sustainability

MDPI

Article

Analysis of the Environmental and Economic Effect of the Co-Processing of Waste in the Cement Industry in Korea

Dowan Kim * and **Chaegun Phae**

Department of Environmental Engineering, Seoul National University of Science and Technology, Seoul 01811, Republic of Korea
* Correspondence: dowan2050@nate.com; Tel.: +82-10-6218-6617

Abstract: Recently, the amount of waste generated in Korea has been increasing, and there have been difficulties disposing of it. As an energy-intensive and raw-materials-oriented industry, the cement industry is facing challenges including overcoming the climate crisis and achieving carbon neutrality. Co-processing was suggested as a solution, but the environmental effects of this have not been specifically studied in Korea. In this study, the effects of using alternative resources (limestone, silica stone, iron ore, and gypsum) and fuel on greenhouse gas (GHG) emissions in the cement industry in Korea were analyzed. GHGs generated from mineral mining were compared to GHGs of alternative resources. The reduction in GHGs by using alternative fuel was calculated via the amount of heat from waste instead of that from bituminous coal. Co-processing can reduce approximately 106.9 kg of CO_2 in one ton of cement. The cost savings were estimated to be about USD 3815 million. In addition, the lifespans of landfills would be extended by 7.55 years.

Keywords: cement; co-processing; waste; greenhouse gas; alternative effect

check for updates

Citation: Kim, D.; Phae, C. Analysis of the Environmental and Economic Effect of the Co-Processing of Waste in the Cement Industry in Korea. *Sustainability* **2022**, *14*, 15820. https://doi.org/10.3390/su142315820

Academic Editor: Shervin Hashemi

Received: 4 September 2022
Accepted: 21 November 2022
Published: 28 November 2022

1. Introduction

With industries growing rapidly and various improvements in people's quality of life, the total amount of waste generated in Korea is also increasing [1]. However, it is difficult to increase the capacity of waste treatment facilities [2,3].

According to Korea Energy Agency, the energy consumption of the domestic cement industry in 2019 was 4.4 million toe, an increase of 4.4% compared to the level in 2018, and the more than 50% of the energy consumption was from coal (bituminous coal).

A treatment called "co-processing" (the use of waste as an alternative raw material) in the cement industry can replace natural materials or energy sources [4,5]. Additionally, this method has been proven to be a sustainable waste management method in that it does not generate secondary waste, reduces GHGs, and is operated stably at high temperatures [6–9]. The EU cement industry already substitutes 43% of its fossil fuels with alternative fuels derived from waste and biomass to supply thermal energy in clinker-making processes.

However, in Korea, there have been no studies on the contribution of co-processing to the cement industry. For this reason, more focus is being placed on emissions from dioxins, carbon monoxide, and heavy metals, which can be easily measured, rather than the positive effects of co-processing. As a result, the government is having difficulties making policy decisions about the expansion of co-processing.

Wastes can be used as fuel and as raw materials in the cement industry. Most are inorganic substances that can be sent to landfills, with fly ash accounting for 39.3% and inorganic sludge accounting for 19.6%. In addition, waste synthetic resin accounts for the largest amount of fuel, 12.6% (Table 1).

Coal ash and inorganic sludge contain chemical components (e.g., SiO_2, Al_2O_3) that are necessary for the manufacturing of cement; using coal ash as a raw material for cement is encouraged in situations in which landfilling is more difficult. Many countries manufacture cement from coal ash, enabling sustainable cement production [10].

Table 1. The amounts of wastes in co-processing in the cement industry in Korea (2019).

Category			Ton/Year	%
Resource	Fly ash	Domestic	2,227,312	39.3
		Import	951,729	
	Sludge	Organic	727,435	9.0
		Inorganic	1,587,714	19.6
	Slag		245,742	3.0
	Dust		25,515	0.3
	Catalyst		13,420	0.2
	Gypsum and lime		108,608	1.3
	Ash		16,232	0.2
	Adsorbent		9076	0.1
	Soil		148,167	1.8
	Metal		-	-
	Foundry and sandblast		606,047	7.5
	Glass		23,764	0.3
	Ceramics		-	-
Fuel	Tire	Domestic	170,905	2.1
		Import	103,787	1.3
	Synthetic resin		1,015,799	12.6
	Rubber		75,931	0.9
	Wood		35,449	0.4
	Other		5	0.0
Total			8,092,643	100.0

A large amount of energy is required for cement curing. Municipal solid waste is a viable choice to replace a portion of fossil fuel use [11]. Therefore, the energy requirement can be economically met by waste synthetic resin.

Korea's cement production is 50,635,456 tons (19). The amount of waste used as an alternative resource and fuel in the cement industry amounted to 8,092,643 tons in 2019. Considering that the annual amount of waste is about 181,491,870 tons/year, the corresponding amounts recycled in the cement industry are 4.5% and 5.2% of the total amount of waste recycling. This is similar to other treatment methods, such as incineration or landfills, considering that 5.2% of waste is incinerated and landfills account for 6.1% of the nation's waste.

In this study, the effects of co-processing in the cement industry in Korea were analyzed in terms of the levels of reduction in raw materials and fuels, coal mining, GHG emissions, factor emissions, and installation costs for incineration and landfill facilities. This study is unique in that it identifies the effect of substituting natural resources and reducing the GHG emissions factor in coal mining based on the status of the cement industry in Korea.

2. Method

2.1. Analysis of Alternative Effects of Resources

The status of co-processing was determined using statistical data from the Korea Cement Association (KCA). Alternative effects were analyzed in terms of environmental aspects. Regarding the environmental aspects, the reduced use of natural resources and the contribution towards carbon neutrality via the reduction in GHG emissions were evaluated.

To calculate the effect of co-processing in the cement industry, it is necessary to examine the amounts that can be saved by recycling. To this end, the effects of alternative natural minerals and fossil fuels were analyzed. The amounts that can be reduced by recycling natural resources, such as limestone, clay, and siliceous raw materials, which are currently used in the process of manufacturing cement, were calculated [12].

In terms of economics, the reduced social costs of disposal due to the recycling of waste and the reduced import costs of bituminous coal were evaluated. Wastes can be used as fuel and as raw materials in the cement industry.

Firstly, the amounts of natural resources that can be reduced by recycling, such as limestone, clay, and siliceous raw materials, were calculated. This was based on the amount of limestone used and the ratio of raw materials required for cement production.

The GHG emissions factor was applied as clay (276.7 kg CO_2/t-prod), silica (12.3 kg CO_2/t-prod) [13,14], iron ore (35.4 kg CO_2/t-prod), and gypsum (100 kg CO_2/t-prod) [15,16]. The exchange rate is 1289.81 USD per 1 KRW. The calculation formulae are expressed here as Equations (1)–(3).

$$\begin{aligned} &GHG\ reduction \\ &= \sum_{i=1}^{n} (\text{alternative of Resource } x_i) \times (\text{emission GHG mining resource } x_i) \end{aligned} \tag{1}$$

The net calorific value of bituminous coal for fuel is 5660 kcal/kg, while it is 8170 kcal/kg for petroleum coke [17]. Calorific values (kcal/kg) were applied to data (average of 6 large cement companies) provided by the KCA. Bituminous coal consumption and the reduction effect of GHGs were calculated using Equations (3) and (4). The emission factor of bituminous coal was calculated by applying IPCC 06.

$$\begin{aligned} &Coal\ consumption\ reduction \\ &= \text{alternative fuel calorific value(kcal)} \div \text{ Coal calorific value (kcal/kg)} \end{aligned} \tag{2}$$

$$\begin{aligned} &Reduction\ effect\ of\ GHG \\ &= \text{Coal consumption reduction} \left(\frac{\text{tons}}{\text{year}}\right) \times \frac{2.44\text{t } CO_2}{\text{Bituminous coal} - \text{t}} \end{aligned} \tag{3}$$

2.2. Savings Associated with Waste Treatment Facility Installation and Operation Costs

Co-processing not only reduces the installation cost of the waste treatment facility (WTF), but it also reduces the costs of operating the WTF. The costs can differ depending on the operation method, but these factors must be considered as major contributions of co-processing. The operating cost was calculated by referring to the estimated regression equation derived in previous work [18]. The dummy variable index was excluded from the review process because it is difficult to calculate this separately, as it is related to incidental costs and profits and includes such processes as incineration heat recovery, power generation, and leachate treatment. The estimation formulae used to calculate the operating cost are expressed as Equations (4) and (5).

The Ministry of the Environment (MOE) has set a standard installation cost unit. For the incineration facility, the operation rate was set to 85% (310 days out of 365 days). The cost per unit for installation applied here was KRW 381 million/ton, and the lifetime of the incineration facility was 20 years.

$$\begin{aligned} &\text{The operating cost of incineration} \\ &= \ln(\text{Co}) = 3.349 + 0.656 \ln(\text{Q}) + 0.416 \ln(\text{Cu}) - 0.181\text{D} \end{aligned} \tag{4}$$

Co: Operating cost (million KRW),
Q: Facility capacity (ton/day),
Cu: Operation rate (1% = 1),
D: Dummy variable

$$\begin{aligned} &\text{The operating cost of the landfill site} \\ &= \ln(\text{Co}) = -0.238 + 0.3056 \ln(\text{Al}) + 0.321 \ln(\text{A}) + 0.384\text{D} \end{aligned} \tag{5}$$

Co = e(ln (Co))
Co: operating cost (million KRW),
Al: annual landfill (m^3/year),
A: landfill area (m^2)
D: Dummy variable

2.3. Effect of Extending the Life of the Landfill

It is not recommended to extend the lifespan of landfills currently in operation as much as possible due to the limited lifetimes of existing landfill sites and the difficulties installing new landfill sites. The cement industry can expand the lifespan of landfill facilities by treating large amounts of waste.

An estimation of the effect of expanding the life of landfills was conducted by calculating the remaining landfill capacity and annual landfill volume of current landfills. To estimate the lifespan extension of landfills, the remaining landfill capacities and annual landfill volumes of current landfills were calculated and investigated. The life extension effect of co-processing was also calculated using Equation (6), assuming that the load on each landfill site was reduced by the capacity calculated when applying the density and ash amount for each type of waste created in the cement industry.

$$\begin{aligned} &Extending\ life\ of\ landfill \\ &= \frac{\text{Residual capacity of industrial waste landfill facility}}{① + ②} \end{aligned} \tag{6}$$

① $the\ Amount\ of\ Annual\ industrial\ waste\ landfill$
② $the\ Amount\ of\ waste\ that\ must\ be\ brought\ to\ landfill,\ if\ it\ is\ not\ treated\ by\ co-processing$

3. Results

3.1. GHG Reduction Effects of Alternative Resources

Table 2 shows the amount of GHG emissions, the amount of alternative resources due to waste recycling in the cement industry, and the amount of GHG emissions generated in the process of mining resources. Additionally, it was found that annual emissions were reduced by 304,945 tons of CO_2 per year, with 130 kg saved per ton of cement and a reduction in GHGs of 31.1 kg CO_2. This amount is only 4~6% of the GHG emission factor, which is currently 510 to 712 kg CO_2/ton of cement of the entire cement industry [19]. However, it can be seen that there is a carbon-neutral effect, even reducing raw materials. In addition, since Korea has mined all of its limestone, it is omitted from this calculation. If lime can be obtained from waste, more greenhouse gases can potentially be reduced.

Table 2. Alternative resource effect via co-processing.

Category	Alternative (Ton/Year)	Emission of GHG during Mining ($kgCO_2$/Ton)	GHG Reduction ($kgCO_2$/Year)
Limestone	-	-	-
Clay	5,706,601	276.7	1,579,016,497
Silica	629,811	12.3	7,746,675
Iron	245,742	35.4	8,699,267
Gypsum	108,608	100.0	10,860,800
Total	6,690,762	-	1,606,323,239
GHG reduction effect by one ton of cement ($kgCO_2$/ton cement)	-	-	31.7

3.2. GHG Reduction Effects of Alternative Fuel

The use of alternative fuels in the cement industry amounts to 1,998,379 tons/year, which has the effect of replacing approximately 24% of the total calories (Table 3). We can compare this figure to that of Germany, which replaces 68.9% of its energy with waste [11], a level that amounts to a third of its total. Co-processing can save about 62.3 million USD/year based on the import price of bituminous coal. The amount of calories used is divided by the amount of bituminous coal, and the reduction in GHGs is 75.2 kg CO_2. The reduction effect in the GHG emissions is lower than that of 89 kg CO_2-equivalents per ton of cement [20]. However, the use of alternative fuels is limited because they usually contain impurities, such as chlorides, which, when present in sufficiently high concentrations, can affect the quality of Portland cement clinkers [21].

Table 3. Alternative fuel effect via co-processing.

Category		Consume (ton/year)	Calories (kcal/kg)	Total Calories (Gcal)
Fuel	Bituminous coal	3,702,000	5660	20,953,320
	Petroleum coke	858,000	8170	7,009,860
	Total (A)	4,560,000	-	27,963,180
Alternative Fuel	Textile	3.5	3000	11
	Tire	274,692	6073	1,668,070
	Synthetic resin	1,015,799	4500	4,571,097
	Rubber	75,931	4730	359,155
	Wood	35,449	3500	124,072
	Waste Derived Fuels	587,821	3500	2,057,372
	Solid Refuse Fuel	8683	6000	52,098
	Total (B)	1,998,379	-	8,831,874
Alternative calorie ratio (B/(A + B)) × 100				24%
Bituminous Coal Alternative Calorie (B ÷ 5660 kcal/kg × Gcal/10^6 kcal × 1000 kg/ton)				1,560,402 ton
GHG reduction effect by one ton of cement (kgCO_2/ton cement)				75.2

3.3. Waste Treatment Facility Installation and Operation Cost Savings

The effect of reducing the installation costs of landfills and incineration facilities by recycling waste was analyzed and is presented in Table 4. These values were calculated by considering recycling combustible waste in the cement industry. It was found that 1767.2 million USD can be saved in terms of the installation costs of incineration facilities to treat waste that is subject to incineration. The corresponding figure is 1.7 USD for the incineration facility installation costs per ton of cement.

Table 4. Incineration facility installation cost and savings by co-processing.

Category		Value	Note
Incineration target waste (ton/year)	Organic sludge	727,435	
	Textile	4	
	Synthetic resin	1,015,799	
	Rubber	75,931	
	Wood	35,449	
	Total	1,854,619	(A)
Required capacity for incineration (ton/day)		5983	(B) = (A) ÷ Operating day (310 day)
Installation costs (million USD/year)		1767.2	(C) = (B) × 3.81 (100 million KRW/ton) × Exchange Rate
Incineration facility depreciation (million USD/year)		88.4	(D) = (C) ÷ 20 year
Savings of cement per ton (USD/year/ton)		1.7	(E) = (D)/Production of cement

Non-combustible and incineration ash generated after the incineration of combustible waste becomes a target material, and approximately 2046.8 million USD is saved out of the total installation cost of constructing a landfill for disposal, which is equivalent to 1.4 USD/ton of cement (Table 5). The operating cost of a landfill was calculated and found to be 42.1 million USD/year, and an operating cost of 8.4 million USD/year was found to be necessary.

Table 5. Landfill installation cost and savings via co-processing.

Category		Landfill Volume (m^3)	Note
Direct landfill waste (non-combustible waste)	Fly ash	1,484,875	Mixed waste for landfill
	Inorganic sludge	1,044,549	Industrial wastewater treatment sludge
	Ash	10,821	Mixed waste for landfill
	Adsorbent	11,345	Ion exchange resin
	Soil	92,604	Construction waste
	Foundry and sandblast	336,693	Foundry
	Glass	19,803	Glass
	Total (A)	3,000,690	
Post-Incineration landfill waste	Organic sludge	43,646	Mixed waste for landfill
	Textile	0	
	Synthetic resin	39,278	
	Rubber	1853	
	Wood	1394	
	Total (B)	86,171	
Total (C)		3,086,861	(A) + (B)
Installation cost (million USD/year)		2051.3	(C) × 22.2 USD/m^3 × 30 year
Landfill depreciation (million USD/year)		68.4	(D) ÷ 30 year
Savings of cement per ton (USD/year/ton)		1.4	(E) = (D)/Production of cement

According to the Japan Cement Association, the use of waste in the cement industry can extend the lifetimes of existing landfills by 5.3 years [22]. The amount of waste estimated to be disposed of in landfills is 3,644,089 m^3/day, which is equivalent to 89% of the annual landfill amount of 3,086,861 m^3/day [23]. As a result of this review, it was found that the lifespan of an industrial waste landfill facility that can be extended by treating waste in the cement industry is 7.55 years (Table 6). Therefore, the effect of extending the lifespan of landfills via co-processing is clear. If co-processing is not implemented, there is a high possibility this will create social problems due to the rapid increases in landfill volumes.

Table 6. Extending the lifespan of landfills for industrial waste via co-processing.

Category	Value	Note
Industrial waste reclamation facility (except public) Remaining landfill capacity (A)	59,969,819	m^3
Annual Industrial waste landfill (B)	3,644,089	m^3
Landfill life (C)	16.46	year, B/A
Amount of landfill if not brought in from the cement industry (D)	3,086,861	m^3
The remaining lifetime of landfill facility when the cement industry does not co-process waste (E)	8.91	year, A/(B + D)
Effect of extending (year)	7.55	C-E

4. Conclusions

Co-processing in the cement industry enables the calculation of benefits in the form of costs, specifically in terms of reductions in the installation and operation costs of waste treatment facilities as well as reductions in GHGs. Large amounts of remnants (waste and by-products) which are inevitably generated from national infrastructure facilities, such as those of the power generation industry and the steel industry, as well as those in social infrastructures, such as sewage treatment facilities and incinerators, can be stably and effectively recycled.

As the cement industry uses waste as an alternative resource and fuel, the alternative effect of each 31.7 kg CO_2/ton cement and 75.2 kg CO_2/ton cement, total GHG reduction per ton of cement is 106.9 kg CO_2.

The GHG reduction effect in the cement industry has been frequently analyzed, but the raw materials/fuel supply and demand conditions in Korea have not. This study analyzed the GHG reduction effect based on the current status of Korea's cement industry, which can be regarded as a substantial. In particular, while GHG reductions have only been calculated for the effects of fuel substitution, this study derived the effects of raw material substitution.

The cement industry of Korea is facing challenges including overcoming the climate crisis and achieving carbon neutrality, as an energy-intensive and raw-material-oriented industry. Co-processing in the cement industry reduces GHGs.

The cost savings were estimated to be about 3815 million USD. In addition, the strategy discussed here would extend the expiration dates of landfills at domestic industrial waste reclamation facilities by 7.55 years.

The cement industry can play an important role in recycling the waste that is inevitably generated, incinerated, and put into landfills. Kilns have many advantages compared to incineration, and it is possible for them to contribute to zero landfill use while also serving to economically and stably stabilize treatment costs via recycling. One problem is that it is necessary to increase the acceptance of residents by operating these facilities in an eco-friendly manner while minimizing secondary pollution in the process of bringing waste into the facility, running pre-treatment programs at the facility, and operating the heat treatment of kilns. To this end, it is necessary to closely manage imported waste to minimize the import of hazardous substances as well as to invest continuously in sealing facilities and upgrades to air pollution prevention facilities.

Author Contributions: Writing—original draft, D.K.; Writing—review & editing, C.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Korea Environmental Industry and Technology Institute (KEITI) as a funding from the Ministry of Environment in 2020.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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

References

1. Statistics Research Institute. *Korean Social Trend, 2020*; Statistics Research Institute: Daejeon, Korea, 2020; pp. 154–196.
2. Ahn, J.Y. *Mid-to Long-Term Development Plan to Secure the Stability of Waste Treatment Facilities*; Korea Environment Institute: Sejong, Korea, 2020.
3. Ministry of Environment. Available online: http://www.me.go.kr/home/web/board/read.do?boardMasterId=1&boardId=1419180&menuId=286 (accessed on 31 December 2021).
4. Baidya, R.; Ghosha, S.K.; Parlikar, U.V. Co-processing of industrial waste in cement kiln—A Robust system for material and energy recovery. *Procedia Environ. Sci.* **2016**, *31*, 309–317. [CrossRef]
5. UNEP. *Technical Guidelines on the Environmentally Sound Co-Processing of Hazardous Wastes in Cement Kilns Basel Convention*; UNEP: Nairobi, Kenya, 2011.
6. Hasanbeigi, A.; Lu, H.; Price, L.; Williams, C. *International Best Practices for Pre-Processing and Co-Processing Municipal Solid Waste and Sewage Sludge in the Cement Industry*; Ernest Orlando Lawrence Berkeley National Laboratory: Berkeley, CA, USA, 2012.
7. Kleshchov, A.; Hengevoss, D.; Terentiev, O.; Hugi, C.; Safiants, A.; Vorfolomeiev, A. Environmental potential analysis of co-processing waste in cement kilns. *Eastern-Eur. J. Enterp. Technol.* **2019**, *4*, 13–21. [CrossRef]
8. Hirose, S. Waste Management Technologies in Japanese Cement Industry- from Manufacturing to Ecofactuaring TM. *J. Water Environ. Technol.* **2004**, *2*, 31–36. [CrossRef]
9. Khan, M.M.H.; Havukainen, J.; Horttanainen, M. Impact of utilizing solid recovered fuel on the global warming potential of cement production and waste management system: A life cycle assessment approach. *Waste Manag. Res. J. A Sustain. Circ. Econ.* **2021**, *39*, 561–572. [CrossRef] [PubMed]
10. Usón, A.A.; López-Sabirón, A.M.; Ferreira, G.; Sastresa, E.L. Uses of alternative fuels and raw materials in the cement industry as sustainable waste management options. *Renew. Sustain. Energy Rev.* **2013**, *23*, 242–260. [CrossRef]

11. VDZ. *Umweltdaten der deutschen Zementindustrie Environmental Data of the German Cement Industry*; VDZ: Düsseldorf, Germany, 2020.
12. Yamaguchi, N.; Kawai, K.; Osako, M.; Matsuto, T. Resource Substitution and LCCO2 Evaluation by Material Flow Analysis of Incinerator Residue Recycling at a Centralized Reductive Melting Facility. *J. Jpn. Soc. Mater. Cycles Waste Manag.* **2018**, *29*, 191–205.
13. *Emission Factor Documentation for AP-42 Section 11.25 Clay Processing Final Report for U. S. Environmental Protection Agency Office of Air Quality Planning and Standards Emission Inventory Branch*; EPA Contract 68-D2-0159 Work Assignment No. I-01 MRI Project No. 4601-01; Office of Air and Radiation (OAR) | US EPA: Washington, DC, USA, 1994.
14. *Emission Factor Documentation for AP-42 Section 11.19.1 Sand and Gravel Processing Final Report for U. S. Environmental Protection Agency Office of Air Quality Planning and Standards Emission Factor and Inventory Group*; EPA Contract 68-D2-0159 Work Assignment No. II-01 MRI Project No. 4602-01; Office of Air and Radiation (OAR) | US EPA: Washington, DC, USA, 1995.
15. The European Commission. Available online: https://climate.ec.europa.eu/system/files/2016-11/bm_study-iron_ore_en.pdf (accessed on 7 May 2021).
16. The European Commission. Available online: https://climate.ec.europa.eu/system/files/2016-11/bm_study-gypsum_en.pdf (accessed on 7 May 2021).
17. Notification on the Quality Labeling Method and Quality Class Classification of Solid Refused Fuel. Available online: https://www.law.go.kr/LSW/admRulLsInfoP.do?admRulSeq=2100000194074 (accessed on 1 February 2021).
18. Choi, S.W.; Kim, J.H. A Study on the Operating Cost Prediction of Incineration Plant and Landfill Facility Using MultI-Regression Analysis. *J. Korea Soc. Waste Manag.* **2018**, *35*, 341–347. [CrossRef]
19. Kajaste, R.; Hurme, M. Cement industry greenhouse gas emissions—Management options and abatement cost. *J. Clean. Prod.* **2016**, *112*, 4041–4052. [CrossRef]
20. Boesch, M.E.; Hellweg, S. Life Cycle Assessment of Waste Co-Processing in Chinese Cement Production. In *Chemical, Biological and Environmental Engineering*; World Scientific: Singapore, 2010; pp. 254–257.
21. Van den Heede, P.; De Belie, N. Environmental impact and life cycle assessment (LCA) of traditional and 'green' concretes: Literature review and theoretical calculations. *Cem. Concr. Compos.* **2012**, *34*, 431–442. [CrossRef]
22. Japan Cement Association. Available online: www.jcassoc.or.jp/cement/2eng/e_01d.html (accessed on 10 May 2021).
23. Ministry of Environment. *National Waste Generation and Disposal Status*; Ministry of Environment: Sejong City, Korea, 2020.