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Characterization of Industrial Hazardous Waste Generation in South Korea using Input-Output Approach

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Abstract: The industrial hazardous waste (IHW) regulation has been highlighted by the Basel Convention, and the South Korean government has announced a plan for the great transition to resource circulation in 2020 to strengthen waste management. Accordingly, South Korea is faced with the challenge of efficiently managing IHW at the national level. For this, research to understand national IHW generation characteristics considering economic activities should be prioritized, but there have been few studies on this. As a first try, this paper aimed to compile the waste extended input-output table for IHW in South Korea for a systematic evaluation of waste generation from the supply and demand perspectives across all economic sectors. This study developed the waste extended input-output table using the 2018 monetary input-output table and industrial sectorial IHW generation. From a supply perspective, considering direct and indirect generation, ‘Electronic and electrical equipment’, ‘Chemical’, and ‘Basic metals’ industries were identified as the top three key sectors in direct IHW generation, with the contribution to more than half of the total amount. Meanwhile, from a demand perspective, considering domestic consumption, investment and exports, domestic consumption contributed more than 48% to the IHW generation. In comparison, net exports contributed about 15%, despite the total output from net exports being only about 6%, implying that scientific regulations and improvements in IHW management from the demand perspective are also required. The results provide insightful policy recommendations for establishing IHW management

30 reflecting the characteristics of industrial waste generation in the national economic system.

31

32 **Keywords:** Industrial hazardous waste; Waste generation; Waste extended input-output analysis;
33 Resource circulation; South Korea

34

35 **Abbreviations**

EEIO	Environmentally-Extended Input-Output
IHW	Industrial Hazardous Waste
IOA	Input-Output Analysis
IOT	Input-Output Table
MOE	Ministry of Environment
WEIO	Waste Extended Input-Output

36

37 **1. Introduction**

38 Waste generation is increasing at a similar rate to economic growth, and it is urgent to reduce the
39 environmental load because it leads to environmental, social, and health problems (Moradi Hanifi et
40 al., 2019; Ojha, 2020; Soliman and Moustafa, 2020). To manage waste generation, which is one of the
41 important environmental loads, various national waste management policies are being implemented
42 worldwide. In line with this, the Basel Convention was adopted to prevent the movement of industrial
43 hazardous wastes (IHW) between countries to protect the environment of the less developed countries
44 that do not have sufficient IHW treatment and management capabilities, and to minimize the
45 production of IHW (Khan, 2020; Liang et al., 2021; Rummel-Bulska and Basavaraj-Schroth, 1994). It
46 means that the world faces a significant challenge in transitioning to a circular economy through
47 efficient IHW management within their own countries.

48 To strengthen waste management, South Korea announced a plan for the great transition to

49 resource circulation in 2020 (MOE, 2020). A consensus exists on the vital role of waste and resource
50 management in achieving the transition from a linear economic model to a circular one. The value of
51 materials and resources is maintained in the supply chain. This plan includes policies in all waste
52 fields and sets the primary goal of reducing waste generated during the industrial production stage. As
53 the first step in this challenge, understanding the qualitative and quantitative characteristics of IHW
54 generation by all industrial sectors is necessary to design a rational policy related to waste and
55 resources in detail.

56 To address environmental issues closely related to industrial activities in the economic system, it
57 is necessary to adopt a methodology that simultaneously considers production and consumption
58 activities across all economic sectors. There are many matured methods in the industrial ecology
59 toolbox that meet these needs to track environmental loads and resource flows within the economy,
60 e.g., input-output analysis (IOA), material flow analysis, and life cycle assessment (Camana et al.,
61 2021; Jin et al., 2021; L. Liu et al., 2021; Malik et al., 2021; Ng and Phan, 2021; Omolayo et al., 2021).
62 IOA is a methodology that tracks the financial transaction, understands the interaction between
63 industrial sectors, producers, and consumers within an economy, and simultaneously considers
64 environmental loads by inter-industry transaction activities. Unlike LCA and MFA, where the process
65 can be limited and analyzed due to truncation errors on the system boundaries, IOA aggregates and
66 analyzes data within a relatively wide range of economic boundaries, consuming less time for data
67 collection. Also, using IOA, objective analysis is possible for more complex processes than LCA and
68 MFA (Fang et al., 2021; Gao et al., 2022; Lase et al., 2021; Z. Liu et al., 2021).

69 As an extended input-output model, the environmentally extended input-output (EEIO) model
70 represents the interdependence between the flows of goods and environmental loads. Many studies
71 through the EEIO model have been conducted on energy, water, waste, and greenhouse gases,
72 including CO₂, etc. (Cheng et al., 2021; Huang and Eckelman, 2021; Lase et al., 2021; Z. Liu et al.,
73 2021; Ohno et al., 2021; Peters et al., 2021; Rama et al., 2021; Tabatabaie and Murthy, 2021; Xu et al.,
74 2021; Zhang et al., 2021). However, most of the studies are on energy or CO₂, and there are still very
75 few studies on waste.

76 The waste extended input-output (WEIO) model is one type of EEIO model in which waste
77 generation is added as a satellite account to an input-output table (IOT). In the WEIO model, the only
78 link between economic activities and waste flows is established by adding waste generation by
79 industrial sectors to the money flows in industrial sectors and final demand (Towa et al., 2020). Some
80 of the few studies using the WEIO model include: Read and Muth (2021) evaluated the costs and
81 potential benefits of food waste reduction intervention in the United States. Meyer et al. (2020)
82 modeled the United States EEIO, including commercial enterprises from 386 industrial sectors of the
83 economy and solid waste generation, and identified industries as potential areas to continue to pursue
84 innovations in material use. Reutter et al. (2017) applied EEIO analysis to estimate environmental and
85 economic factors embodied in Australian food waste. Reynolds et al. (2015) quantified the tonnages,
86 costs, and environmental impact of food rescued and compared food rescue to other food waste
87 disposal methods of composting and landfill using the EEIO model on waste.

88 As shown above, the EEIO model has been applied to waste research in the United States and
89 mainly in Australia. However, the application to IHW was rather limited. Especially, there were few
90 studies on the generation of IHW in both supply and demand aspects, which this research contributes.
91 Moreover, to our best knowledge, the South Korea application had not been reported yet. Therefore,
92 this study formulated the first version of the South Korean WEIO model of 20 industry sectors for
93 2018. We use this WEIO table to calculate the direct, total, and indirect IHW generation coefficients
94 by industry from a production perspective and IHW generation inducement coefficients from a
95 demand perspective, respectively.

96 The organization of this paper is as this. After this introduction section, section 2 presents the
97 methods and data, section 3 shows the results and discusses the key findings and section 4 draws the
98 conclusions and policies implications.

99

100 **2. Methodology and Data**

101 **2.1. Waste Extended Input-Output Analysis**

102 In this study, the basic structure of the WEIO table, which links the amount of IHW generation in
 103 physical units to the IOT indicated in the monetary units, is shown in Table. 1. Using this WEIO table,
 104 we can analyze the direct and indirect coefficients of IHW generation from industrial activities and the
 105 impacts of final demand.

106

107 **Table. 1. Structure of waste extended input-output table**

	Intermediate demand			Final demand	Imports	Total output
Intermediate input	x_{11}	x_{1j}	x_{1n}	Y_1	M_1	X_1
	x_{i1}	x_{ij}	x_{in}	Y_i	M_i	X_i
	x_{n1}	x_{nj}	x_{nn}	Y_n	M_n	X_n
Value added	V_1	V_j	V_n			
Total input	X_1	X_j	X_n			
Waste type	w_{11}	w_{1j}	w_{1n}			
	w_{i1}	w_{ij}	w_{in}			
	w_{z1}	w_{nj}	w_{zn}			
Total waste generation	W_1	W_j	W_n			

108

109 The calculation through the WEIO table is conducted based on the IOA concept. In IOA, the total
 110 output of an economy, X , can be expressed as the sum of intermediate consumption by industry, $A \cdot X$,
 111 and final demand Y , as shown in Eq. (1).

112

$$A \cdot X + Y = X \quad (1)$$

113

114 Where A is the technical coefficients matrix ($a_{ij} = x_{ij}/X_j$), X is the vector of total output and
 115 Y is the vector of final demand. Matrix A is a square table with elements of x_{ij} , representing the
 116 amount of input i required per unit of output j . Column of the matrix A presents the inputs needed

117 for the production of a specific output. Therefore, matrix A is a constellation of techniques and can be
118 considered a technical matrix. Eq. (1) can be rewritten as Eq. (2) with the expression for X .

119

$$X = (I - A)^{-1} \cdot Y \quad (2)$$

120

121 In Eq. (2), I is the identity matrix and $(I - A)^{-1}$ is Leontief inverse matrix, represents the
122 effects of one unit of final demand on each industry's total production to include the direct and indirect
123 effects within the supply chain.

124 We can calculate the direct IHW generation coefficients (L_{direct}) by dividing the total amount of
125 IHW generation by sector (W) by total output (X), as Eq. (3).

126

$$L_{direct} = \frac{W_i}{X_i} = \hat{L} \quad (3)$$

127

128 The total IHW generation coefficients (L_{total}) can be computed by multiplying the diagonal
129 matrix of the direct IHW generation coefficients ($L_{direct} = \hat{L}$) by the Leontief matrix, as Eq. (4). It
130 also includes the concept of an IHW generation inducement coefficient to meet one unit of demand.

131

$$L_{total} = \hat{L} \cdot (I - A)^{-1} \quad (4)$$

132

133 The indirect IHW generation coefficients ($L_{indirect}$) can be obtained as the difference between
134 the total IHW generation coefficients (L_{total}) and the direct IHW generation coefficients (L_{direct}), as
135 Eq. (5).

136

$$L_{indirect} = L_{total} - L_{direct} \quad (5)$$

137

138 In terms of demand perspective, the final demand Y is an exogenous sector and consists of
 139 domestic consumption, investment, and net export. This study is analyzed by dividing it into
 140 consumption, investment, and net export, as shown in Eq. (6).

141

$$Y = Y_C + Y_I + Y_E - M = Y_C + Y_I + Y_N \quad (6)$$

142

143 It is defined, Y_C as a vector of consumption, including private consumption and government
 144 consumption, Y_I a vector of investment including private fixed capital formation, gross fixed capital
 145 formation, changes in inventories, and net acquisition of valuables, Y_E as a vector of export, M as a
 146 vector of import, and Y_N as a vector of net export ($Y_E - M$).

147 The IHW generation inducement coefficients are computed as Eq. (7), Eq. (8), and Eq. (9) by
 148 multiplying direct IHW generation coefficients by the ratio of the final demand sector, i.e., the ratio of
 149 consumption, investment, and net exports to final demand.

150

$$L_C = \hat{L} \cdot (I - A)^{-1} \cdot \frac{Y_C}{Y} \quad (7)$$

$$L_I = \hat{L} \cdot (I - A)^{-1} \cdot \frac{Y_I}{Y} \quad (8)$$

$$L_N = \hat{L} \cdot (I - A)^{-1} \cdot \frac{Y_N}{Y} \quad (9)$$

151

152 Where, L_C , L_I , and L_N are the IHW generation inducement coefficients by consumption,
 153 investment, and net export, respectively.

154 In this research, the scope for direct and indirect waste generation was defined differently from

155 other researches. (Ruiz-Peñalver et al., 2019; Ruiz Peñalver et al., 2014; Salemdeeb et al., 2016)
 156 looked at waste generation by direct and indirect suppliers by distinguishing those who directly supply
 157 the industry, called direct suppliers, and those that do not directly supply the industry but are suppliers
 158 to the industry's suppliers referred to as indirect suppliers. However, this assumption makes the error
 159 that the waste generated directly is counted as more than the actual amount because even the waste
 160 from the primary supplier is included in the direct waste generation. Therefore, in this paper, we
 161 defined direct waste as the waste generated by an industry's on-site production process and indirect
 162 waste as the waste generated throughout the production processes of all industries in that supply chain
 163 underpinning the production of this final product. Table. 2 briefly shows the explanation and example
 164 of direct, indirect, and total waste generation.

165

166 **Table. 2. Definition of direct, indirect, and total waste generation**

Definition	Description
Total waste generation	Waste generated by all supply chains of production (Direct waste generation + Indirect waste generation) $(W_{total} = \hat{L} \cdot (I - A)^{-1} \cdot Y)$
Direct waste generation	Waste generated by an industry's on-site production process Ex: Waste from the crops production process in 'Agriculture' sector $(W_{direct} = \hat{L} \cdot Y)$
Indirect waste generation	Waste generated throughout the production process of all industries underpinning the production of the final product Ex: Waste from agricultural machinery in 'Machinery equipment' and pesticide manufacturing process in 'Chemical' sectors $(W_{indirect} = W_{total} - W_{direct})$

167

168 **2.2. Data Sources**

169 Among the three data sources, data on IHW generation consisting of 32 industry sectors in South
 170 Korea was obtained from the (Korea Ministry of Environment, 2018). The input-output table (IOT) of
 171 South Korea, is a comprehensive statistical table that records interrelationships between industries for
 172 all goods and services produced during the year (Bank of Korea, 2018). Unlike the IHW data, there is

173 33 industry sector in IOT, so in this study, the sectors were reclassified in 20 sectors according their
 174 common trait as shown in Table. 3 and Appendix 1.

175

176 **Table. 3. Reclassification of industry sectors**

No.	Industry Sectors	
	Complete Name	Name used in this research
01	Agriculture, hunting, forestry and fishing	Agriculture (Ag)
02	Mining and quarrying	Mining (Mi)
03	Food products, beverages and tobacco	Food (Fo)
04	Textiles, textile products, leather and footwear	Textile (Tex)
05	Wood and products of wood and cork, pulp, paper, paper products, printing and publishing	Wood (Wo)
06	Coke, refined petroleum products and nuclear fuel	Coke (Cok)
07	Chemicals and chemical products, rubber and plastic	Chemical (Che)
08	Non-metallic mineral	Non-metallic mineral (Nm)
09	Basic metal	Basic metal (Bm)
10	Fabricated metal	Fabricated metal (Fm)
11	Computer, electronic and optical equipment, electrical machinery and apparatus, etc.	Electronic and electrical equipment (Ee)
12	Machinery and equipment, etc.	Machinery equipment (Me)
13	Motor vehicles, trailers and semi-trailers, other transport equipment	Transport equipment (Te)
14	Manufacturing etc.	Other manufacturing (Om)
15	Electricity, gas and water supply	Electricity, gas and water supply (EI)
16	Construction	Construction (Con)
17	Wholesale and retail trade	Wholesale and retail trade (Who)
18	Transport and storage	Transport and storage (Tr)

19	Education, health and social work
20	Other services

Education, health and social work (Ed)
Other services (Os)

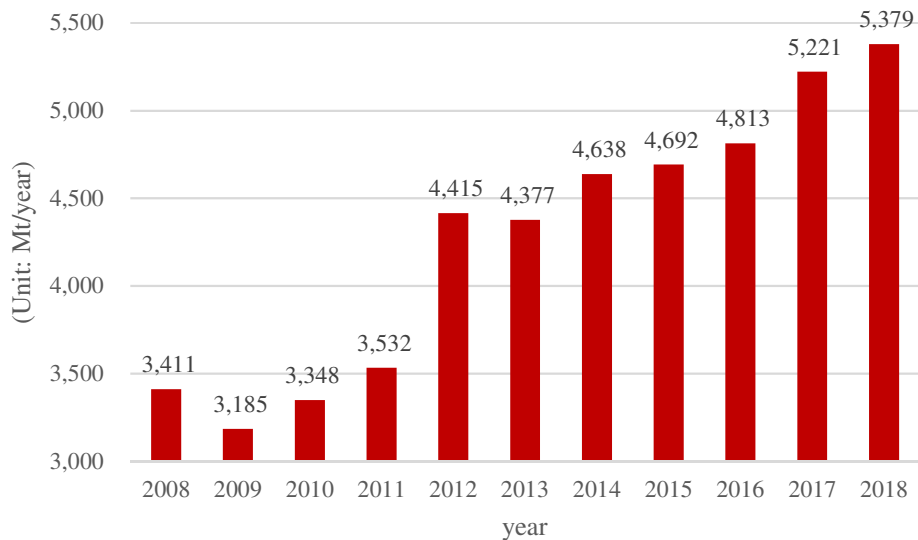
177

178 **3. Results and discussion**

179 **3.1. Overview of industrial hazardous waste generation**

180 The industrial hazardous waste (IHW) generation from 2008 to 2018 is shown in Fig. 1. With the
 181 economic growth, the amount of IHW has increased from 3,411 Mt/year in 2008 to 5,379 Mt/year in
 182 2018 at 57.68%. The amount of IHW generation in 2009 decreased compared to 2008 due to the
 183 economic crisis in 2008, but has been steadily increasing since 2009. In particular, there has been a
 184 significant increase in 2012.

185



186

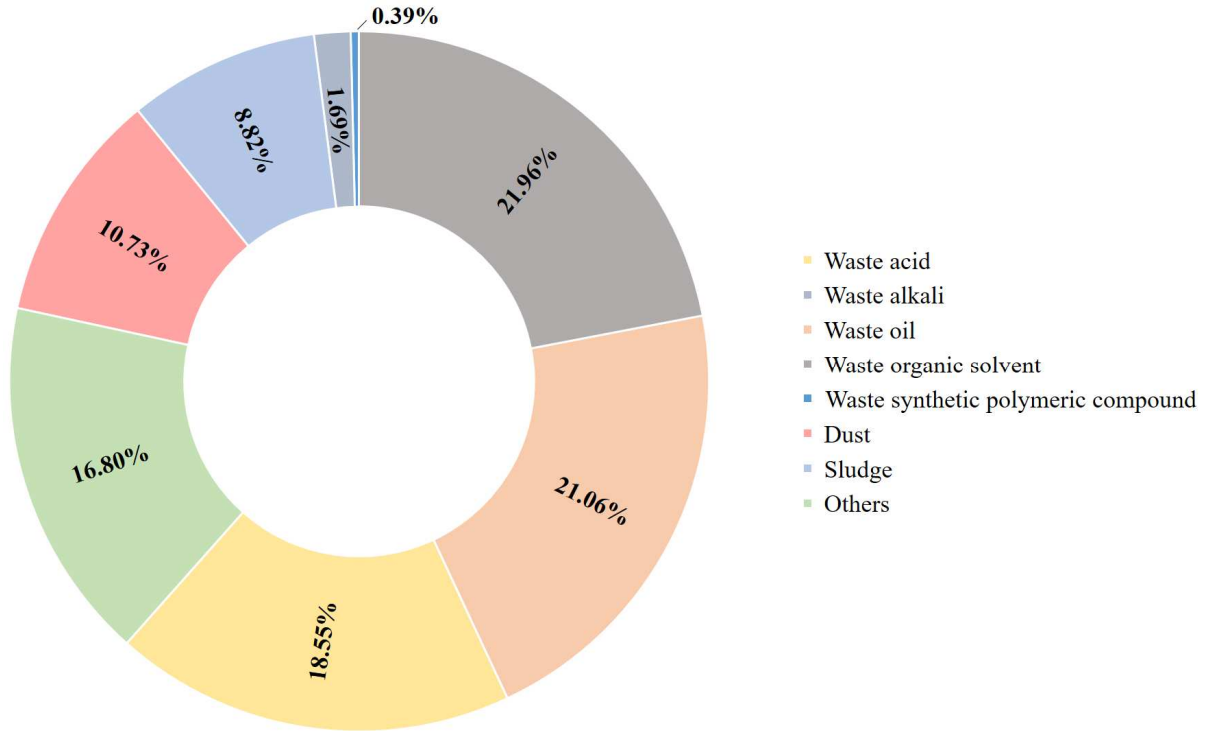
187 **Fig. 1. Industrial hazardous waste generation from 2008 to 2018**

188

189 The IHW are composed of waste acid, waste alkali, waste oil, waste organic solvent, waste
 190 synthetic polymeric compound, dust, sludge, and others. More than 60% of the IHW generation

191 consists of waste organic solvent, waste oil, and waste acid with 21.96% (3,236 tonnes/day), 21.06%
 192 (3,103 tonnes/day), and 18.55% (2,734 tonnes/day), respectively in 2018 as shown in Fig. 2.

193



194

195 **Fig. 2. Composition of industrial hazardous waste in 2018**

196

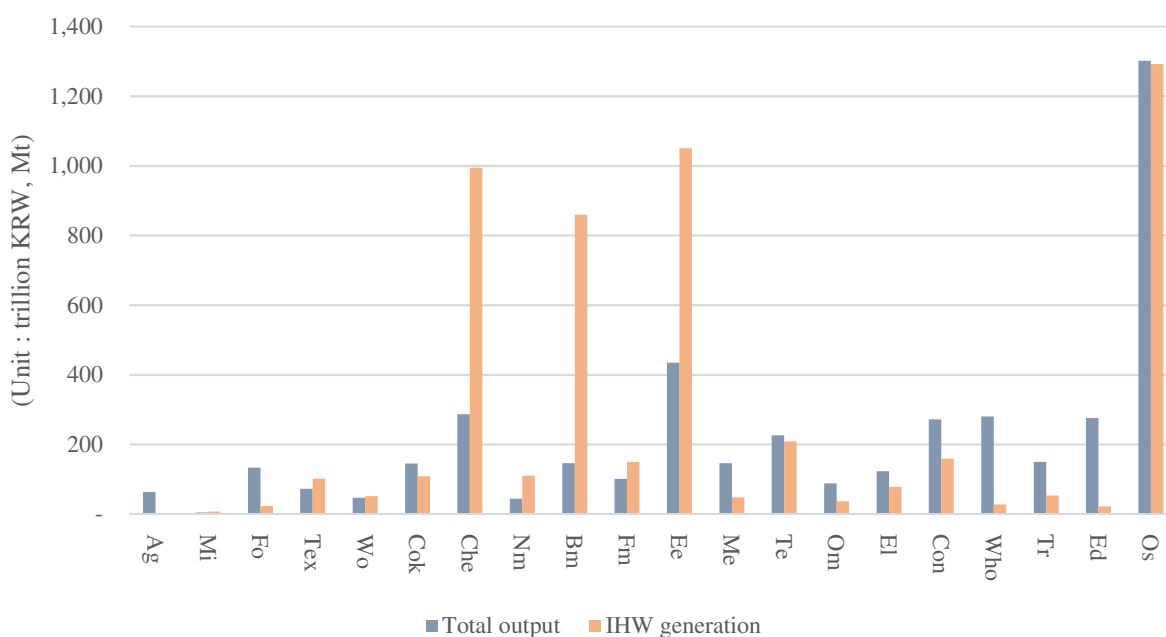
197 **3.2. Total output and industrial hazardous waste generation by industry**

198 According to Fig. 3, South Korea's total output in 2018 was 4,337 trillion KRW, and the amount
 199 of IHW generated was 5,379 Mt. 'Agriculture', the primary industry, has a total output of 63 trillion
 200 KRW. Still, there is no IHW generated in this industry. The total output of the manufacturing industries,
 201 the secondary industry, is 2,267 trillion KRW, accounting for 52.27%, while IHW generated is 3,984
 202 Mt, accounting for 74.08%. In particular, 'Electronic and electrical equipment', 'Chemical', and
 203 'Basic metal' industries contribute significantly to the IHW generation compared to the total output.
 204 IHW generation accounts are 19.53%, 18.48%, and 15.98%, respectively, indicating that they account
 205 for more than 50% of the total IHW generation, while the total outputs are 10.01%, 6.60%, and 3.36%,

206 respectively. In addition, the service industries, the tertiary industry, that account for 46.29% of the
 207 total output with 2,007 trillion KRW, accounts for 25.92% of the IHW generation with 1,394 Mt. As
 208 such, it is seen that the characteristics of IHW generation and economic contribution are very different
 209 for each industry.

210

211



212

213 **Fig. 3. Total output and industrial hazardous waste generation by industry**

214 Note: Unit is KRW (1 USD was approximately equal to 1115.7 KRW in 2018).

215

216 More than half of South Korea's industrial total output comes from the secondary industry. Since
 217 the secondary industry is made up of manufacturing industries, it generates a lot of IHW due to the
 218 characteristics of the manufacturing industry, contributing as much as four-thirds to the generation of
 219 IHW in South Korea. However, according to Lee et al. (2021), South Korea's industry is showing a
 220 shift towards the service industry. The tertiary industry that corresponds to the service industry
 221 accounts for almost another half of the total industrial output of South Korea, showing that it has a
 222 large share of the South Korean industry. But because of the characteristic of the service industry, the

223 IHW generation is only about a quarter. It shows the inclusive characteristics of the nexus between
224 South Korean industry and IHW generation that the total output is not proportional to the amount of
225 IHW generation. In particular, three major industries in the secondary industry contribute more to the
226 IHW generation than total output.

227

228 **3.3. Industrial hazardous waste generation coefficients from a supply perspective**

229 The direct, indirect, and total IHW generation coefficients, one of the IHW generation
230 characteristics in 2018, were calculated by industry according to Eq. 4, 5, and 6 and summarized in
231 Fig. 4. And the amounts of the direct, indirect, and total IHW generation are shown in Appendix 2. The
232 average of direct IHW generation coefficient is 1.26, and seven industries out of twenty industries are
233 above average. 'Basic metal' showed the highest direct IHW generation coefficient with 5.90,
234 followed by 'Chemical (3.47)', 'Non-metallic mineral (2.50)', 'Electronic and electrical equipment
235 (2.42)', 'Mining (1.62)', 'Fabricated metal (1.49)', and 'Textile (1.41)'. The total IHW generation
236 averages 3.79, and seven industries have higher values than the average, slightly different from the
237 direct IHW generation coefficient. The industry with the highest total IHW generation coefficient is
238 'Base metal', has a coefficient of 11.42, and then 'Chemical (6.88)', 'Electronic and electrical
239 equipment (5.64)', 'Fabricated metal (5.50)', 'Non-metallic mineral (5.10)', 'Transport equipment
240 (5.04)', and 'Textile (4.29)' are followed. The average of the indirect IHW generation coefficient is
241 2.52, and the 'Basic metal' shows the highest coefficient of 5.51. And 'Transport equipment (4.12)',
242 'Fabricated metal (4.02)', 'Machinery equipment (3.46)', 'Chemical (3.41)', 'Electronic and electrical
243 equipment (3.22)', 'Textile (2.88)', 'Construction (2.69)', and 'Non-metallic mineral (2.59)' are the
244 following most significant contributors.

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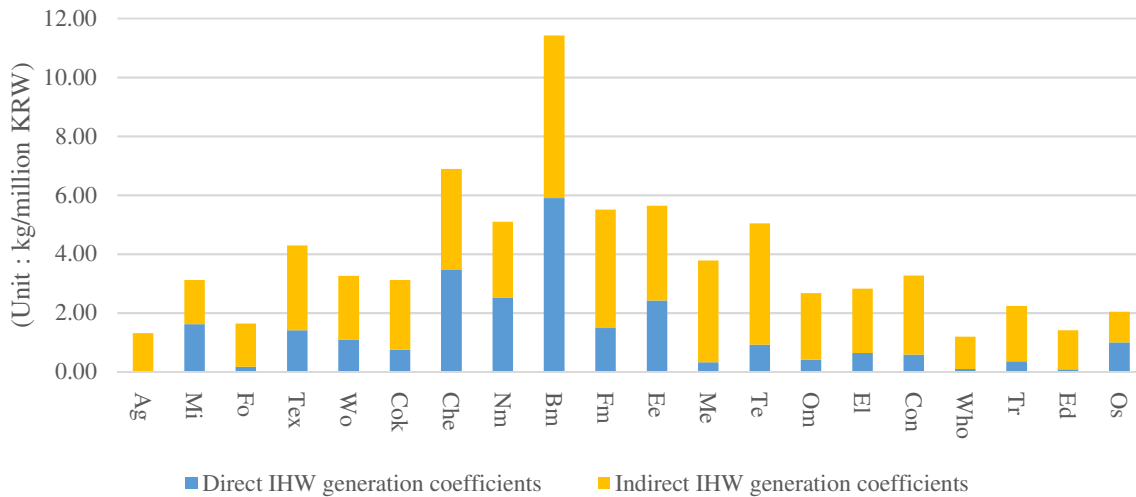


Fig. 4. Industrial hazardous waste generation coefficients by industry

These results show that in all industries except for ‘Mining’, ‘Chemical’, and ‘Basic metal’, the indirect IHW generation coefficients are larger than the direct IHW generation coefficients. In particular, in ‘Food’, ‘Machinery equipment’, ‘Wholesale and retail trade’, and ‘Education, health and social work’ sector, indirect IHW generation coefficients are 8.66, 10.56, 11.29, and 16.80 times larger than direct IHW generation coefficients, respectively. Even in the ‘Agriculture’ sector, there is no direct IHW generation, only indirect IHW generation. It means that IHW generated during the production and use of raw materials and components used in the industry has more influence on the entire IHW generation than IHW generated by the industry itself. Moreover, the total, direct, and indirect IHW generation coefficients of ‘Textile’, ‘Chemical’, ‘Non-metallic mineral’, ‘Basic metal’, ‘Fabricated metal’, and ‘Electronic and electrical equipment’ are above average, indicating that it is essential to consider the IHW generation characteristic of these six industry sectors when establishing waste management policies.

From an overall point of view, the average value of the indirect IHW generation coefficient is almost twice that of the direct IHW generation coefficient, which means that two times the amount of direct IHW are potentially generated as indirect IHW through the supply chain. This result shows that it is highly necessary to make scientific IHW management policy considering the direct and indirect IHW generation together.

266

267 **3.4. Industrial hazardous waste inducement from a demand perspective**

268 From the supply perspective, the previous step identified the direct, total, and indirect IHW
 269 generation coefficients. However, since the supply of products and services is derived by the final
 270 demand, analysis from a demand perspective is also necessary. Therefore, in this step, we calculated
 271 the contribution of IHW generation induced by intermediate and final demand, such as domestic
 272 consumption, investment, and net export, to understand the effects of total demand on the IHW
 273 generation in the economic system.

274 As shown in Table. 4, the contribution of IHW induced from intermediate and final demand are
 275 64.05% and 35.95%, respectively. Among the final demand, the contribution of consumption,
 276 investment, and net export are 2,592 Mt (48.18%), 1,961 Mt (36.46%), and 826 Mt (15.35%),
 277 respectively. However, the total output from consumption, investment, and net export are 2,606 trillion
 278 KRW (60.09%), 1,460 trillion KRW (33.66%), and 271 trillion KRW (6.25%), respectively. It can be
 279 confirmed that almost half of the IHW generation inducement is due to consumption, which implies
 280 that consumption must also be considered when managing IHW generation. Also, we confirmed that a
 281 large amount of IHW is generated compared to the total output generated by net exports. While the
 282 total output by net exports is only 6.25%, the amount of IHW induced by net exports is 15.35%.

283

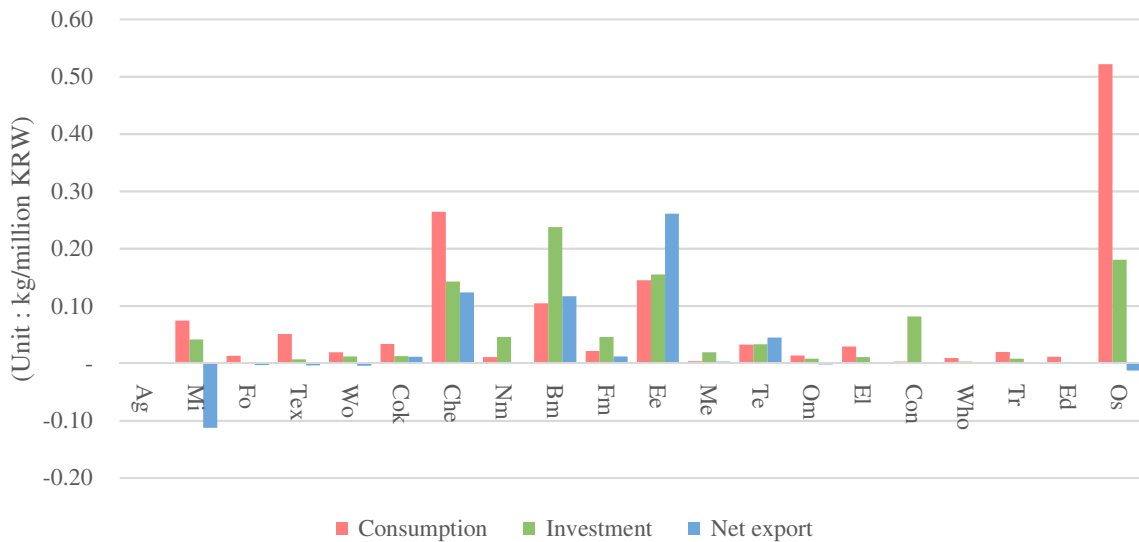
284 **Table. 4. Industrial hazardous waste generation induced from a demand perspective**

Unit	Total output trillion KRW (% , %p)	IHW generation Mt (% , %p)
Intermediate demand	6,196 (58.83)	9,583 (64.05)
Final demand	4,337 (41.17)	5,379 (35.95)
Consumption	2,606 (60.09)	2,592 (48.18)
Investment	1,460 (33.66)	1,961 (36.46)
Net export	2,701 (6.25)	826 (15.35)
Total	10,533 (100.00)	14,961 (100.00)

285

286 In addition, the IHW generation inducement coefficients from consumption, investment, and net
 287 exports, which were calculated by Eq. 7, 8, 9, were 1.38, 1.05, and 0.44, respectively. This means that
 288 1.38 kg, 1.05 kg, and 0.44 kg of IHW were induced per one million KRW of final demand for
 289 domestic consumption, investment, and exports. Fig. 5 shows the IHW generation inducement
 290 coefficients by industry.

291



292

293 **Fig. 5. Industrial hazardous waste inducement coefficients**

294

295 It was found that the IHW generation inducement coefficient by consumption, which has the
 296 greatest impact on IHW generation among the final demand sectors, was significantly affected in the
 297 order of ‘Other services (0.52)’, ‘Chemical (0.26)’, ‘Electronic and electrical equipment (0.14)’, and
 298 ‘Basic metal (0.10)’. Among them, consumption of ‘Other services’ seems to have an
 299 overwhelmingly high impact on IHW generation. The contribution of IHW generation induced by
 300 investment is the largest from ‘Basic metal (0.24)’, followed by ‘Other services (0.18)’, ‘Electronic
 301 and electrical equipment (0.15)’, and ‘Chemical (0.14)’. The IHW generation induced by net exports
 302 has the largest contribution by ‘Electronic and electrical equipment (0.26)’, followed by ‘Chemical
 303 (0.12)’, and ‘Base metal (0.12)’. Whereas, the IHW generation inducement coefficient of ‘Other
 304 services (-0.01)’ is a negative value. It means that an increase in exports of ‘Other service’ affected

305 waste reduction, unlike other industries.

306 These results identify the characteristics of IHW generation in consideration of the demand and
307 supply side. This implies that improving clean production and resource efficiency is necessary from a
308 supply perspective. Furthermore, from the demand perspective, classic policy instruments (regulatory,
309 economic, and informational) and incentives on the consumer behavioral approach are needed to
310 reduce IHW generation.

311

312 **4. Conclusions and future work**

313 Even though the world has reached a point in which IHW management needs to be more
314 systematized due to the Basel Convention and the transition to a circular economy, South Korea's
315 waste management policies have not yet been made based on objective and rational evidence. So we
316 need to focus on developing a methodology to support establishing effective policies by quantifying
317 the characteristics of IHW generation, considering the relationship between economic activities and
318 waste generation.

319 This paper aims to formulate the first version of the South Korean WEIO model of IHW. Through
320 the first version of the WEIO model of IHW, we calculated the direct, indirect, and total IHW
321 generation coefficients from the supply perspective, and the contribution of IHW generation from the
322 demand perspective of consumption, investment, and net export.

323 The results can be summarized on the supply side and the demand side. First, in terms of a
324 supply-side point of view, it was found that more than 50% of direct IHW generation is from
325 'Chemical', 'Basic metal', and 'Electronic and electrical equipment'. And the direct, total, and indirect
326 IHW generation coefficients of these three sectors are above average, indicating that the main point
327 would be to consider and reflect the characteristics of IHW generation in those three sectors when the
328 South Korean government plans waste management policies innovation. Also, it showed that the
329 average value of the indirect IHW generation coefficient is almost twice that of the direct IHW
330 generation coefficient, which must be reflected in the waste policies establishment. To plan the

331 reduction of IHW generation, it is necessary to consider the direct IHW generated by each industry
332 and the indirect IHW generated from the industry's supply chain as well. To this end, it can be said
333 that waste management policies should be established to improve the resource efficiency and cleaner
334 production of all industries in the supply chain, not just one industry.

335 From the demand side, the contribution of IHW generation induced from consumption,
336 investment, and net export are 48.18%, 36.46%, and 15.35%, respectively. It shows that not only the
337 supply side but also the demand side, especially consumption, is a factor that must be carefully
338 addressed in the IHW reduction strategy to achieve a sustainable economy. In other words, it is as
339 urgent to establish policy instruments and incentives to improve the consumer behavioral approach as
340 much as the technological and environmental policies. The results obtained from this research imply
341 that this first South Korean WEIO model can be used to identify IHW hotspots in industrial activity
342 and quantify the contribution of direct and indirect IHW generation, contributing to the establishment
343 of waste policy strategies.

344 However, we have to admit some limitations of the first version of the South Korean WEIO table.
345 First, the different sector classifications of waste data and IOT forced us to reclassify industry sectors,
346 merging several industries into one. Especially the service sector is simplified in the waste data but
347 more granular in the IOT. Due to the simplification of waste data, it is unfortunate that detailed
348 analysis could not be done in the service sector, a tertiary industry. Second, the current version does
349 not provide any additional information about residues generated from the waste treatment process.
350 This limitation is expected to be addressed in the next version of the waste input-output (WIO) table to
351 reflect waste treatment activities. Despite these limitations, introducing the first version of the South
352 Korean WIO table is the first step toward better understanding the characteristics of the IHW
353 generation. For in-depth study in the future, a more refined WIO model needs to be developed and
354 applied.

355

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360

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464 [w](https://doi.org/10.1007/s11356-021-13716-w)

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466

467 **Appendix 1. Reclassification of industry sectors**

IHW data from Korean National Statistics (32 sectors)	IOT data from Korea Bank (33 sectors)	Reclassified sectors (20 sectors)
	Agriculture, hunting, forestry, and fishing	Agriculture
Mining and quarrying	Mining and quarrying	Mining
Food	Food products, beverages, and tobacco	Food
Beverages		
Tobacco		
Textiles products	Textiles and leather products	Textile
Clothing, clothing accessories, and fur products		
Leather, bags, and shoes		
Wood products	Wood, paper, and printing	Wood
Pulp, and paper products		
Printing and reproduction of recorded media		
Coke and refined petroleum products	Coke and refined petroleum products	Coke
Chemical products	Chemical products	Chemical
Medical material and medicines		
Rubber and plastics products		
Non-metallic mineral products	Non-metallic mineral products	Non-metallic mineral
Basic metal	Basic products	Basic metal
Fabricated metal	Fabricated metal products	Fabricated metal
Electronic parts, computer, video, sound, and communication equipment	Computer, electronic, and optical equipment	Electronic and electrical equipment
Medical, precision, optical instruments, and watches		
Electrical equipment	Electrical equipment	
Other machines and equipment	Machinery and equipment	Machinery equipment
Car and trailer	Transport equipment	Transport equipment
Other transport equipment		
Furniture	Other products	Other manufacturing
Other products		
Repair of industrial machinery and equipment		

Electricity, gas steam, and water	Electricity, gas, and steam	Electricity, gas, and water supply
	Water, waste treatment, and recycling service	
Construction	Construction	Construction
Wholesale and retail	Wholesale and retail	Wholesale and retail trade
Transport	Transport and storage	Transport and storage
Education	Education	Education, health, and social work
	Health and social work	
Other service	Restaurants and accommodation service	Other services
	Information communication and broadcasting service	
	Financial and insurance service	
	Real estate service	
	Science and technology service	
	Business support service	
	Public administration, national defense, and social security	
	Arts, sports, and leisure-related service	
	Other services	
	Others	

468

469 **Appendix 2. Total output and industrial hazardous waste generation**

Industry sectors		Total output		IHW generation	
		(trillion KRW)	(%)	(Mt)	(%)
Primary industry	Ag	63	1.45	-	-
	Subtotal	63	1.45	-	-
Secondary industry	Mi	5	0.10	7	0.14
	Fo	133	3.06	22	0.42
	Tex	73	1.68	102	1.90
	Wo	47	1.08	51	0.95
	Cok	145	3.33	108	2.02
	Che	286	6.60	994	18.48
	Nm	44	1.01	110	2.05
	Bm	146	3.36	859	15.98
	Fm	100	2.32	150	2.78
	Ee	435	10.01	1,051	19.53
	Me	146	3.37	48	0.89
	Te	226	5.21	208	3.87
	Om	88	20.02	36	0.67
	El	123	2.83	78	1.45
Con	272	6.27	159	2.95	
	Subtotal	2,267	52.27	3,984	74.08
Tertiary industry	Who	280	6.46	27	0.50
	Tr	150	3.45	53	0.98
	Ed	276	6.36	22	0.41
	Os	1,302	30.02	1,292	24.03
	Subtotal	2,007	46.29	1,394	25.92
Total		4,337	100.00	5,379	100.00

470

471 **Appendix 3. Industrial hazardous waste generation coefficients**

472 (Unit: kg/million KRW)

Industry Sectors		Total IHW generation coefficients	Direct IHW generation coefficients	Indirect IHW generation coefficients	
Primary industry	Ag	1.31	-	1.31	
	Mi	3.12	1.62	1.50	
	Fo	1.63	0.17	1.47	
	Tex	4.29	1.41	2.88	
	Wo	3.25	1.09	2.17	
	Cok	3.11	0.75	2.36	
	Che	6.88	3.47	3.41	
	Nm	5.10	2.50	2.59	
	Secondary industry	Bm	11.42	5.90	5.51
		Fm	5.50	1.49	4.02
Ee		5.64	2.42	3.22	
Me		3.78	0.33	3.46	
Te		5.04	0.92	4.12	
Om		2.67	0.41	2.26	
El		2.82	0.64	2.18	
Con		3.27	0.58	2.69	
Tertiary industry		Who	1.19	0.10	1.09
		Tr	2.24	0.35	1.88
	Ed	1.41	0.08	1.33	
	Os	2.04	0.99	1.05	
Average		3.79	1.26	2.52	

473

474 **Appendix 4. Industrial hazardous waste generation inducement coefficients**

475 (Unit: kg/million KRW)

Industry Sectors		Inducement coefficient by consumption	Inducement coefficient by investment	Inducement coefficient by net export	
Primary industry	Ag	-	-	-	
	Mi	0.07	0.04	-0.11	
	Fo	0.01	0.00	-0.00	
	Tex	0.05	0.01	-0.00	
	Wo	0.02	0.01	-0.00	
	Cok	0.03	0.01	0.01	
	Che	0.26	0.14	0.12	
	Nm	0.01	0.05	0.00	
Secondary industry	Bm	0.10	0.24	0.12	
	Fm	0.02	0.05	0.01	
	Ee	0.14	0.15	0.26	
	Me	0.00	0.02	0.00	
	Te	0.03	0.03	0.05	
	Om	0.01	0.01	-0.00	
	El	0.03	0.01	0.00	
	Con	0.00	0.08	-0.00	
		Who	0.01	0.00	0.00
	Tertiary industry	Tr	0.02	0.01	0.00
Ed		0.01	0.00	-0.00	
Os		0.52	0.18	-0.01	
Total		1.38	1.05	0.44	

476

Graphical abstract

(Unit: kg/million KRW)

