

Case Report

# A Case Study of Environmental Policies and Guidelines for the Use of Coal Ash as Mine Reclamation Filler: Relevance for Needed South Korean Policy Updates

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Received: 30 April 2019; Accepted: 30 June 2019; Published: 2 July 2019



**Abstract:** The South Korean government is pursuing a national project to use the complex carbonates found in coal ash to capture CO<sub>2</sub> and promote coal ash recycling. One possible approach is the use of coal ash as fill material in mine reclamation, but environmental concerns have so far blocked the implementation of this procedure, and no relevant regulations or guidelines exist. In this study, we review international approaches to the environmental management of coal ash recycling and consider how the lessons learned can be applied to South Korea. Each studied country was proactively using coal ash for beneficial uses under locally suitable conditions. The United States, European Union, United Kingdom, Australia, and Japan are all putting coal ash to beneficial use following thorough analyses of the environmental impact based on several considerations, including bulk concentration, coal ash leachate concentration, field inspections, and water quality monitoring. Our findings can contribute to the development of proper regulations and policies to encourage the use of recycled coal ash in South Korea as an approach to managing carbon emissions and climate changes. There are currently no relevant regulations in South Korea, so we consider the adoption of the strictest standards at each stage of the other cases at the time of introduction. Based on our findings, detailed and appropriate management guidelines can be developed in the future. Establishing management plans for complex carbonates, verifying their environmental stability, and using them as fill material will provide clear benefits for South Korea in the future.

**Keywords:** South Korea; mine reclamation; coal ash; complex carbonates; environmental policy

## 1. Introduction

Despite commitments and efforts to increase the share of renewable energy in the global energy supply, coal remains one of the world's biggest energy sources, generating considerable amounts of coal fly ash [1]. Globally, many efforts are being made to recycle the 7.8 billion tons of coal ash currently being generated annually, only 53.3% of which is currently recycled. For example, in 2016, the United States reused 60.2 million tons of coal combustion products (CCPs) out of 107.4 million tons produced. Although the rate of ash utilization thus increased from 52% to 56%, the total volume of material utilized stayed about the same as production declined. Even though the coal ash production volume has declined 7% since 2015 as coal's share of the total energy generation shrank in response to environmental regulations and competition from other energy sources, the coal ash utilization volume remained approximately level with that of the prior year [2]. Coal ash has been successfully used for

many years in a wide range of applications, including in building material, asphalt, concrete pavement, soil stabilization, road base, structural fill, embankments, mine reclamation, mineral filler, and fertilizer, as well as in small-scale applications, such as the production of zeolites and geopolymers [3]. The United States and Australia, which have large land areas and many developed mines, also recycle coal ash as landfill material and filling.

South Korea generated about 9 million tons of coal ash in 2016; this figure is expected to reach 14 million tons in 2021 and increase about 1.6 times over the next 10 years. The construction of circulating fluidized bed combustion (CFBC) power plants generates coal ash containing 40% CaO or more. The capacity of current South Korean disposal facilities is nearing saturation, and some recently built power plants are targeting 100% recycling of generated coal ash [4]. Recently, South Korea has been developing complex carbonate minerals that use coal ash to capture carbon dioxide, an important approach to carbon dioxide reduction and coal ash recycling. Although these materials are intended for use as a high-function green cement and mine fill, they cannot be legally used for the latter purpose at present. In South Korea, coal ash (the main component of complex carbonates) can only be legally used for 15 applications, not including fill material in mine reclamation sites. There is a movement to legalize the use of coal ash at mine reclamation sites, but this effort is on hiatus due to concerns regarding the environmental impact, including the potential contamination of soil, ground surfaces, and groundwater resulting from the presence of soluble metal species in ash leachate [5]. Therefore, in order to safely use coal ash at mine reclamation sites in South Korea, its environmental impacts must first be assessed and predicted.

Currently, the United Kingdom, Japan, the European Union, the United States, Australia, and Canada all make beneficial use of coal ash as a mine fill material. Therefore, in this study, we analyzed these entities' relevant regulations and environmental management guidelines to assess the best practices for verifying and managing environmental stability when using coal ash for this purpose. We also considered the relevant regulations and guidelines for domestic waste recycling and mine fill in different countries. Based on these case studies, we then developed the necessary environmental management guidelines for the use of complex carbonates as fill material for mine reclamation sites in South Korea.

## 2. Case Studies

### 2.1. United States (US)

Code of Federal Regulations (CFR) Title 40 contains regulations related to environmental protection; those dealing with waste are 40 CFR 257 (Criteria for Classification of Waste Disposal Facilities and Practices) [6] and 40 CFR 261 (Identification and Listing of Hazardous Waste) [7]. These rules do not apply when coal combustion residuals (CCRs) are used in construction material or fill; instead, the Surface Control and Reclamation Act (SMCRA) [8], state regulations, and water quality standards must be satisfied.

In the United States, laws and regulations on coal ash are applied differently from state to state. We focused on such management in Pennsylvania, where coal ash is actively used for mine reclamation projects. Here, the use of coal ash was legalized following the revision of the 1986 Solid Waste Management Act in July 1992, after which the "Guidelines for Beneficial Use of Coal Ash at Coal Mines" [9] were developed in accordance with the regulations. Further revisions were made in 1997 and 1998 to provide guidance on certification standards and procedures for the use of coal ash in mining sites. In December 2010, the addition of Title 25, Chapter 290 of the state code, "Beneficial Use of Coal Ash" [10], codified all the requirements for the use, certification, and management of coal ash.

Certification follows two steps: certification of the ash itself and certification at the mine site. The first ensures that coal ash does not cause pollution and meets the minimum physical and chemical standards for further use. This requires defining the coal of origin, the combustion method, and the collection and storage method. For example, the concentration criteria for leaching and bulk conditions

of coal materials are given in Tables 1 and 2, respectively [11]. The former criteria have not been finalized in the regulations, because the potential for contamination and the impact on health can vary by circumstances. The parameters presented here are based on the state's Department of Environmental Protection (DEP)'s experience and the results of studies by the National Research Council. The hydraulic conductivity, density, and acid neutralization capacity should also be measured. Even if the criteria are met, the generator should continue to prove that the coal ash meets the certification criteria through regular monitoring reports.

**Table 1.** Parameters required for leaching tests and their maximum acceptable leaching limits in the state of Pennsylvania in the United States (US) [11].

Parameter	Leaching Limit (mg/L)	Parameter	Leaching Limit (mg/L)
Ag	2.5	Mg	*
Al	5.0	Mn	2.5
As	0.25	Mo	4.375
B	15	Na	*
Ba	50	NH <sub>3</sub>	30
Be	0.1	Ni	2.5
Ca	*	NO <sub>2</sub>	1.0
Cd	0.125	NO <sub>3</sub>	10
Cl	250	Pb	0.375
Co	17.5	SO <sub>4</sub>	2500
Cr	2.5	Sb	0.15
Cu	25	Se	0.5
F	*	Tl	0.05
Fe	7.5	V	6.125
Hg	0.05	Zn	50
K	*	pH	7 or above

\* Limit not established.

**Table 2.** Parameters required for bulk chemical analysis and their loading limits in the US state of Pennsylvania [11].

Parameter	Loading Rate (lbs/acre)	Parameter	Loading Rate (lbs/acre)
Al	*	Mg	*
Sb	*	Mn	*
As	36	Hg	15
Ba	*	Mo	16
Be	*	Ni	370
B	60	K	*
Cd	34	Se	88
Ca	*	Ag	*
Cr	2672	Na	*
Co	*	S	*
Cu	1320	Ti	*

Table 2. Cont.

Fe	*	V	*
Pb	264	Zn	2464

\* Limit not established.

Certified coal ash is not necessarily suitable at all mine sites, requiring second site-based certification based on local characteristics, such as groundwater hydrology, mine waste chemistry, and local rivers. Groundwater assessments generally include conditions in wells, ponds, mine waste leachates, and abandoned mine shafts. Upgradient groundwater should also be studied, especially if pollution is already present. In addition, a minimum of three downgradient groundwater sites should be assessed.

Coal ash use can be implemented once it has passed these certification steps. The use of coal ash at mine sites also requires water quality monitoring plans to be submitted to the state's DEP. This should be planned so that the impact of coal ash use can be clearly determined based on an in-depth analysis of groundwater and surface water flows within mine site and the surrounding area. The water quality monitoring points should be representative of the overall water quality based on adequate samples and include both upgradient and downgradient locations. The reported values should meet all standards for drinking water in the state (Table 3). If measured values exceed these standards, then the DEP should be notified, and the water should be purified until stabilization is achieved.

**Table 3.** Water quality standards for monitoring coal ash use at mine reclamation sites in the US state of Pennsylvania [11].

Parameter	Limit (mcl)	Parameter	Limit (mcl)
Ag	*	Mg	*
Al	*	Mn	*
As	0.01	Mo	*
B	*	Na	*
Ba	2	NH <sub>3</sub>	*
Be	0.004	Ni	*
Ca	*	NO <sub>2</sub>	*
Cd	0.005	NO <sub>3</sub>	*
Cl	*	Pb	0.015
Co	*	SO <sub>4</sub>	*
Cr	0.1	Sb	*
Cu	1.3	Se	0.005
F	4	Tl	0.002
Fe	*	V	*
Hg	0.002	Zn	*
K	*		

\* Limit not established.

## 2.2. European Union (EU)

The use of CCPs in Europe is being influenced by standardization and environmental legislation. In December 2010, a new Waste Framework Directive took effect in the EU, by which each member state has to define CCPs as byproducts and determine when a material is removed from waste status.

The producers of CCPs are required to register their products according to the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation as a precondition for placing a product on the market [12,13]. The new law's legal framework was established to improve waste management, promoting the prevention, reuse, and recycling of waste while exempting certain wastes from waste laws. It redefines byproducts as not being waste if they can be appropriately handled and put to beneficial use without potential negative influence on the environment and human health while conforming to general environmental regulations and certifications.

The law also sets criteria for end of waste (EoW) to prevent the discarding of certain materials having other applications that can be achieved in environmentally safe and economically beneficial ways. Examples include construction waste, coal ash, slag, scrap metal, glass, wastepaper, and tires. To be considered as EoW, the material should be clearly discernable during the recovery process and should avoid producing negative environmental impacts. Criteria were set for each potential material by the Institute for Prospective Technological Studies (IPTS) and the Joint Research Centre (JRC) based on a study performed at the request of the European Council [14]. In summary, the EU has been actively pursuing the beneficial use of CCPs under the condition that their environmental impact is thoroughly taken into consideration. In line with this, every member country has been independently devising regulations on the use of industrial byproducts.

#### United Kingdom (UK)

The UK sets standards for the production and use of byproducts from specific wastes through quality protocols (QPs) that define how to recover waste and turn it into a usable product [15]. These are a key mechanism in the national guidelines for waste recycling, which define the processes for using mass-produced materials, the product quality to be maintained, the point at which waste ceases to be waste, and when it can be used as a regular product (without the need for waste management controls). The UK's Environment Agency's Waste Protocols Project has established nine EoW QPs with another nine under development [16]. Waste types already covered include biodegradable waste compost, blast furnace slag, wood waste, and non-packaging plastics, which are recycled to produce products for use in agriculture, construction, energy, and manufacturing. In addition, the EQual project encouraged businesses to recycle waste into new products in ways that protected human health and the environment [17]. EQual helped businesses decide whether their recycled waste met regulatory standards when used in new products and provided technical guidance for regulating waste sites.

For example, the UK's Building Research Establishment has suggested guidelines for the environmental monitoring of fly ash grouting using two methods for groundwater monitoring: large-scale lysimeter experiments and collection from wells and piezometers in nearby areas. These are recommended prior to, during, and after construction. Groundwater quality should be determined using the stricter threshold value of either the Drinking Water Standard (DWS) or the Environmental Quality Standard (EQS), because the effects of some pollutants on humans and organisms are variable [18].

### 2.3. Australia

Similar to the US, Australia's Environmental Protection Act and management regulations apply different standards to the use of coal ash in each state: material with identical characteristics may be classified as inert waste in one state but as specified waste in another state, leading to different handling requirements. Water quality monitoring generally follows the Australian and New Zealand Guidelines for Fresh and Marine Water Quality produced by the Australian and New Zealand Environment Conservation Council (ANZECC), with each state further devising its own regulations [19].

#### 2.3.1. Queensland

In Queensland, coal ash use is regulated by the 2011 Waste Reduction and Recycling Act [20] and is divided into three categories (bound, unbound, and soil ameliorant) with varying general

conditions for the use of each that limit the harmful environmental effects of coal ash use. In addition, certifications for management and use of coal ash are required for the generator, transporter, and user. These regulations were revised in 2019 to state that coal combustion products are not waste and should be used as a resource based on Article 159 of the original law, following the relevant requirements and conditions. This reflects Queensland's vision of leading improved waste management in Australia by preventing unnecessary consumption or waste by adopting innovative resource restoration methods and managing all products and materials as valuable and finite resources.

In order for coal ash to be considered as EoW, the producer should monitor and analyze the resources, submitting annual reports using the criteria shown in Table 4 [21]. The concentration of pollutants should fall within the difference between the mean and standard deviation (at least 95% confidence interval), and statistical analysis should be performed to prove that no anomalies are present. Otherwise, analyses should be performed every six months; if actual or potential changes in resource composition are detected, further monitoring should be performed and appropriate measures should be taken [22]. Such monitoring and analysis should be performed by individuals with appropriate qualifications. Resource producers should document and store records of the source, date of dispatch, contact details of the recipient, and quantity of supply of the resource.

**Table 4.** Resource quality criteria in Queensland, Australia (total maximum concentration) [22].

Parameter	Bound Applications (mg/kg)	Unbound Applications (mg/kg)	Soil Ameliorant and Land Applications (mg/kg)
As (total)	*	20	20
Be	*	*	60
B	*	100	10 <sup>1</sup>
Cd	*	1	1
Cr (total)	*	100	100
Cr (III)	*	*	100
Cr (VI)	*	1.5	1
Co	*	100	100
Cu	*	100	100
Pb	*	50	50
Hg	*	1	1
Mo	*	*	10
Ni	*	60	60
Se	*	10	5
Zn	*	200	200
Electrical conductivity (us/cm)	*	*	10,000
pH	*	5–12.5	5–12.5

\* No specified level (monitoring is still required), <sup>1</sup> Measured using the hot CaCl<sub>2</sub> method.

Resource users applying for unbound status must not use the resource below the groundwater table, within 50 m of a water supply bore, or in areas with a pH greater than 8 [22].

Water quality management in Queensland should primarily satisfy the Queensland Water Quality Guidelines (QWQ 2009), based on national standards [23,24], which aim to protect environmental values (EVs) through management approaches that vary by EV. The selection of parameters for evaluating EV protection levels depends on the evaluation purpose. The selected parameters should be highly specific to the given situation, and the most appropriate and cost-effective parameters should be selected, rather than simply monitoring a series of conventional parameters. The development of corresponding guideline values aids in this process [23].

### 2.3.2. New South Wales

In this state, the 2014 Coal Ash Exemption was applied as a Resource Recovery Exemption under Part 9, Clauses 91 and 92 of the Environment Operations (Waste) Regulations. Coal ash use should primarily satisfy the conditions given in Table 5 [25,26]. This exemption states that the use of coal ash or coal ash mixture is permitted if a consumer meets certain exemption requirements according to the 1997 Environment Operations Act. Here, coal ash refers to fly ash and floor ash obtained by burning coal in Australia and not to brine-conditioned or treated ash.

**Table 5.** Assessment procedures and criteria for coal ash use in New South Wales, Australia [25].

Parameter	Procedure	Criteria (mg/kg)	Frequency
Total metals (Cd, Pb, Hg)	US EPA 200.2	Cd (10) Pb (100) Hg (5)	Annual
Leachable TCLP metals	US EPA 1311	various	Annual

The exemption requires that coal ash satisfies all the requirements for chemicals and other substances and that it is mixed with a substance satisfying the requirements of the Resource Recovery Order before being used as a soil ameliorant for plant cultivation, as a cement admixture such as concrete, or in underground or road construction contexts as pipe bedding material; selected backfill adjacent to structures; road pavement, base, and sub-base structures; composite filler in asphalt pavements; rigid and composite pavement structures; working platforms atop earthworks; or fill for reinforced soil structures (including geo-grid applications). Prior to use, producers should prepare a plan that clearly describes the procedures for coal ash sample preparation and storage and then perform sampling and testing as required by the relevant regulations. The specified conditions are designed to minimize the potential hazards to the environment, human health, or agriculture. The coal ash supplier should evaluate whether the material is appropriate for its intended use and whether such use would produce any harmful effect. Coal ash must not be supplied if the average or maximum value of any sampled attribute exceeds the relevant standard (Table 6).

**Table 6.** Compositional requirements for coal ash use in New South Wales, Australia [26].

Parameters	Maximum Average Concentration for Characterization	Maximum Average Concentration for Routine Testing	Absolute Maximum Concentration
Hg	0.5	*	1
Cd	0.5	0.5	1
Pb	25	25	50
As	10	*	20
B	75	*	150 for engineering uses; 60 for soil amendments
Cr (total)	25	25	50
Cu	20	*	40
Mo	10	*	20
Ni	25	25	50
Se	10	10	20
Zn	35	35	70
Electrical conductivity <sup>1</sup>	*	*	None for engineering uses; 4 for soil amendments
pH in non-cementitious mixes <sup>2</sup>	7–12.5	7–12.5	6–13
pH in cementitious mixes	*	*	*

<sup>1</sup> Although thresholds are not provided for electrical conductivity, this must be tested, and records must be kept.

<sup>2</sup> Ranges given for pH are minimum to maximum acceptable. \* Not required.



New South Wales requires follow-up monitoring based on ANZECC guidelines and the state's own WQO (water quality objectives) that consider EVs and long-term goals. The criteria, restrictions, and conditions in the regulations are not intended to be directly applied, but rather considered by the industry, community, or planning/regulating authority when a situation arises that exerts an impact on the present and future environment [27].

#### 2.4. Japan

In Japan, technologies are being developed for the practical application of coal ash recycling in diverse areas, including evaluating the conversion of coal ash into useful material and developing construction methods using such material. Japan is also focused on ensuring the quality and environmental stability of a reliable coal ash supply to improve recycling efficiency.

A variety of quality evaluation and management methods have been established. For example, for construction applications, quality responsibilities are clearly delineated into three areas: the original coal ash, the coal ash product, and the construction usage. Each source (i.e., power plants) independently carries out a quality assurance process for ash provided to construction projects, consultations are carried out prior to the start of construction, and technical guidance is provided during construction.

Coal ash environmental safety criteria are independently managed based on the Environmental Standards of Soil Pollution, the strictest standards in Japan. Coal ash is applied to public construction projects only when the leachate from hardeners such as concrete and processed products has been confirmed to satisfy the standard values. For low-strength ameliorated soil, where coal ash is mixed with soil, only coal ash without any leachate concerns is selected for use to ensure safety. For use in ameliorated soil in public construction projects, a public institute carries out leaching tests to verify safety. For example, Shikoku Electric Power carries out a two-step leaching test to ensure coal ash safety by conducting leaching tests on (1) the original coal ash and (2) the product incorporating the coal ash. The environmental safety responsibilities are distributed among the producer, the intermediate contractors, and the final user [28].

A substantial proportion of Japanese coal ash recycling occurs through coastal development projects including embankments, beachfront parks, river banks, beach mounding, breakwater foundations, revetments and quays, ground reinforcements, and land development. As such applications imply direct contact with sea water, the concerns regarding environmental stability are inevitably greater.

When coal ash mixtures are used in civil works and road construction, where they are differentiated from the surrounding soil, they are excluded from soil pollution laws, and soil environmental standards do not apply. As a result, to ensure a separate and appropriate environmental safety standard, regulations were established based on basic ideas on environmental safety quality and test methods for circulated materials. Tests are performed in two steps: mixture test and environmental safety model inspection and construction and environmental safety level test [29]. The criteria for environmental safety stipulate that the environmental catalyst surrounding the area where coal ash mixture is used must satisfy environmental standards. Whether a leaching test should be carried out and the method used depend on the micropollutant leachate path. Test selection is based on the potential application of the Soil Pollution Plans Act and the probability of direct ingestion.

Japanese environmental safety standards differ between general applications (identical to Soil Pollution Plans Act regulations) and port applications (which have been altered). As port facilities are semi-permanent, their monitoring period is different, and the environmental standard reference values for coal ash mixtures used in this context are less stringent than for general applications (Table 7). As the contribution of coal ash to elevated levels of various substances leaching into sea water in port facilities has been shown to be negligible, reference values in this setting have been set as three or more times the typical soil pollution standards. Standards for fluorine and boron, which have higher background concentrations in sea water, are 20 times the typical value.



Sampling involves collecting the coal ash mixture used in the investigated area in a sufficient amount to allow for retesting if necessary. Environmental safety inspections are carried out once prior to construction, but additional investigations may occur within the same site if (1) there is a possibility of increasing micropollutants due to significant changes in the quality of coal ash being supplied as the source for the coal ash mixture, (2) there has been a change in the facilities or processes producing the coal ash mixture, or (3) the mixing conditions are new. However, if such changes involve only the mix ratio between coal ash and other materials, additional investigations may be omitted.

**Table 7.** Coal ash leachate standards for general and port applications in Japan [29].

Parameter	General Applications (mg/L)	Port Applications (mg/L)	Contents (mg/kg)
Cd	0.003	0.009	150
Pb	0.01	0.03	150
Cr <sup>6+</sup>	0.05	0.15	250
As	0.01	0.03	150
Ag	0.0005	0.0015	15
Se	0.01	0.03	150
F	0.8	15	4000
B	≤1	20	4000

## 2.5. Republic of Korea

In South Korea, coal ash is defined as a specified byproduct based on the Act on the Promotion of Saving and Recycling of Resources. This refers to any byproduct that specially requires the recycling of the whole or a part of the substance for efficient use. Coal ash recycling methods follow the Waste Control Act and the Act on the Promotion of Saving and Recycling of Resources, while specific recycling and construction methods are defined by the Ministry of Environment's Guidelines on the Recycling of Steel Slag and Coal Ash by the Discharging Entity [30].

The latter rule stipulates that coal ash recycling may only be applied in the following 15 uses: in concrete admixture such as ready-mixed concrete; as a source of cement; as a lightweight aggregate; as a secondary product source for cement; as an aggregate for mounding or molding or roads; as a source of wood adhesive; as an alternative source for manufacturing cement clinker; as an aggregate for a drainage layer; as a source for ceramics production; as a fill material for rubber and plastic; as a source for paint, abrasives, or insulators; as a source for iron and steel manufacturing (metal recovery); and as a source of upper soil fertilizer (only as a floor material). In order for coal ash to be used as a fill material for mine reclamation, this regulation must be expanded.

Recycling beyond the defined uses is provisionally allowed by the Recycling Environmental Assessment so as to promote waste recycling [31]. This may be useful in the environmental assessment of general waste recycling, but in the case of applications to specific fields, such as mine reclamation and large waste quantities, tests for total pollutant amounts or long-term environmental impacts are limited. Moreover, this procedure includes many general environmental assessments that consider neither the purpose of recycling nor the characteristics of the relevant area while testing for unnecessary aspects. The criteria for environmental assessment are also ambiguous, as the properties of media and their purpose for use are not clearly stated, although the criteria are based on the process test standards for soil pollutants, the leachate test standards for upflow permeability, the process test standards for waste, and common global test standards. In order to properly assess the actual use of complex carbonates sourced from coal ash as fill material for mine reclamation in South Korea, far more specific methods of environmental management should be developed.

### 3. Discussion

The environmental management of coal ash recycling varies by country. In the US, where regulations and use vary by state, Pennsylvania actively pursues coal ash recycling and uses it as mine fill with regulations based on coal ash bulk concentration, coal ash leachate concentration, field inspection, and water quality monitoring. In Europe, there is a general effort to use waste proactively as long as it does not have any negative influence on the environment and human health while conforming to environmental certifications and general environmental regulations. In the UK, efforts are taken to use waste proactively through various projects based on the substances produced, relying on QP and water quality monitoring. In Australia, similar to the US, each state has its own management regulations. Queensland defines coal ash bulk concentration as the management focus, whereas New South Wales focuses on both this and leachate concentration. In terms of water quality monitoring, both states primarily consider the Australian and New Zealand Guidelines for Fresh and Marine Water Quality but each state has individual EV standards and follow them. Japan promotes coal ash recycling in diverse areas, clearly distinguishing between coal ash itself, coal ash products, and construction applications. The coal ash environmental safety criteria in Japan are independently managed and based on the Environmental Standards of Soil Pollution—the strictest standards in Japan.

In South Korea, current regulations regarding the purpose of coal ash recycling do not specify its use as fill material in mine reclamation, preventing its use for that purpose. As part of efforts to expand the scope of waste recycling, the Recycling Environmental Assessment provisionally allows coal ash use but allows only two categories—media-contact type and non-media-contact type—making it difficult to carry out purpose-driven environmental assessments and thus placing a limitation on the use of coal ash. To overcome this limitation and to simultaneously assess and verify the environmental stability of complex carbonates, new environmental management methods should be developed for this application.

We compared the coal ash leachate standards that permit its use in mine reclamation in each country (Table 8) and the related water quality monitoring standards (Table 9). Although environmental assessment standards cannot be standardized, as each country uses distinct approaches reflecting their regional characteristics and environments, there are currently no relevant regulations in South Korea. Therefore, we propose the adoption of the strictest standards. Moreover, each step of the environmental management strategy, from the generation of coal ash in the future and the production of complex carbonates to the construction and use of coal ash as a filler material in abandoned mines and the respective monitoring, must be discussed.

**Table 8.** The coal ash leachate standards of the countries.

Parameter (mg/kg)	US (Pennsylvania)	Australia (New South Wales)	Japan	South Korea	EPA-TCLP Hazardous Waste Limit	Environmental Management Proposal (SPLP)
Al	5	*	*	*	*	5
As	0.25	0.5	0.01	1.5	5	0.25
B	50	*	*	*	*	50
Ba	15	10	≤1	*	100	10
Be	0.1	*	*	*	*	0.1
Cd	0.125	0.05	0.003	0.3	1	0.05
CN	*	*	*	1	*	1
Cr	2.5	*	*	*	5	2.5
Cr+6	*	*	0.05	1.5	*	*
Cu	25	10	*	3	*	25

\* Not defined.

Table 8. Cont.

Fe	7.5	*	*	*	*	7.5
Hg	0.05	0.01	0.0005	0.005	0.2	0.01
Mn	2.5	*	*	*	*	2.5
Pb	0.375	0.5	0.01	3	5	0.375
Se	*	0.1	*	*	1	0.1
Tl	0.05	*	*	*	*	0.05
Zn	50	50	*	*	*	50

\* Not defined.

Table 9. Water quality monitoring criteria of the countries.

Parameter (mg/L)	US Pennsylvania (Drinking Water)	UK (Drinking Water)	South Korea (Drinking Water)	South Korea (Groundwater)	Environmental Management Proposal
Al	*	*	0.2	*	0.2
As	0.01	0.01	0.01	0.05	0.01
B	*	*	1	*	1
Ba	2	*	*	*	2
Be	0.004	*	*	*	0.004
Cd	0.005	0.005	0.005	0.01	0.005
CN	*	0.05	0.01	0.01	0.05
Cr	0.1	0.05	0.05	*	0.05
Cr+6	*	*	*	0.05	
Cu	1.3	*	*	*	1.3
F	4	1.5	1.5	*	1.5
Fe	*	*	0.3	*	0.3
Hg	0.002	0.001	0.001	0.001	0.001
Mn	*	*	0.3	*	0.3
Pb	0.015	0.01	0.01	0.1	0.01
Se	0.05	0.01	0.01	*	0.01
Tl	0.002	*	*	*	0.002
Zn	*	*	3	*	3

\* Not defined.

#### 4. Conclusions

A national project in South Korea is being pursued to develop the use of complex carbonates to capture CO<sub>2</sub> in coal ash, thus capturing carbon emissions and allowing for the large-scale recycling of coal ash. One intended approach is to use complex carbonates as fill material in mine reclamation, but environmental concerns, such as the environmental safety of coal ash, have thus far prevented their use for this purpose in South Korea.

In several other countries, coal ash—the main raw material for compound carbonate—is used as a mine filling material, and suitable environmental management has been implemented. We examined environmental regulations and guidelines on the use of recycled coal ash in other countries to assess its potential application as a fill material in mine reclamation in South Korea. Each studied country was proactively using coal ash for beneficial uses under locally suitable conditions. The environmental assessment standards cannot be standardized, as each country uses distinct approaches reflecting their regional characteristics and environments. Thus, we propose managing each step under the strictest conditions.

This study analyzed the regulations and policies needed to utilize complex carbonate as mine filler. In the future, it will be studied as well as environmental assessment verification based on experimental data and economic assessments. Our findings, which are based on case studies of other countries, can guide the future of coal ash use in South Korea in a safe and wise manner that will overcome opposition to its use based on incorrect presumptions of negative impacts and unnecessary restrictions. Hopefully, the safe use of complex carbonates will contribute to climate change mitigation and help create a sustainable society through recycling resources.

**Author Contributions:** conceptualization, H.-y.S., S.-w.J., and H.J.; investigation, H.C. and H.J.; writing—original draft preparation, H.C.; writing—review and editing, H.J.; funding acquisition, S.-w.J.

**Funding:** This study was conducted by Korea Environment Institute on “A study on the assessment and verification of environmental safety about abandoned mine filler (2018)”. This study was funded by the Ministry of Science and ICT, Ministry of Environment, Ministry of Trade, Industry and Energy, and the National Strategy Project for the National Research Foundation of Korea—Carbon Upcycling (NRF-2017M3D8A2085336).

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Izquierdo, M.; Querol, X. Leaching behaviour of elements from coal combustion fly ash: An overview. *Int. J. Coal Geol.* **2012**, *94*, 54–66. [CrossRef]
2. Coal Ash Recycling Reached Record 56 Percent Amid Shifting Production and Use Patterns. American Coal Ash Association (ACAA), 2017. Available online: <https://www.aaa-usa.org/Portals/9/Files/PDFs/News-Release-Coal-Ash-Production-and-Use-2016.pdf> (accessed on 22 April 2019).
3. Yao, Z.T.; Ji, X.S.; Sarker, P.K.; Tang, J.H.; Ge, L.Q.; Xia, M.S.; Xi, Y.Q. A comprehensive review on the applications of coal fly ash. *Earth Sci. Rev.* **2015**, *141*, 105–121. [CrossRef]
4. *Study on the CO<sub>2</sub>/Environmental Monitoring Standardization*; Korea Institute of Geoscience and Mineral Resources (KIGAM): Daejeon, Korea, 2018; p. 104.
5. Praharaj, T.; Powell, M.A.; Hart, B.R.; Tripathy, S. Leachability of elements from sub-bituminous coal fly ash from India. *Environ. Int.* **2002**, *27*, 609–615. [CrossRef]
6. 40 CFR 257, U.S. Government Publishing Office. Available online: <https://www.govinfo.gov/app/details/CFR-2011-title40-vol25/CFR-2011-title40-vol25-part257> (accessed on 22 April 2019).
7. 40 CFR 261, U.S. Government Publishing Office. Available online: <https://www.govinfo.gov/app/details/CFR-2012-title40-vol27/CFR-2012-title40-vol27-part261> (accessed on 22 April 2019).
8. Surface Control and Reclamation Act (SMCRA). U.S. Department of the Interior. Available online: <https://www.osmre.gov/lrg.shtm> (accessed on 22 April 2019).
9. Guidelines for Beneficial Use of Coal Ash at Coal Mines. Pennsylvania Department of Environmental Protection, 2016. Available online: <http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=7891&DocName=GUIDELINES%20FOR%20BENEFICIAL%20USE%20OF%20COAL%20ASH%20AT%20COAL%20MINES.PDF%20> (accessed on 22 April 2019).
10. Beneficial Use of Coal Ash. Pennsylvania Code, Chapter 290. Available online: <https://www.pacode.com/secure/data/025/chapter290/chap290toc.html> (accessed on 22 April 2019).
11. *Coal Ash Monitoring Parameters and Certification Standards*; Pennsylvania Department of Environmental Protection: Harrisburg, PA, USA, 2017.
12. Feuerborn, H.J. Coal combustion products in Europe—An update on production and utilisation, standardisation and regulation. In Proceedings of the World of Coal Ash Conference, Denver, CO, USA, 9–12 May 2011.
13. Waste Framework Directive (2008/98/EC). European Commission. Available online: <http://ec.europa.eu/environment/waste/framework/> (accessed on 22 April 2019).
14. End of Waste Criteria. Joint Research Centre of the European Commission. Available online: <http://susproc.jrc.ec.europa.eu/activities/waste/index.html> (accessed on 22 April 2019).
15. Quality Protocols: Converting Waste into Non-Waste Products. U.K. Government. Available online: <https://www.gov.uk/government/collections/quality-protocols-end-of-waste-frameworks-for-waste-derived-products> (accessed on 22 April 2019).

16. Waste Protocols Project. U.K. Environment Agency. Available online: [https://uk.practicallaw.thomsonreuters.com/3-503-1368?transitionType=Default&contextData=\(sc.Default\)&firstPage=true&comp=pluk&bhcp=1](https://uk.practicallaw.thomsonreuters.com/3-503-1368?transitionType=Default&contextData=(sc.Default)&firstPage=true&comp=pluk&bhcp=1) (accessed on 22 April 2019).
17. EQual: Ensuring Quality of Waste-Derived Products to Achieve Resource Efficiency. U.K. Government. Available online: <https://www.gov.uk/government/groups/equal-ensuring-quality-of-waste-derived-products-to-achieve-resource-efficiency> (accessed on 22 April 2019).
18. *Stabilising Mine Workings with Pfa Grouts: Environmental Code of Practice*; BRE Construction Division: Newcastle, UK, 2006; ISBN 1-86081-909-5.
19. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian Government. Available online: <http://www.waterquality.gov.au/guidelines/anz-fresh-marine> (accessed on 22 April 2019).
20. Waste Legislation. Queensland, Australia Government. Available online: <https://www.qld.gov.au/environment/pollution/management/waste/recovery/legislation> (accessed on 22 April 2019).
21. End of Waste (EOW) Framework. Queensland, Australia Government. Available online: <https://environment.des.qld.gov.au/waste/end-of-waste-framework.html> (accessed on 22 April 2019).
22. *End of Waste Code, Coal Combustion Products (ENEW07359717)*; Department of Environment and Science: Queensland, Australia, 2019. Available online: <https://environment.des.qld.gov.au/assets/documents/regulation/wr-eowc-approved-coal-combustion-products.pdf> (accessed on 22 April, 2019).
23. Water Quality Guidelines. Queensland Government. Available online: [https://environment.des.qld.gov.au/water/guidelines/#document\\_availability](https://environment.des.qld.gov.au/water/guidelines/#document_availability) (accessed on 22 April 2019).
24. Shen, B.; Poulsen, B.; Luo, X.; Qin, J.; Thiruvencatachari, R.; Duan, Y. Remediation and monitoring of abandoned mines. *Int. J. Min. Sci. Technol.* **2017**, *27*, 803–811. [[CrossRef](#)]
25. *CCP Environment Monitoring Program 2007/8*; Ash Development Association of Australia (ADAA): Port Kembla NSW, Australia, 2007; Available online: [http://www.adaa.asn.au/uploads/default/files/adaa\\_emp\\_2007.pdf](http://www.adaa.asn.au/uploads/default/files/adaa_emp_2007.pdf) (accessed on 22 April 2019).
26. *Resource Recovery Exemption Under Part 9, Clauses 91 and 92 of the Protection of the Environment Operations (Waste) Regulation 2014*; New South Wales EPA: Sydney NSW, Australia, 2014. Available online: <https://www.epa.nsw.gov.au/-/media/3F3155BCFE174DBB9201025C7CE4964A.ashx?la=en> (accessed on 22 April 2019).
27. Water Quality. New South Wales Office of Environment & Heritage. Available online: <https://www.environment.nsw.gov.au/water/waterqual.htm> (accessed on 22 April 2019).
28. *Effective Utilization of Coal Ash*; Japan Society of Civil Engineers: Tokyo, Japan, 2003. (In Japanese)
29. Kojima. Challenges and regulation for international trade in recyclable waste. *Econ. Stud.* **2014**, *63*, 71–84. (In Japanese)
30. *Guidelines of Application of Steel Slag and Coal Combustion Products (CCPs)*; Korea Ministry of Environment: Sejong, Korea, 2016. (In Korean)
31. *Regulations on the Procedures and Methods for the Evaluation of Recycling Environment*; Korea Ministry of Environment: Sejong, Korea, 2016. (In Korean)



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