

[44] Decision No. 2056/2018/QD-BCT on the Promulgation of a sample scheme for treatment and consumption of ash, slag, and gypsum of thermal power plants, chemicals, and fertilizers.

[45] Documentary No. 496/2019/BGTVT-CQLXD. Instructions for using ash, slag, gypsum as raw materials for the production of building materials and in construction works.

[46] Documentary No. 6278/2019/BGTVT-KHCN. Using ash and slag from coal-fired thermal power plants as backfill materials for the construction project of some expressways on the North-South East route.

[47] Electricity and Renewable Energy Authority. Updating national power development plan for the period of 2021-2030, with a vision to 2045. http://vepg.vn/wp-content/uploads/2021/05/2.EREA_VEPG_29.4.2021_NTA_04052021_VN_1.pdf