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Analysis of Economic Growth-Industrial Activities-Industrial Hazardous Waste Nexus in South Korea by Multi-level Approaches

Daye Lee

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de doctorat
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Daye LEE

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THESE

pour l'obtention du grade de

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Spécialité : SYSTEMES SOCIOTECHNIQUES

présentée et soutenue par

Daye LEE

le 14 décembre 2021

**Analysis of Economic Growth-Industrial Activities-Industrial
Hazardous Waste Nexus in South Korea by Multi-level Approaches**

JURY

M. Guido SONNEMANN	PROFESSEUR DES UNIVERSITES	Président
M. Seok-Young OH	PROFESSOR	Rapporteur
M. Daeseung KYUNG	ASSISTANT PROFESSOR	Examineur
Mme Valérie LAFOREST	DIRECTRICE DE RECHERCHE EMSE	Examinatrice
M. Junbeum KIM	PROFESSEUR ASSOCIE UTT	Directeur de thèse
M. Hung-Suck PARK	PROFESSOR	Directeur de thèse

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Daye Lee

Abstract

Industrial hazardous waste (IHW) has been a fatal negative impact on the environment and humans. It caused social problems, such as waste transactions between countries in unequal status from developed countries to less developed countries. To prevent this, the Basel Convention has been signed to regulate the transboundary movements and trade of IHW. Under this convention, the world was required to have the capacity manage IHW in domestic level efficiently. Thus, resource circulation policies are being implemented around the world. In line with this, South Korea announced the ‘2020 great transition plan to resource circulation’ and set the goal of reducing the amount of IHW as the first step of this plan. However, they still struggle to establish a waste policy based on reasonable grounds, and there are few studies for this. Therefore, in this research, based on the industrial ecological concept, characteristics of IHW generation was analyzed by modified IPAT equation and LMDI method in national level. Then to identify the IHW footprint in sector level in terms of production and demand and the factors affecting IHW increase or decrease among final demand change factors, import substitution factors, and production technology factors, IHW extended input-output table was established. In addition, IHW generation prospects by changes of final demand, waste management method and cost were estimated by scenario analysis using waste input-output table for IHW of South Korea, developed in this study.

The results of this study, based on the industrial ecological concept, are expected to contribute to the basic research of establishing a rational waste policy that reflects the characteristics of each industry by quantitatively evaluating the generation and management of waste.

Keywords : Industrial ecology; Circular economy; Hazardous wastes; Input-output analysis

Abstract (Version Français)

Les déchets industriels dangereux (DID) ont non seulement eu un impact négatif fatal sur l'environnement et les humains, mais ont également causé des problèmes sociaux, tels que les transactions de déchets entre des pays situés à des emplacements inégaux des pays développés aux pays moins développés. Pour éviter cela, la Convention de Basel a été signée pour réglementer les mouvements transfrontaliers et le commerce des DID. En vertu de cette convention, le monde devait avoir la capacité de gérer efficacement les DID au niveau national. De plus, des politiques de circulation des ressources sont mises en œuvre partout dans le monde. Dans cette optique, la Corée du Sud a annoncé que nous réduirons la production des DID grâce à un plan de grande transition vers la circulation des ressources en 2020. Cependant, ils peinent encore à établir une politique des déchets fondée sur des motifs raisonnables, et il existe peu d'études à ce sujet. Par conséquent, dans cette recherche, basée sur le concept écologique industriel, les caractéristiques de la production de DID ont été analysées par l'équation IPAT modifiée et la méthode de LMDI au niveau national. Ensuite, pour identifier l'empreinte des DID au niveau sectoriel, le tableau entrées-sorties (TES) de la Corée du Sud et la production et le traitement des DID ont été liés pour modéliser le TES de DID de la Corée du Sud. À travers le tableau en développement, cette recherche a identifié les caractéristiques de la production des DID en termes de production et de demande par industrie. Il a analysé les facteurs affectant l'augmentation des DID parmi les facteurs de changement de la demande finale, les facteurs de substitution des importations et les facteurs de technologie de production. Cela a contribué à l'identification des points chauds des DID. Enfin, nous nous sommes concentrés sur l'analyse des effets des changements dans les méthodes de traitement des DID.

Les résultats de cette étude, basée sur le concept d'écologie industrielle, devraient contribuer à la recherche fondamentale pour établir une politique rationnelle des déchets qui reflète les caractéristiques de chaque industrie en évaluant quantitativement la production et la gestion des déchets.

Mots Clés : Écologie industrielle ; Économie circulaire ; Déchets dangereux ; Analyse entrées-sorties

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List of abbreviations

CE	Circular Economy
EIO	Environmental Input-Output
GDP	Gross Domestic Product
GIS	Geographic Information System
IDA	Index Decomposition Analysis
IE	Industrial Ecology
IHW	Industrial Hazardous Waste
IOA	Input-Output Analysis
IOT	Input-Output Table
LCA	Life Cycle Assessment
LMDI	Log-Mean Divisia Index
MFA	Material Flow Analysis
MOE	Ministry of Environment
OECD	Organization for Economic Cooperation and Development
SDA	Structural Decomposition Analysis
WEIOA	Waste-Extended Input-Output Analysis
WEIOT	Waste-Extended Input-Output Table
WIOA	Waste Input-Output Analysis
WIOT	Waste Input-Output Table

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Chapter 1 : Introduction

Waste generation is increasing at a similar rate to economic growth, and it is urgent to reduce the environmental loads. To manage the waste generation, which is one of the important environmental loads, resource recycling policies are being implemented around the world. A consensus exists on the vital role of waste and resource management in achieving the transition from a linear economic model to a circular one. The value of materials and resources is maintained in the supply chain. In addition, the Basel Convention was created to prevent the movement of industrial hazardous wastes (IHW) from developed countries to developing countries to protect the environment of developing countries that do not have sufficient IHW treatment and management capabilities and minimize the production of IHW. The world faces a significant challenge in transitioning to a circular economy through efficient IHW management within their own countries. As the first step in that challenge, quantitative identification of IHW generation is necessary to design rational policy related to waste and resource in detail. Waste input-output analysis (WIOA) is one of the tools that is used worldwide for this purpose. However, research on IHW with WIOA is still lacking.

Chapter 1 provides the background of this research, research objectives, and questions and specifies the assessment tools and scope used in this research work. At the end of this chapter, brief research outlines have also been given to help the reader understand the interrelationship and continuity of each chapter.

1.1. Background

After the industrial revolution, population growth and global industrialization have led to a steady increase in global GDP, as shown in Figure 1-1. Rapid industrialization has spurred economic growth, increasing incomes, creating jobs, and reducing poverty. However, meanwhile, it also caused environmental problems like resource depletion, environmental pollution, and climate change (Biskaborn et al., 2021; Cherniwchan, 2012; Mudakkar et al., 2013).

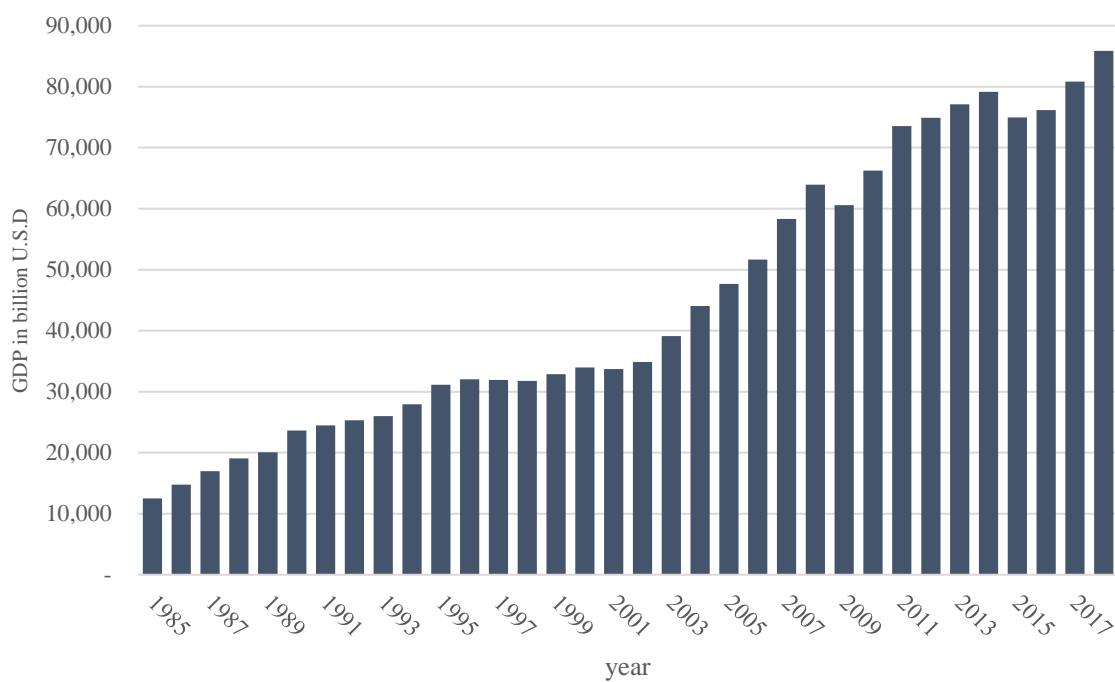


Figure 1-1. Global gross domestic product at current prices from 1985 to 2018 (IMF, 2021)

One of several environmental loads, over the past few years, solid waste is an inevitable consequence of economic growth, industrialization, urbanization, and the rise of human living

standards (Alam & Ahmade, 2013; Hoornweg et al., 2013; Hoornweg & Bhada-Tata, 2012; Hossain et al., 2011). As producers supply products using natural resources through industrial activities, consumers purchase and consume them, resulting in mixed wastes, such as household waste, agricultural waste, municipal solid waste, industrial waste, etc. Among them, industrial hazardous waste (IHW), characterized by ignitability, corrosiveness, reactivity, and toxicity, etc. is directly connected to industrial activities and could have harmful effects on the environment, human health, and society (H. Guo et al., 2018; Moradi Hanifi et al., 2019; Ojha, 2020; Yi et al., 2011). For these reasons, countries worldwide have been strengthening IHW management and regulating the illegal trade of IHW by the Basel Convention, an international treaty that controls the movement and trade of hazardous waste between countries (Khan, 2020; Rummel-Bulska & Basavaraj-Schroth, 1994; S. Yang, 2020). Despite the convention, IHW had flowed into less developed countries disguised as raw material and secondary resources (Grether et al., 2012). In recent years, the Chinese, Malaysian, Philippine, Indonesian, Vietnamese, and Cambodian governments have banned the import of foreign waste (Qu et al., 2019; C. Wang et al., 2020). Now, it is time for the world to ensure environmentally friendly IHW management strategies suitable to their contexts.

Like other countries, South Korea has experienced increasing industrial waste issues due to unprecedented rapid industrialization, urbanization, and economic growth. To address the waste problems, waste-related laws and regulations have been issued timely, focusing on safe treatment in the 1980s, recycling treatment from the 1990s to the early 2000s, and resource circulation after the mid-2000s as shown in Figure 1-2 (MOE, 2020; W. S. Yang et al., 2015).

Law	Regulations
<p>1980s: Safe Treatment</p> <ul style="list-style-type: none"> • Wastes Control Act (1986) 	<ul style="list-style-type: none"> • Wastes Treatment standards and methods (1986) • Waste Treatment Facility Installation Standards (1986) • Permission of Waste Treatment Business (1986)
<p>1990s ~ Early-2000s: Recycling Treatment</p> <ul style="list-style-type: none"> • Act on the Promotion of Saving and Recycling of Resources (1992) • Act on the Transboundary Movement of Hazardous Wastes and Their Disposal(1992) • Promotion of Installation of Waste Disposal Facilities and Assistance, etc. To Adjacent Areas Act (1995) • Construction Waste Recycling Promotion Act (2003) 	<ul style="list-style-type: none"> • Waste Charge System (1992) • Obligation of Separate disposal (1992) • Waste Import and Export Permission System(1992) • Restrictions of Overpacking (1994) • Volume-based Disposal System (1995) • Extended Producer Responsibility (EPR) system (2003) • Obligation of Recycled Aggregate use (2004)
<p>Mid-2000s ~ : Resource Circulation</p> <ul style="list-style-type: none"> • Act on Resource Circulation of Electrical and Electronic Equipment and Vehicles (2007) • Framework Act on Resources Circulation (2018) 	<ul style="list-style-type: none"> • Prohibition of Direct Landfill of Food Waste (2005) • Import and Export Waste Declaration System (2008) • Environmental Guarantee System for Electrical and Electronic Product (2008) • Volume-based Disposal System for Food Waste (2012) • Environmental Evaluation of Recycling (2016) • Waste Disposal Charge System (2018) • Resource Circulation Performance Management System (2018)

Figure 1-2. The development of waste laws and regulations in South Korea

Since the mid-2000s, policies related to resource circulation have been implemented to achieve ‘Zero Waste’ through waste circulation and minimizing waste generation. Representative laws related to IHW include the Act on Resource Circulation of Electrical and Electronic Equipment and Vehicles (2007), Import and Export Waste Declaration System (2008), and Framework Act on Resources Circulation (2018).

In 2020, the South Korean government announced a new resource circulation plan to overcome the limitations of the existing waste-related laws and regulations. The first key task of this new plan is to reduce waste generation by reducing the amount of IHW generated in the product manufacturing stage. To this end, the South Korean government has been expanding support for customized consulting opportunities and facility improvement at workplaces that generate large amounts of IHW.

Recently, researches on IHW generation and management have been increased in South Korea. Yoon et al. (2021) analyzed the characteristics of dust waste from 28 metal manufacturing facilities in South Korea in terms of environmental safety. Park et al. (2020) analyzed the causality between consumer beliefs and behavior in South Korea in the social aspect to establish strategies for maximizing the flow of electrical and electronic equipment waste. And Choi et al. (2019) proposed advanced management of IHW in South Korea from a systemic point of view by creating a link between industry, waste, hazardous chemicals, and their hazardous characteristics and treatment methods. However, as far as we know, few studies have focused on IHW generation characteristics, which is highly required for sustainable industrial hazardous waste management policy design in South Korea.

(Shin et al., 2015) conducted a study to examine the impact of waste policy changes by developing a waste input-output table for industrial wastes in South Korea. In their study, however, a wider range of industrial wastes, not IHW, were targeted, and it was comprehensively carried out by dividing only combustible wastes and non-combustible wastes. In addition, the waste treatment method was limited only to incineration and landfill. This research seems to be lacking in the comprehensiveness of the data, still for reflection of the reality of the data. Because this research was conducted using data on the unit cost of waste treatment obtained through a survey of private waste treatment facilities. Since these data is limited to the data of the facilities that responded to the survey, it is considered that they have no scientific basis for use in policy impact assessment research and lack of validity.

1.2. Research objectives and questions

This research focuses on, firstly, identifying factors affecting IHW generation in South Korea and then quantitatively analyzing the IHW intensity by industry and factors affecting the increase in IHW generation and understanding the impact of changes in IHW treatment methods. For these objectives, this research applies and develops various environmental assessment tools based on the concept of industrial ecology to understand the characteristics of IHW generation in terms of demand and supply, and the multiplier effect of changes in IHW treatment methods and treatment unit cost. The past waste input-output table (WIOT) made for industrial waste in South Korea was insufficient to reflect reality. To solve this research gap, this study focuses on developing tools that reflect the South Korean situation as much as possible through more detailed IHW types, waste treatment methods, and data estimation based on environmental engineering logic.

The objective is to provide a tool to quantitatively analyze the IHW generation flow and the effects of treatment methods by modeling the waste input-output table for IHW by using accessible data in public. This research aims to achieve this research objective by addressing the following questions:

1. From a macro perspective, what are the characteristics of IHW generation by industry in South Korea?
2. How is the industrial structure of South Korea changing? How is this changing in terms of supply and demand? What industries have distinctive characteristics in changing the industrial structure?

3. Where are the direct and indirect IHW hotspots by industry and waste type in South Korea? Also, how much IHW is induced by consumption, investment, and net exports.
4. Which factors and how much influence the increase or decrease in IHW generation?
5. What kind of economic and environmental ripple effect will be happened from the change of the waste treatment methods and treatment unit cost?

1.3. Assessment tools and scope

The quantitative evaluation tools used in this research work are based on environmental engineering and industrial ecology. The methods used in this research include decoupling analysis, modified IPAT, Log-mean Divisia Index (LMDI) decomposition analysis, Waste-Extended Input-Output Analysis (WEIOA), Waste Input-Output Analysis (WIOA), and Structural Decomposition Analysis (SDA).

Decoupling refers to the situation that in the process of economic development, the total amount of material energy consumption does not increase with economic growth but decreases instead. And the decoupling analysis refers to breaking the linkage between “environmental pressure” and “economic output” (UNEP, 2011). IPAT equation is the mathematical notation of a formula put forward to describe the impact of human activity on the environment. It equates human impact on the environment to a function of three factors: population (P), affluence (A) and technology (T). This equation can also be modified and used for various environmental analysis with other factors affecting the environment by human activity (Chertow, 2000). The LMDI methodology is a type of factor decomposition analysis to analyze

changes in those factors of modified IPAT equation, and is used to identify drivers using log-mean weights factor (Ang & Wang, 2015a). The WEIOA is the methodology to analyze the characteristic of waste generation linking economic system through using the waste-extended input-output table (WEIOT) by adding a waste generation satellite to the input-output table (IOT). Using WEIOT, SDA is performed to identify factors affecting the increase or decrease of waste generation within the economic system. Further developed here, waste input-output table (WIOT) is formed by adding waste treatment section. Using the modelled WIOT, it is possible to perform scenario analysis that examines economic and environmental changes due to changes in waste treatment methods and unit costs.

These approaches are used in various combinations to address research questions. The results obtained from the evaluation methods described above are used to recommend policy for the great transition towards a circular economy.

The scope of this research is the generation and treatment of IHW in the industrial system of South Korea, and 2008 and 2018 are limited to the time scope.

1.4. The framework of the research work

Under the background and research objectives, this research work is organized like Figure 1-3.

Table 1-1 provides the title of the chapters with their brief description. For the first step, boundary of this research is put as economic system and IHW of South Korea. As the first analysis, the overall characterizations of IHW generation in South Korea through decoupling

and index decomposition analysis was performed in macro level. And industrial structure was analyzed from demand and supply perspectives. After that, the characterization of IHW generation and SDA for identifying factors affecting IHW generation increase through WEIOA was conducted in micro level. And for the final step, the WIOT was modeled, and the effect of changes of waste treatment methods and unit costs was analyzed through WIOA. This research concluded by suggesting policy implications.

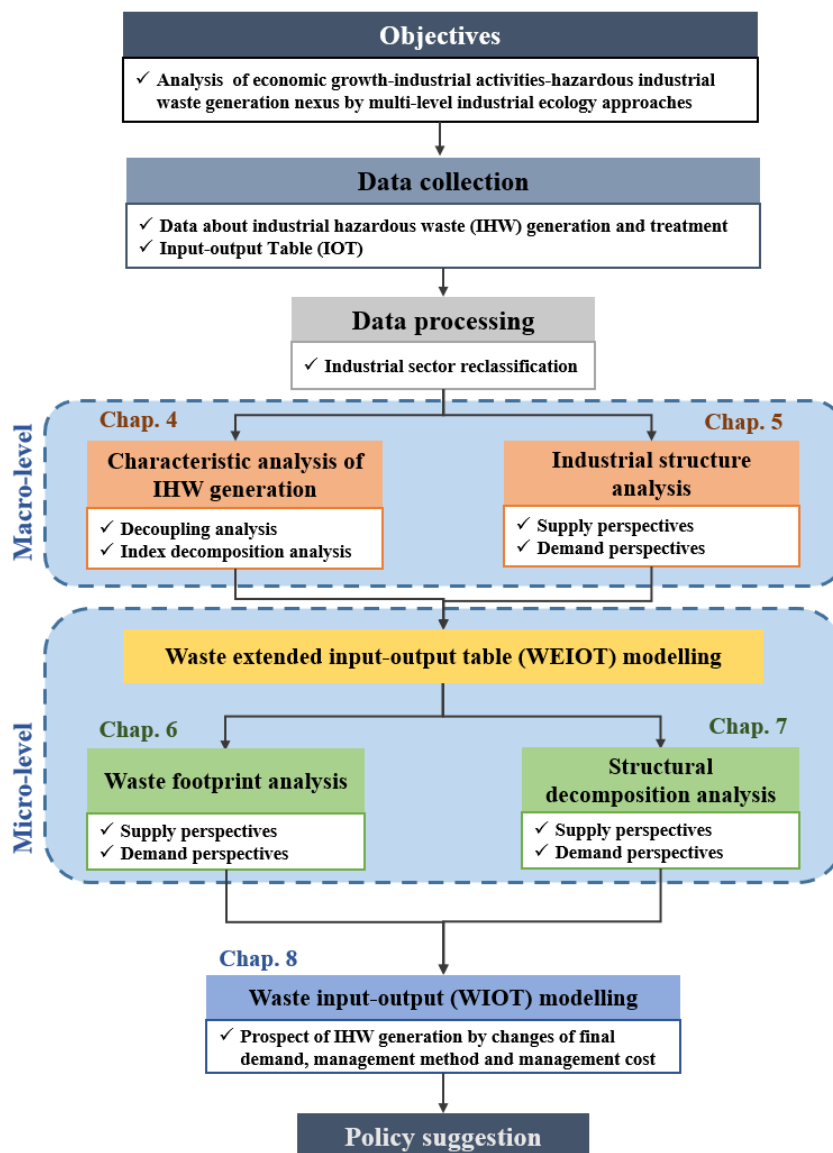


Figure 1-3. Framework of research work

Table 1-1. Outline of the research work

Title	Description	Pages
Chapter 1 Introduction	Introduces the background of this research as well as the research objectives and questions	1-10
Chapter 2 Literature review	Conducts a comprehensive review on the theories (industrial ecology, circular economy), research target (industrial hazardous waste), and industrial ecological methodologies	11-33
Chapter 3 Methodology and data	Describes and explains the methodologies used to this research and data	34-38
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Chapter 2 : Literature review

This chapter presents basic and sufficient background knowledge on related terms, concepts, and literature, which is necessary to lay the foundation for research for the purpose of research. It mainly consists of three parts, including the basic concepts of industrial ecology and circular economy, which are the basic theory of this research, and as well as a literature review on the concept, type, and treatment method of industrial hazardous waste, which is the target of this research. In addition, it includes the concept, history, and application in various fields of industrial ecological tools such as decoupling analysis, decomposition analysis, input-output analysis, and waste input-output analysis used in this research work.

By providing brief and comprehensive literature reviews on concepts of industrial ecology, industrial hazardous waste, and industrial ecological tools, this chapter aims to ensure that all readers fully understand these concepts in a wide range of fields, regardless of their respective backgrounds or expertise.

2.1. Review on the theory

2.1.1. Industrial ecology

Industrial ecology (IE) is a word that combines the words ‘industry’ and ‘ecology’ and is defined as a “broad, holistic framework for guiding the transformation of the industrial system to a sustainable basis” (E. A. Lowe & Evans, 1995). It is a concept to enable industrial activities to produce goods using resources organically as if in the form of a natural ecosystem (L.W et al., 1992; S., 1997; T.E., 1996). The ultimate goal of IE is to develop an almost closed-loop industrial ecosystem to improve environmental sustainability. Based on this concept, IE, as an interdisciplinary study field, was developed to provide a new conceptual framework for understanding the interactions between industrial systems and environments, societies at various scales (Huber, 2000; E. Lowe, 1993). It had become popular in 1989 with a Scientific American article by (Frosch & Gallopoulos, 1989) who suggested firstly the need for an industrial ecosystem where the use of energy and materials is optimized, waste and pollution are minimized, and that every products in the manufacturing process has an economically viable role (Ayres & Ayres, 2002; Diwekar & J.Small, 1998).

IE approach includes many tools and methodologies such as Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Input-Output Analysis (IOA), Geographic Information System (GIS), and other tools that include industrial symbiosis concepts (J. Kim & Perez, 2015). These tools can be applied to study specific networks containing resources, energy, and environmental pollutant (e.g., waste, air pollutant, water pollutant, soil pollutant, etc.) flows at various levels (e.g., industry, community, city, region, and nation, world levels) (Horváth & Harazin, 2016; Schiller et al., 2014; Von et al., n.d.; G. Wang et al., 2014).

2.1.2. Circular economy

The linear economic system of ‘mass production-consumption-disposal’, which was primarily aimed at increasing raw material extraction, production, and goods shipment in the early days of industrialization, caused a variety of environmental problems, such as large amounts of waste, climate change, and instability in supply and demand of resources (Jackson, 2019; Sariatli, 2017; van den Bergh, 2017). To solve these global environmental problems and achieve sustainable development, it is necessary to break away from the existing linear economic structure and transform into a circular economy (CE) that reduces the use of natural resources and pursues a virtuous cycle of resources (Hartley et al., 2020; Korhonen et al., 2018; Moraga et al., 2019; Morseletto, 2020; Prieto-Sandoval et al., 2018). CE provides economic systems with a circular alternative flow model by turning end-of-life commodities into resources of others, closing the loops of industrial ecosystems and minimizing waste (Korhonen et al., 2018; Cahya, 2016; International Reference Centre for the Life Cycle of Products, 2015). This approach requires more efficient and effective use of raw materials, a longer lifespan of the products, and the emission of waste should be avoided as far as possible. Unlike the past, which focused on dealing with waste, CE focuses on reducing waste itself by treating waste as a resource and creating resource circulation.

CE has emerged in earnest since the 1990s to solve the various environmental problems currently facing industrialized countries. According to a study of seven European countries, the transition to a circular economy has been shown to be a dramatic low-carbon economy that cuts each country’s greenhouse gas emissions by up to 70% and increases the workforce by around 4% (Stahel, 2016). For the past ten years, the USA (Lonca et al., 2020), Japan (Jialin et

al., 2017; Wuyts et al., 2019), China (Ali et al., 2018; Junming et al., 2018), EU (de Sadeleer et al., 2020; Milios, 2018), and South Korea (Herrador et al., 2020; Jang et al., 2020; Lee & Cha, 2021), etc. have been establishing new policies to achieve the mid to-long-term goals of the CE through research to foster a CE by promoting reproduction and reuse.

2.2. Review on industrial hazardous waste

2.2.1. The definition of industrial hazardous waste

Waste is defined as ‘materials that are no longer necessary for human life or industrial activities, such as garbage, combustion ash, sludge, waste oil, and waste acid, etc.’. The form does not necessarily mean a solid-state and could be a liquid or a gas contained in a container.

In South Korea, waste is classified into household waste, industrial waste based on waste sources, and industrial waste is classified into general waste, construction waste, and hazardous waste according to the generation characteristics and hazardous properties as Figure 2-1.

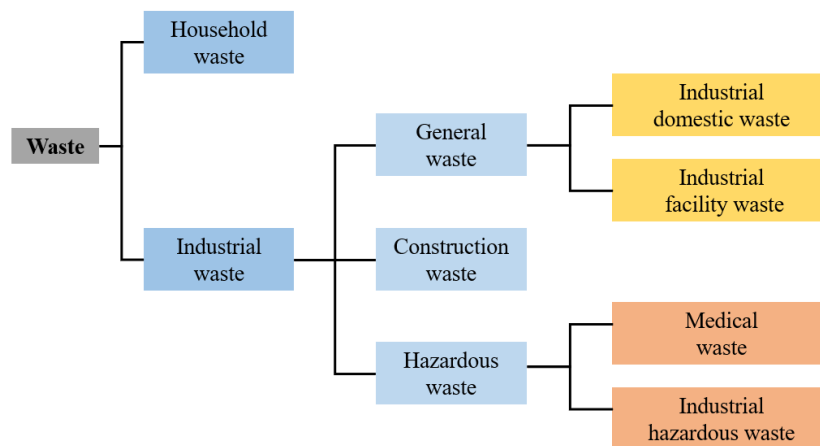


Figure 2-1. The classification of waste (Waste Control Act, 2019)

Hazardous waste is defined as waste prescribed by a Presidential decree for harmful substances such as waste oil, waste acid, etc. when it is generated from specific facilities and is leaked to the surrounding environment. And it is largely classified into industrial hazardous waste and medical waste.

2.2.2. The types of industrial hazardous waste

Hazardous waste is stipulated in 「Waste Management Act」, classified and defined in terms of the waste's sources, toxicity, and characteristics. In general, hazardous waste includes by-products and general waste containing hazardous substances generated from industrial activities, and hazardous chemical substances that are returned or discarded after the expiration date has passed. As shown in Table 2-1, in South Korea, hazardous waste is classified into 11 large categories, 35 medium categories, and 95 small categories, and industrial hazardous waste.

Table 2-1. The classification of hazardous waste (Waste Control Act, 2019)

	Large category	Medium category	Small category
Hazardous waste	1. Waste generated in a specific facility	(a) Waste synthetic polymeric compound	95 types
		(b) Sludge	
		(c) Waste pesticide	
	2. Corrosive waste	(a) Waste acid	
		(b) Waste alkali	
	3. Waste containing hazardous substance	(a) Slag	
		(b) Dust	
		(c) Waste molding sand / Waste sand	
		(d) Waste refractory / Waste piece of pottery	
		(e) Ash	
		(f) Stabilizing / Solidification compound	
		(g) Waste catalysis	
		(h) Waste absorbent / Waste adsorbent	
		(i) Waste fluorescent lamp residue	
	4. Waste organic solvent	(a) Waste halogen organic solvent	
		(b) Other waste organic solvent	
	5. Waste paint / waste lacquer	(a) Waste oil paint	
		(b) Waste water paint	
		(c) Waste lacquer	
	6. Waste oil	(a) Waste mineral oil	
		(b) Waste animal and vegetable oil	
		(c) Other waste oil	
	7. Waste asbestos	(a) Waste asbestos from disorganization process	
		(b) Dust collected from asbestos product process	
		(c) Equipment used for removing asbestos	
	8. Waste containing PCBs	(a) Waste oil containing PCBs	
		(b) Waste organic solvent containing PCBs	
		(c) Liquid containing PCBs	
		(d) Non liquid containing PCBs	
	9. Waste toxic substances	(a) Prohibited substances according to Article 2(5) of the 「Chemical Substance Control Act」	
		(b) Waste reagent for research and inspection	
		(c) Other wastes toxic substances	
	Medical waste	10. Medical waste	
(b) Hazardous medical waste			
(c) General medical waste			
11. Other wastes notified by the Minister of Environment			

Industrial hazardous waste falls under categories 1 to 9, and 11 in large categories; waste generated in a specific facility (waste synthetic polymeric compound, sludge, waste pesticide), corrosive waste (waste acid, waste alkali), waste containing hazardous substance (slag, dust, waste molding sand/waste sand, waste refractory/waste piece of pottery, ash, stabilizing/solidification compound, waste catalysis, waste absorbent/waste adsorbent, waste fluorescent lamp residue), waste organic solvent (waste halogen organic solvent, other waste organic solvent), waste paint/waste lacquer, waste oil, waste asbestos, waste containing PCBs, waste toxic substances, and other wastes notified by the Minister of Environment.

2.2.3. Treatment method of industrial hazardous waste

Industrial hazardous waste treatment methods are classified into incineration, high-temperature incineration, high-temperature melting, solidification, landfill, physicochemical treatment, and recycling according to the source and characteristics of the waste. Physicochemical treatment is subdivided into neutralization, hydrolysis, oxidation, reduction, evaporation, concentration, coagulation, precipitation, and stabilization, etc. And recycling is subdivided into refining treatment, extraction of reclaimed fuel oil.

The Ministry of Environment categorizes them into incineration, landfill, recycling, and others and publishes statistics every year. Others include treatment methods other than incineration, landfill, and recycling. Table 2-2 shows treatment methods for 22 types of industrial hazardous waste.

Table 2-2. Treatment method of industrial hazardous waste (Waste Control Act, 2019)

Waste type	Incineration	Landfill	Recycling	Others
Process sludge	○	○	○	-
Slag	○	○	○	-
Waste organic solvent	○	-	○	○
Dust	○	○	○	○
Ash	○	○	○	○
Stabilizing/ Solidification compound	-	○	-	-
Waste refractory/ Waste piece of ceramic	-	○	-	-
Waste pesticide	○	-	-	-
Waste acid	○	○	○	○
Waste asbestos	○	○	-	○
Wastewater sludge	○	○	○	○
Waste alkali	○	○	○	○
Waste oil	○	○	○	○
Waste toxic substances		-	○	-
Waste molding sand/ Waste sand	-	○	○	-
Waste catalysis	-	○	○	-
Waste paint and lacquer	○	-	○	○
Waste synthetic rubber	○	-	○	-
Waste synthetic resins	○	-	○	-
Waste absorbent/ Waste adsorbent	○	○	○	-
Waste halogen organic solvent	○	-	○	-
Waste containing PCBs	○	-	-	-

2.3. Review on methodologies

2.3.1. Decoupling analysis

The decoupling theory was first proposed by the Organization for Economic Cooperation and Development (OECD) in 2002 (OECD, 2002). It refers to breaking the linkage between “environmental pressure” and “economic output” (UNEP, 2011). The OECD proposed its own decoupling model, dividing “decoupling” into two types: absolute decoupling and relative decoupling. Based on the OECD decoupling model, Vehmas et al. (2018) expanded the decoupling state from two types to six types, including strong decoupling, weak decoupling, strong coupling, weak coupling, expansive coupling, and recessive coupling. And in 2005, Tapio introduced six decoupling types including expansive negative decoupling, weak decoupling, strong decoupling, recessive decoupling, weak negative decoupling, strong negative decoupling, and two kinds of coupling as expanding coupling, recessive coupling, as shown in Figure 2-2 (Tapio, 2005).

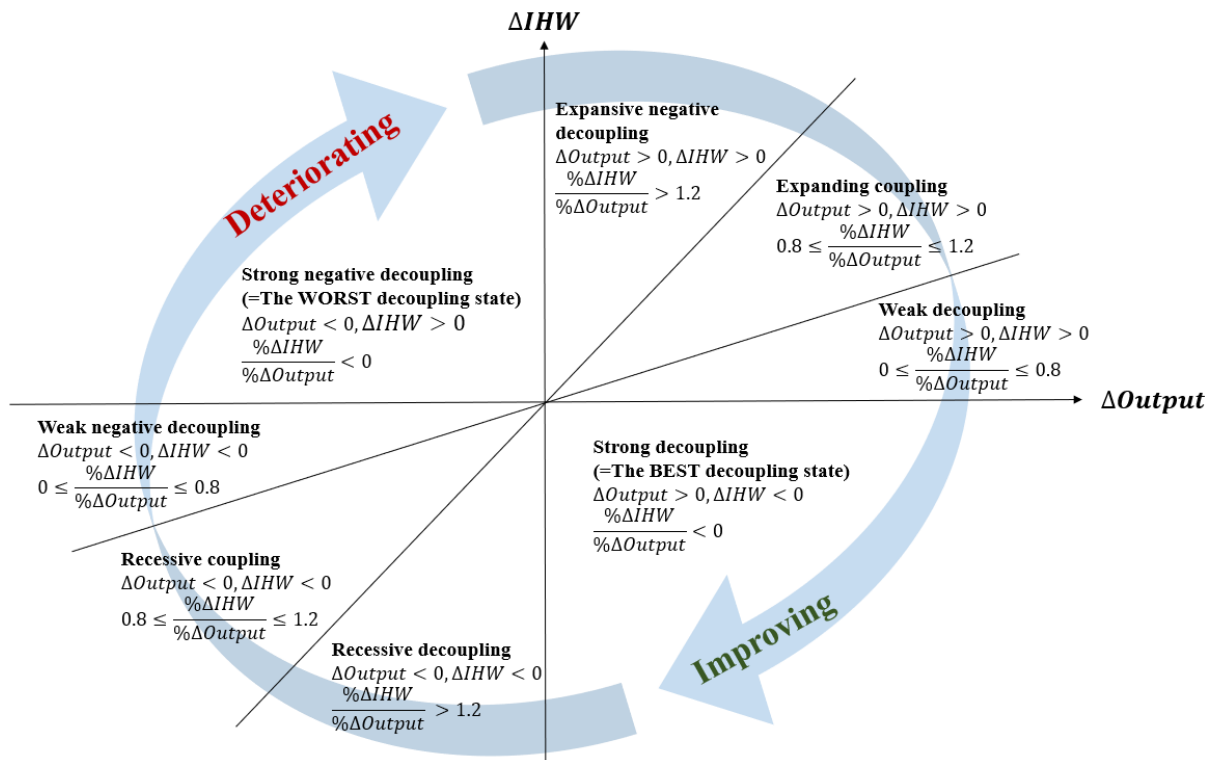


Figure 2-2. The degrees of coupling and decoupling of industrial hazardous waste generation (ΔIHW) from economic growth ($\Delta Output$) (Modified Tapio (2005))

To analyze sustainability of economic development, industrialization, and urbanization, decoupling and index decomposition analysis have been widely used. In resources and environment field, the Tapio decoupling model has been mostly applied to analyze the decoupling relationship between economic growth and GHG emissions (Gao et al., 2021; Cappes et al., 2020; Hang et al., 2019; B. Chen et al., 2017), CO₂ emissions (J. Chen et al., 2018; Hu et al., 2020; Jin et al., 2020; Luo et al., 2017; Riti et al., 2017), and energy consumption (Akizu-Gardoki et al., 2018; Boqiang Lin & Wang, 2019; Xi Chen et al., 2020; Li et al., 2021; Wei et al., 2020). However, in recent years, the decoupling analysis has also begun to be adopted in waste research (Xingpeng Chen et al., 2014; Jaligot & Chenal, 2018; Teli, 2021; Tsiamis et al., 2018).

2.3.2. Index decomposition analysis

The methodology for decomposing and analyzing the factors of change over time of socio-economic indicators is divided into Index Decomposition Analysis (IDA) methodology and Structural Decomposition Analysis (SDA) methodology. IDA methodology has begun to study the effect of changes in industrial structure or energy intensity by sector on the industry's energy use trend in the late 1970s (Ang, 2004). This analysis period is relatively free because only reference year's data and the comparative year are used. As shown in Figure 2-3, the IDA methodology can be divided into the Laspeyres index methodology and the Divisia index methodology. In the late 1970s and early 1980s, a method approaching the Laspeyres index methodology was mainly used. Since then, more studies have begun using the Divisia index methodology in energy factor decomposition analysis (Ang et al., 1998; Ang & Liu, 2001), starting with studies proposing the Divisia index methodology against the Laspeyres index methodology. Among the Divisia IDA methodologies, the Log-Mean Divisia Index (LMDI) methodology is evaluated to be superior to other IDA methodologies. It has usability, ease of application, and convenience of interpretation of results, and no residuals remain after decomposition (Ang, 2005; Muller, 2006). The LMDI methodology can be divided into additive decomposition and multiplicative decomposition. The difference is that additive decomposition is an index decomposition methodology of the difference for the total change (Difference/Total Change), and multiplicative decomposition is an index decomposition methodology of the ratio of for the total change (Ration/Total Change) (Ang & Wang, 2015b).

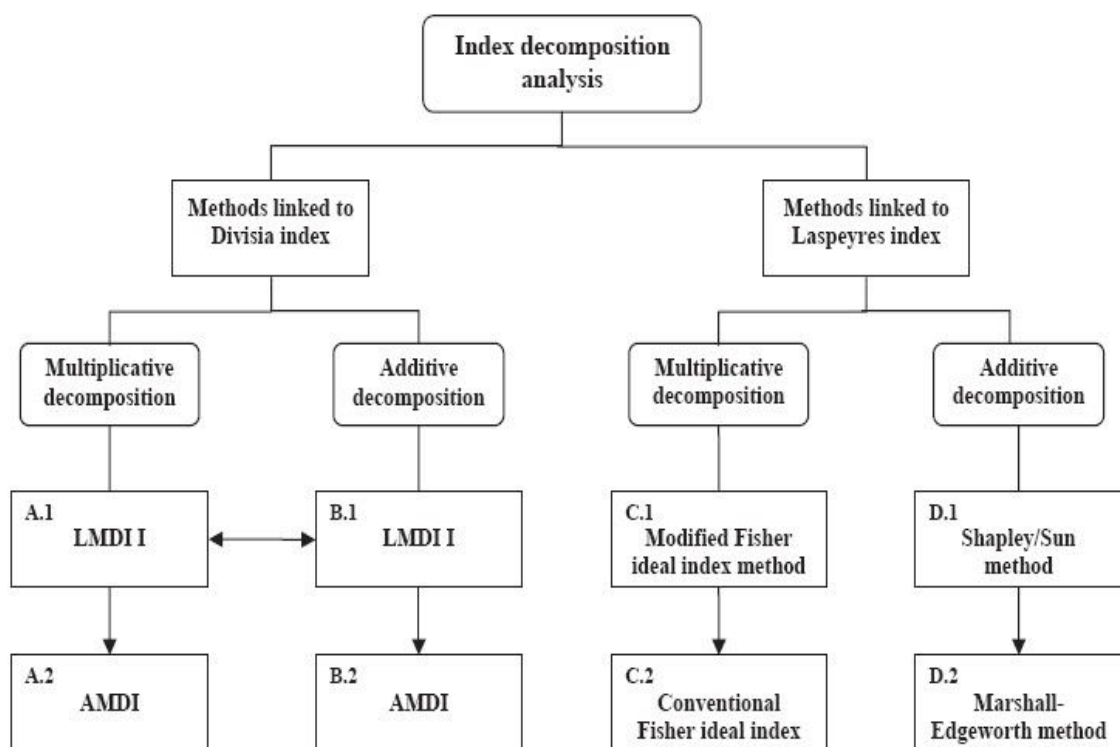


Figure 2-3. Recommended methods for energy decomposition analysis (Ang, 2004)

Decomposition analysis studies have been mainly used for GHG, including CO₂ emissions (Chontanawat et al., 2020; S. Guo et al., 2020; Jiang et al., 2021; Mohmmmed et al., 2019; Nkam Taka et al., 2020; Serrano-Puente, 2021; Talaei et al., 2020; X. Wang et al., 2020), but started to be applied for waste research recently in the world. (Zhang et al., 2021b) analyzed the socioeconomic drivers and identified the key supply chains that cause changes in industrial solid waste generation using monetary input-output tables in China. (Madden et al., 2019) explored regional variation in the decoupling of waste generation from mean income in Australia, following the waste Kuznet’s curve hypothesis. (Yagi & Kokubu, 2019) performed LMDI analysis for 5 Japanese manufacturing sectors to investigate the effects of material and

financial factors on corporate waste generation. (Jaligot & Chenal, 2018) investigated the influence of socio-economic drivers on municipal solid waste generation in Switzerland. (Xingpeng Chen et al., 2014) decomposed industrial solid waste discharge (ISWD) into six influencing factors: population, per capita GDP, industrial structure, investment intensity in treatment of industrial solid waste (ISW), investment efficiency of ISW recycle, and ISWD intensity.

2.3.3. Input-output analysis

In the national economic system, each industry has a direct and indirect relationship with each other through the process of purchasing and selling goods and services to each other for production activities. Input-output table (IOT) is defined as a comprehensive statistical table of the national economy. The interrelationship between industries for a certain period are recorded in a matrix format according to certain principles. Quantitative analysis of the interrelationship between industries using such an IOT is called input-output analysis (IOA), which can be used to establish economic policies and calculate ripple effects.

The basic structure of the IOT is shown in Table 2-3 and the vertical direction of IOT shows the input structure of each industry, and the horizontal direction of IOT shows the distribution structure. The vertical (column) direction consists of the intermediate input sector, which is the purchase details of raw materials and components. The value-added sector is the purchase details of labor or capital, and the sum is the total input. The horizontal (row) direction is divided into two sectors: intermediate demand, in which products of each industrial sector are sold as intermediate goods, and final demand, in which products are sold as consumer goods,

capital goods, and exports goods. The final demand sector includes consumption, investment, and exports. The sum of intermediate demand and final demand is total demand, and the total demand minus imports are the total output. The total input and output, which are the sums of the two directions, coincide with industry, indicating a supply-demand balance (Miernyk, 2020).

Table 2-3. The basic structure of the input-output table

		Intermediate output			Final demand			Imports	Total output
		1	...	n	Consumption	Investment	Exports		
Intermediate input	1	x_{11}	...	x_{1n}	Y_{C1}	Y_{I1}	Y_{E1}	M_1	X_1
	⋮	⋮	...	⋮	⋮	⋮	⋮	⋮	⋮
	n	x_{n1}	...	x_{nn}	Y_{Cn}	Y_{In}	Y_{En}	M_n	X_n
Added value		V_1	...	V_n					
Total output		X_1	...	X_n					

IOA began in 1936 when Leontief made out an economic table that collectively expressed the flow of all goods and services in the U.S. economy and '*Quantitative Input-Output Relations in the Economic System of the United States* (Leontief, 1936)'. After that, an IOT for the U.S. economy for 1919-1929 was made out and published as 'The Structure of American Economy, 1919-1929: An Empirical Application of Equilibrium Analysis (Leontief, 1942)'. He continued to publish 'The Structure of American Economy, 1919-1939: An Empirical Application of Equilibrium Analysis (Leontief, 1951)', which can be said to be the source of IOA.

The basic principle of IOA is to measure and analyze the size of production generated by final demand through input coefficients. For this, it is necessary to understand the concept of the input coefficient and production inducement coefficient. The input coefficient is a basic coefficient for IOA, and it is obtained by dividing the intermediate input of each industry by the industry's total input (= total output). It represents the unit of intermediate goods required for each sector to produce one unit of product, so it means the production technology structure of each sector. The input coefficient table is made by collecting the input coefficient vectors of each sector into one matrix, which is called the technical coefficients matrix. The input coefficient constituting the technical coefficient matrix can be expressed as Eq 2-1.

$$a_{ij} = \frac{X_{ij}}{X_j} \quad \text{Eq 2-1}$$

Where a_{ij} is the input coefficient of industry i for production of one unit of industry j , X_{ij} is the input from industry i to industry j , and X_j is total input of industry j .

The technical coefficients matrix is the medium that plays the most important role in calculating the direct and indirect correlation effects and ripple effects between sectors. In the case of many sectors, it is difficult to individually calculate the infinitely repeated production inducement effect using the input coefficient, so the production inducement coefficient is derived and used by a mathematical method called the inverse matrix.

The total output is obtained by subtracting the supply sector's imports and residues from the total demand (intermediate demand + final demand) in the IOT. This relationship can be expressed as a simultaneous equation, called supply-demand equation. When an economy is

composed of n sectors, the supply-supply equation for each product sector on the IOT can be expressed as the following Eq 2-2. Y_i is the final demand of industry i , M_i is the imports of industry i , and Z_i is the residue of industry i .

$$\begin{aligned}
 a_{11}X_1 + \dots + a_{1j}X_j + \dots + a_{1n}X_n + Y_1 - M_1 - Z_1 &= X_1 \\
 \vdots & \\
 a_{i1}X_1 + \dots + a_{ij}X_j + \dots + a_{in}X_n + Y_i - M_i - Z_i &= X_i \\
 \vdots & \\
 a_{n1}X_1 + \dots + a_{nj}X_j + \dots + a_{nn}X_n + Y_n - M_n - Z_n &= X_n
 \end{aligned}
 \tag{Eq 2-2}$$

Eq 2-3 is obtained from Eq 2-2 as a matrix.

$$\begin{bmatrix} a_{11} & \dots & a_{1j} & \dots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \dots & a_{ij} & \dots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \dots & a_{nj} & \dots & a_{nn} \end{bmatrix}
 \begin{bmatrix} X_1 \\ \vdots \\ X_j \\ \vdots \\ X_n \end{bmatrix}
 +
 \begin{bmatrix} Y_1 \\ \vdots \\ Y_j \\ \vdots \\ Y_n \end{bmatrix}
 -
 \begin{bmatrix} M_1 \\ \vdots \\ M_j \\ \vdots \\ M_n \end{bmatrix}
 -
 \begin{bmatrix} Z_1 \\ \vdots \\ Z_j \\ \vdots \\ Z_n \end{bmatrix}
 =
 \begin{bmatrix} X_1 \\ \vdots \\ X_j \\ \vdots \\ X_n \end{bmatrix}
 \tag{Eq 2-3}$$

$$A \cdot X + Y - M - Z = X$$

Where A is the technical coefficients matrix, X is the vector of total output, Y is the vector of the vector of final demand, M is the vector of imports, and Z is the vector of residue.

We can get Eq 2-4 by solving the Eq 2-3 for X .

$$X - AX = Y - M - Z$$

$$(I - A) \cdot X = Y - M - Z \tag{Eq 2-4}$$

$$X = (I - A)^{-1} \cdot (Y - M - Z)$$

Where $(I - A)^{-1}$ is production inducement coefficient matrix (Leontief inverse matrix), and I is an identity matrix which diagonal elements are all 1 and all other elements are 0 as Eq 2-5.

$$I = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & & \vdots \\ 0 & 0 & 0 & \cdots & 1 \end{bmatrix} \quad \text{Eq 2-5}$$

The change in final demand can be independently estimated and the corresponding level of change in production can be measure by calculating the production inducement coefficient using the input coefficient in this way. The production inducement coefficient represents the direct and indirect ripple effect on the production of each sector when one unit of final demand is required and has the meaning of a cumulative multiplier. It can be seen more clearly in the process of calculating the production inducement coefficients using input coefficients. When a certain real number a is $0 < a < 1$, $(I - a)^{-1}$, which is the multiplicative inverse of $(I - a)$, can be expressed as the sum of infinite geometric series as in Eq 2-6 below.

$$(I - a)^{-1} = \frac{1}{1 - a} = 1 + a + a^2 + a^3 + \dots \quad \text{Eq 2-6}$$

Applying Eq 2-6, $(I - A)^{-1}$ is expressed as Eq 2-7.

$$(I - A)^{-1} = I + A + A^2 + A^3 + \dots \quad \text{Eq 2-7}$$

On the right side of this equation, the identity matrix I is the direct production effect of each sector to satisfy one unit of final demand for each sector's product, and A is the input unit of intermediate goods required for the production of one unit of each sector, that is, the primary production ripple effect. A^2 is the input unit of intermediate goods required for the production in each sector from the primary production ripple effect, that is, the secondary production ripple effect. Similarly, A^3 , A^4 , \dots are the tertiary, fourth, and \dots th production ripple effects, respectively. Therefore, $(I - A)^{-1}$ means the production inducement coefficient, which is the sum of the direct and indirect production ripple effects caused by increasing one unit of final demand. Since the production inducement coefficient has the property of multiplier representing the ripple effect derived from the final demand, it is also called the Leontief multiplier.

Based on this concept, it is being actively carried out in the fields of energy, water, GHG, and CO₂ that link the environment and resource with economy for assessment and evaluation for sustainability and resource circulation (Bagoulla & Guillotreau, 2020; Beylot et al., 2020; Deng et al., 2020; Malik et al., 2021; Wieland et al., 2019; Zheng et al., 2020; Zhong et al., 2021).

2.3.4. Waste-extended input-output analysis

There are many links between the environment and the economy and IOA has been used to quantify and understand environmental problem since Leontief's Environmental IO (EIO) model (Leontief 1970) was introduced to account for pollution, with Converse (1971) being

the first to extend EIO towards quantifying and understanding problems of waste generation. One way to display these links is to use the environment ‘satellite’ at the bottom of the IOT. The basic structure of the waste-extended input-output table (WEIOT), which links the amount of industrial hazardous waste (IHW) generation in physical units to the IOT indicated in the monetary units, is shown in Table 2-4.

Table 2-4. The basic structure of waste-extended input-output table

		Intermediate output			Final demand			Imports	Total output
		1	...	n	Consumption	Investment	Exports		
Intermediate input	1	x_{11}	...	x_{1n}	Y_{C1}	Y_{I1}	Y_{E1}	M_1	X_1
	⋮	⋮	...	⋮	⋮	⋮	⋮	⋮	⋮
	n	x_{n1}	...	x_{nn}	Y_{Cn}	Y_{In}	Y_{En}	M_n	X_n
Added value		V_1	...	V_n					
Total output		X_1	...	X_n					
Waste type	1	w_{11}	...	w_{1n}					
	⋮	⋮	...	⋮					
	z	w_{z1}	...	w_{zn}					
Total waste generation		W_1	...	W_n					

This WEIOT shows the structure of the waste input-output matrix covering the industrial production sector, the waste generation sector, and the waste treatment sector, which generally has the shape of a non-square matrix. The non-square matrix is that the number of types of waste is usually more significant than the number of waste treatment numbers, and a plurality

of different treatment methods may exist for a specific waste.

The upper part of Table 2-4 consists of input-output of goods and services, final demand, and total output, similar to the general IOT. However, it is different from the IOT in that the waste treatment sector is added here. And all sectors appearing at the upper part are expressed in monetary units. X_0 matrix represents the input of IOT composed of N industries, and X_z matrix represents the input of the production sector to the waste treatment sector composed of T treatment methods. The lower part of Table 2-4 shows the unique structure of the waste input-output matrix. The sectors indicated in this part represent the flow of waste generated in the production and treatment sectors, and all values are expressed in physical units. W_0 matrix represents the amount of waste generation in the goods production sector, W_z matrix represents the amount of waste generated from the waste treatment sector, and the W_f vector represents the amount of waste generated in the final demand sector. The W_z matrix is waste generated from the final waste treatment, including ash generated during incineration and residue generated from the recycling process. In the case of the landfill, since the waste itself is landfilled as the final stage, it can be considered that no significant solid waste is generated except for leachate.

The waste generation coefficient by industry (w) is expressed as the amount of waste generated (W) relative to the total output (X) by industry.

$$w = \frac{W}{X} \quad \text{Eq 2-8}$$

Eq 2-9 is derived when the diagonal matrix of waste generation coefficient ($\hat{w} = W/X$) is multiplied by both sides of Eq 2-4.

$$W = \hat{w} \cdot (I - A)^{-1} \cdot (Y - M - Z) \quad \text{Eq 2-9}$$

Where, $\hat{w} \cdot (I - A)^{-1}$ is the waste generation inducement coefficient.

2.3.5. Structural decomposition analysis

Structural decomposition analysis (SDA) is one methodology for decomposing and analyzing the factors of change over time of socio-economic indicators. This method based on the time-series IOT (Peng et al., 2018). Also, it is based on comparative static analysis, which decomposes historical changes of a policy variable into determinant effects. SDA has been applied, for example, to analyze the demand and technological driving forces of energy use, CO₂ emission and various other pollutants and resources (Hoekstra & Van Den Bergh, 2002). The strength of SDA is that it is capable of detailed analysis of changes in the economic structure. Since it is based on the input-output model, it is possible to distinguish the direct and indirect influence of final demand and input technology changes. Assuming that the matrix of technical coefficients, A , defines the intermediate input requirements per unit output of each sector, the input-output model is (Miller & Blair, 1985):

$$X = L \cdot Y \quad \text{Eq 2-10}$$

Where $L = (I - A)^{-1}$ is the Leontief inverse matrix and Y is the vector of final demand. Decomposing this equation results in a the ‘technical coefficient effect’, due to changes in the intermediate input structure, and a ‘final demand effect’, attributable to changes in Y :

$$\Delta X = \Delta L \cdot Y + L \cdot \Delta Y$$

Eq 2-11

Both effects can be decomposed in more detail.

SDA has become one of the most used tools in input-output research, a practical approach to decomposing changes in many environmental and socioeconomic variables, such as economic growth, energy consumption, and pollutant emissions (Lenzen, 2016). It has been widely applied at the global level (Hoekstra et al., 2016; Malik and Lan, 2016; Roson and Sartori, 2015), national level (Huang et al., 2020; He et al., 2019; Guevara and Rodrigues, 2016; Liang et al., 2013; Weber, 2009), and regional level (Shang et al., 2017; Okuyama, 2014; Wang et al., 2013). The main environmental indicators that have been investigated include energy (Guevara and Rodrigues, 2016; Weber, 2009), CO₂ (Hoekstra et al., 2016; Malik and Lan, 2016; Wang et al., 2013), water (Shang et al., 2017; Roson and Sartori, 2015), and waste (Huang et al., 2020; He et al., 2019). However, identifying the drivers of IHW based on the WIO model is still uncommon. Therefore, a systematic analysis is needed for rational policy establishment.

2.3.6. Waste input-output analysis

The EIO model of waste flow requires a one-to-one correspondence between waste types and treatment methods to facilitate multiplier calculation. This requirement results in a symmetric IOT where the waste flows are aggregated and simplified, ensuring loss of details. To overcome these shortcomings, (Shinichiro Nakamura & Kondo, 2009) introduced a separate matrix listing waste allocation to the treatment sector into their WIOT (Waste input-output table)

so that multiple waste types can be treated simultaneously by different treatment sectors. To reflect pollution generation and treatment activities, environmental satellite augment IOT with additional rows and columns (Shinichiro Nakamura & Kondo, 2009). This waste IO (WIO) model introduced by S. Nakamura & Kondo (2002), was developed to link monetary flows of products and services with physical waste flows generated and treated.

As a pioneer of WIO, Japan has a well-set up WIO system and data at the national level. Therefore, researches on it in Japan are being conducted most actively. (Shinichiro Nakamura, 2020) identified the product origins of waste and factors behind the waste flows that would not be recognizable by waste footprint, using the WIO data recently developed and published by the Japanese Ministry of the Environment (MOE). (Shinichiro Nakamura & Kondo, 2018) developed a dynamic WIO model that fully considers the issue of quality in recycling that fully takes into account the issues of recycling quality and explained the mechanism of recycling. (Beylot et al., 2018) provided a mapping of the changes in French household waste footprints with indications of where these changes would actually occur in the economy and geographically using WIO model. (Beylot et al., 2016) investigated the benefits of waste management policies on air pollutions and resource consumption caused by the final demand in France using hybrid monetary physical IO model. Further, studies using WIO are being conducted in Australia (He et al., 2020; Fry et al., 2016; Reynolds et al., 2016; Reynolds et al., 2015), the US (Meyer et al., 2020; Read et al., 2020), China (Zhang et al., 2021; Huang et al., 2020; Huang et al., 2020b; Xiao et al., 2020) Spain (Camacho et al., 2020; Ruiz-Peñalver et al., 2019; Ruiz Peñalver et al., 2014), Taiwan (Liao et al., 2019; Chen et al., 2017), the UK (Salemdeeb et al., 2016), and (Tisserant et al., 2017) for 48 world regions.

Chapter 3 : Methodology and data

Among the various industrial ecological tools, the concepts, terms, and applications of decoupling, IOA, WIOA, and decomposition analysis were well discussed in the previous chapters. The need for research on IHW and limitations on the lack of data and research in this IHW area were also pointed out through Chapter 1 and Chapter 2. Until now, the research objectives, questions, and scope of this study have been clearly established.

This chapter proposes a comprehensive overview of the methodology used within this research work while giving a list of the data source.

3.1. Methodology

This research develops and applies a methodology to analyze the characteristics of IHW generation, IHW footprint, and scenarios comprehensively and in detail at the national and industrial level by modifying various industrial ecological tools. An overview of the methodology of this research work is summarized in Figure 3-1.

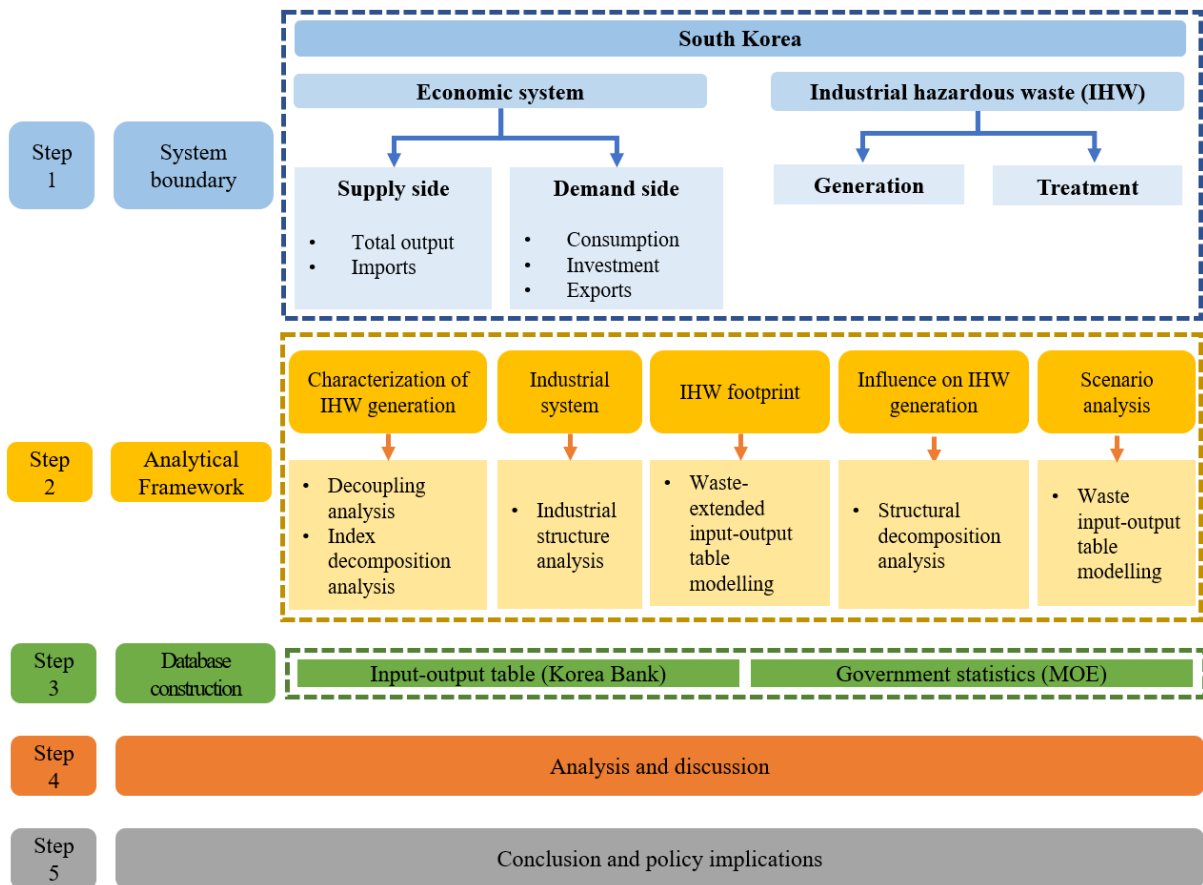


Figure 3-1. Overview of the methodology of this research work

This research begins with the collection of national data on IHW generation and treatment and IOT. Due to the industry classification inconsistency in the collected data, it is necessary to reclassify the industry sectors and process the data. Data on IHW consists of 32 industry sectors. Unlike the IHW data, there are 33 industry sectors in IOT, so in this research, the sectors are reorganized in 20 sectors according to their common trait as shown in Table 3-1.

Table 3-1. Classification of industry

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	Electronic and electrical equipment (Ee)
12	Machinery and equipment	Machinery equipment (Me)
13	Motor vehicles, trailers and semi-trailers, other transport equipment	Transport equipment (Te)
14	Other manufacturing	Other manufacturing (Om)
15	Electricity, gas, and water supply	Electricity, gas, and water supply (El)
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	Education, health, and social work (Ed)
20	Other services	Other services (Os)

According to this reclassified industry, through decoupling analysis and IDA, the characteristics of IHW generation in South Korea are comprehensively identified and changed in the industrial structure between 2008 and 2018 are analyzed. Detailed methodologies and results for these are covered in Chapter 4 and Chapter 5, respectively. Then, based on the methodology of WEIOA, the modeled WEIOT is used as a tool for IHW footprint analysis and SDA. The formula and results for these analyses are placed in Chapter 6 and Chapter 7, respectively. As a final step, WIOT of IHW in South Korea is modeled and scenario analysis is conducted to analyze the environmental and economic impacts of changes in the industrial structure of IHW generating hotspot industries, waste treatment methods, and treatment unit costs. The detailed description of this modelling methodology and scenario analysis results are covered in Chapter 8.

3.2. Data sources

The data collection process is the most basic but essential task. However, officially published data were not enough to constitute a WIO for IHW in South Korea. South Korea's IOT is regularly updated and published, but in the case of IHW related data, it was not easy to find useful data for WIOT creation.

This step aims to gather as sufficient and correct information as possible to create a WIOT of IHW that best reflects and reproduces reality. The data sources are shown in Table 3-2.

Table 3-2. Data and the sources

Data	Sources
Input-Output Table (2018)	Bank of Korea (2018)
IHW generation and treatment (2018)	Korea Ministry of Environment (2018)
IHW treatment cost for incineration and landfill	No. 2015-500 of ‘Tipping fees of industrial hazardous waste at public treatment facility’
IHW treatment cost for recycling	‘Treatment unit price for each type of waste for calculation of performance guarantee insurance for neglected wastes’ according to Article 40 (5) of ‘Waste Management Act’
The amount of ash generated from incineration facility (2016)	‘National waste statistical survey’ (2016)
Residue emission factor by waste type and treatment facility	‘Appendix 3’ of No. 2019-53 of ‘Announce on resource circulation performance management operation for business entities’

Chapter 4 : Characteristics of industrial hazardous waste generation*

The reduction of IHW generated in the production process is one of the key tasks of the new resource recycling plan announced by the South Korean government in 2020. For efficient and sustainable IHW management, the analysis of IHW generation characteristics has great significance. For the first time, this study conducted decoupling, and decomposition analysis to identify IHW generation characteristics by industry in South Korea during 2008-2018, and key findings were obtained.

One critical finding was that the industrial total output factor was significantly influence the increase of IHW generation in every industry, and the factors of industrial structure and characteristic of IHW generation and their degree of affecting the IHW generation are different by industry. Because IHW generation characteristics vary from industry to industry, integrated waste reduction plans would be ineffective to reduce IHW generation across all industry sectors. Therefore, in order to design a sustainable national IHW management strategy, it is highly recommended to include customized IHW generation reduction targets and measures in consideration of industrial specific generation characteristics of the country.

* Reproduced from “Lee. D., Kim. J., Park. H., Characteristics of industrial hazardous waste generation in South Korea from 2008 to 2018 based on decoupling and decomposition analysis, *Waste Management and Research*, 2021” copyrighted by SAGE Publications.

4.1. Methodology

4.1.1. Decoupling analysis

Decoupling status can be estimated by the Output elasticity values of environmental pressure (IHW generation), which shows in Eq 4-1:

$$\text{Output elasticity of IHW generation} = \frac{\% \Delta IHW}{\% \Delta Output} \quad \text{Eq 4-1}$$

In this paper, we conducted the decoupling analysis of IHW generation (as an environmental pressure value) from economic growth by calculating the Output elasticity according to Eq 4-1.

4.1.2. Index decomposition analysis

The decomposition equation used in this research is multiplying the factors the researcher wants to find out. The decomposition identity for analyzing the characteristics of IHW generation in Korea is expressed as Eq 4-2, a modified IPAT identity. The IPAT and Kaya identities are representative, and the IPAT identities are more commonly used for environmental studies and the Kaya identities for CO₂ emissions. Since applying IPAT identity to carbon emissions from an energy source is called the Kaya identity, the Kaya identity can be a kind of IPAT identity.

$$I = Total\ output \times \frac{Output_{industry}}{Total\ output} \times \frac{WG_{industry}}{Output_{industry}} = P \times S \times C \quad Eq\ 4-2$$

Where I is an environmental impact (IHW), $Output_{industry}$ is the output by industry, and $WG_{industry}$ is the amount of IHW generation by industry. P is total output, S is industrial structure, and C is characteristic of IHW generation.

Based on Eq 4-2, the changes of each factor can be represented in Eq 4-3 as follows:

$$\Delta I = I_{t,i} - I_{t,0} = \Delta P + \Delta S + \Delta C \quad Eq\ 4-3$$

$$\Delta P = \left(\frac{I_{t,i} - I_{t,0}}{\ln I_{t,i} - \ln I_{t,0}} \right) \times \ln \left(\frac{P_{t,i}}{P_{t,0}} \right)$$

$$\Delta S = \left(\frac{I_{t,i} - I_{t,0}}{\ln I_{t,i} - \ln I_{t,0}} \right) \times \ln \left(\frac{S_{t,i}}{S_{t,0}} \right) \quad Eq\ 4-4$$

$$\Delta C = \left(\frac{I_{t,i} - I_{t,0}}{\ln I_{t,i} - \ln I_{t,0}} \right) \times \ln \left(\frac{C_{t,i}}{C_{t,0}} \right)$$

Where, $\frac{I_{t,i} - I_{t,0}}{\ln I_{t,i} - \ln I_{t,0}}$ is the weight factor in Eq 4-4. Changes in the patent counts of a I (ΔI)

are decomposed based on changes in the factors, P, S, and C.

4.2. Results

4.2.1. Overview of industrial hazardous waste generation

Industrial hazardous waste (IHW) generation and output by the type of industry are shown in Table 4-1 and Figure 4-1.

Table 4-1. Output and industrial hazardous waste generation by primary, secondary, and tertiary industry in 2008 and 2018

(Unit: million KRW (%), ton (%))

Year	2008		2018	
Industry	Output	IHW Generation	Output	IHW Generation
Primary industry	47,865,564 (1.75)	- (-)	62,829,781 (1.45)	- (-)
Secondary industry	1,588,088,426 (57.96)	2,167,562 (52.27)	2,266,506,096 (52.27)	3,984,387 (74.28)
Tertiary industry	1,104,163,255 (40.30)	1,243,601 (63.54)	2,007,228,200 (46.29)	1,394,188 (25.92)
Total	2,740,117,234 (100.00)	3,411,163 (100.00)	4,336,564,077 (100.00)	5,378,575 (100.00)

The most significant portion of the output in 2008 was the secondary industry, contributing 57.96%, followed by the tertiary industry and the primary industry, contributing 40.30% and 1.75%, respectively. In 2018, the secondary, the tertiary, and the primary industries contributed a lot to the output in that order by 52.27%, 46.29%, and 1.45%. It shows that the output of the tertiary industry increased while the primary and secondary industries decreased.

Looking at the IHW generation, we can see that no IHW is generated at all in the primary industry, but only in the secondary and tertiary industries.

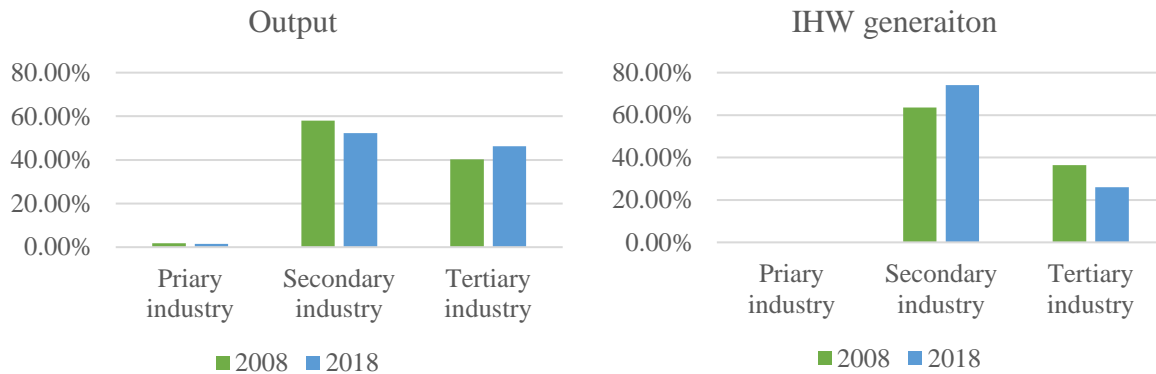


Figure 4-1. Output and industrial hazardous waste generation by type of industry in 2008 and 2018

In 2008, 63.54% of IHW was generated from the secondary industry and 36.46% from the tertiary industry. But in 2018, the IHW generation in the secondary industry increased to 74.08%, and in the tertiary industry decreased to 25.92%. As opposed to the tertiary industry, where the output proportion increased but the IHW generation proportion decreased, the secondary industry showed an increase in the IHW generation proportion despite the decrease in the output proportion. It was confirmed that it is necessary to subdivide further and analyze the industrial sector.

Table 4-2 shows the output and IHW generation by 20 industrial sectors reclassified different industrial classifications of IOT and IHW generation data according to their common trait.

Table 4-2. Output and industrial hazardous waste generation by industry sector in 2008 and 2018

(Unit: million KRW (%), ton (%))

Year	2008		2018	
Industry	Output	IHW Generation	Output	IHW Generation
Agriculture	47,865,564 (1.75)	- (-)	62,829,781 (1.45)	- (-)
Mining	3,811,611 (0.14)	646 (0.02)	4,519,229 (0.10)	7,302 (0.14)
Food	87,729,106 (3.20)	18,837 (0.55)	132,822,086 (3.06)	22,484 (0.42)
Textile	44,112,903 (1.61)	102,631 (3.01)	72,644,653 (1.68)	102,163 (1.90)
Wood	31,799,468 (1.16)	15,004 (0.44)	47,032,314 (1.08)	51,156 (0.95)
Coke	137,110,659 (5.00)	85,048 (2.49)	144,538,465 (3.33)	108,497 (2.02)
Chemical	195,324,786 (7.13)	460,003 (13.49)	286,315,794 (6.60)	994,000 (18.48)
Non-metallic mineral	29,942,931 (1.09)	27,759 (0.81)	43,962,144 (1.01)	110,107 (2.05)
Basic metal	195,207,180 (7.12)	525,292 (15.40)	145,600,764 (3.36)	859,488 (15.98)
Fabricated metal	65,296,040 (2.38)	154,638 (4.53)	100,495,199 (2.32)	149,646 (2.78)
Electronic and electrical equipment	254,121,198 (9.27)	606,242 (17.77)	434,603,762 (10.01)	1,050,589 (19.53)
Machinery equipment	97,828,849 (3.57)	20,910 (0.61)	146,210,491 (3.37)	47,864 (0.89)
Transport equipment	183,219,338 (6.69)	108,612 (3.18)	225,748,464 (5.21)	208,004 (3.87)
Other manufacturing	16,574,463 (0.60)	8,616 (0.25)	87,603,115 (2.02)	36,236 (0.67)
Electricity, gas, and water supply	64,975,201 (2.37)	32,456 (0.95)	112,655,552 (2.83)	78,092 (1.45)
Construction	181,034,693 (6.61)	870 (0.03)	271,754,064 (6.27)	158,759 (2.95)
Wholesale and retail trade	126,636,525 (4.62)	4,244 (0.12)	280,000,474 (6.46)	27,120 (0.50)
Transport and storage	113,111,873 (4.13)	36,272 (1.06)	149,651,747 (3.45)	52,821 (0.98)
Education, health, and social work	154,794,572 (5.65)	228 (0.01)	275,733,813 (6.36)	21,833 (0.41)
Other services	709,620,274 (25.90)	1,202,856 (35.26)	1,301,842,166 (30.02)	1,292,415 (24.03)
Total	2,740,117,234 (100.00)	3,411,163 (100.00)	4,336,564,077 (100.00)	5,378,575 (100.00)

Looking at the output, in 2008, 'Other services' accounted for the largest proportion with 709,620 billion KRW (25.90%). Secondary industries are followed by 'Electronic and electrical equipment' with 254,121 billion KRW (9.27%), 'Chemical' with 195,325 billion KRW (7.13%), 'Basic metal' with 195,207 billion KRW (7.12%), 'Transport equipment' with 183,219 billion KRW (6.69%). In 2018, 'Other services' contributed the most to the output with 1,301,842 billion KRW (30.02%), followed by 'Electronic and electrical equipment', 'Chemical', 'Wholesale and retail trade', and 'Education, health, and social work', with 434,604 billion KRW (10.02%), 286,316 billion KRW (6.60%), 280,000 billion KRW (6.46%), 275,734 (6.36%), respectively. We can see that all of the top five industries except for 'Other services' were secondary industries in 2008. In contrast, the top industries except for 'Electronic and electrical equipment' and 'Chemical' were tertiary industries, indicating that the output of the tertiary industry is growing remarkably.

In IHW generation, 'Other services' contributed the most with 1,202,856 tonnes (35.26%) and 1,292,415 tonnes (24.03%) in both 2008 and 2018. And 'Electronic and electrical equipment', 'Basic metal', and 'Chemical' are common industries that contributed the most after the 'Other services'. In 2008, 'Electronic and electrical equipment' contributed the most with 606,242 tonnes (17.77%), were followed by 'Basic metal' with 525,292 tonnes (15.40%), 'Chemical' with 460,003 tonnes (13.49%). However, in 2018, the rankings of 'Chemicals' and 'Basic metal' were switched. In 2018, 'Electronic and electrical equipment' contributed the most with 1,050,589 tonnes (19.53%), and were followed by 'Chemical' with 994,000 tonnes (18.48%), 'Basic metal' with 859,488 tonnes (15.98%). Unlike the output in 2018 occupied by the tertiary industries in the top groups except for the two secondary industries, the top group of IHW generation in both 2008 and 2018 occupied by secondary industries except 'Other

services' sector. This data means that although South Korea's production is shifting towards the tertiary industries from secondary industries, the IHW generation is still contributed a lot from the secondary industries.

4.2.2. Decoupling analysis

To investigate the temporal variation in the decoupling and coupling of IHWG from economic growth, we calculated the Output elasticity (decoupling value) during 2008-2018 based on Eq 4-1. The result is shown in Table 4-3 and Figure 4-2.

Table 4-3. Decoupling values of industrial hazardous waste generation from the output

(Unit: %, -)

Period	The change rate of output	The change rate of IHW generation	Decoupling value
2008-2009	1.27	-6.64	-5.22
2009-2010	9.84	5.14	0.52
2010-2011	12.59	5.50	0.44
2011-2012	4.24	24.99	5.90
2012-2013	0.84	00.86	-1.02
2013-2014	1.88	5.95	3.16
2014-2015	4.31	1.15	0.27
2015-2016	2.39	2.60	1.09
2016-2017	6.20	8.47	1.37
2017-2018	4.03	3.01	0.75
2008-2018	58.26	57.68	0.99

As shown in Figure 4-2, the amount of IHW generation is steadily increasing with South Korea's economic growth. Still, the result of the decoupling analysis shows a form of decoupling for most of the period from 2008 to 2018.

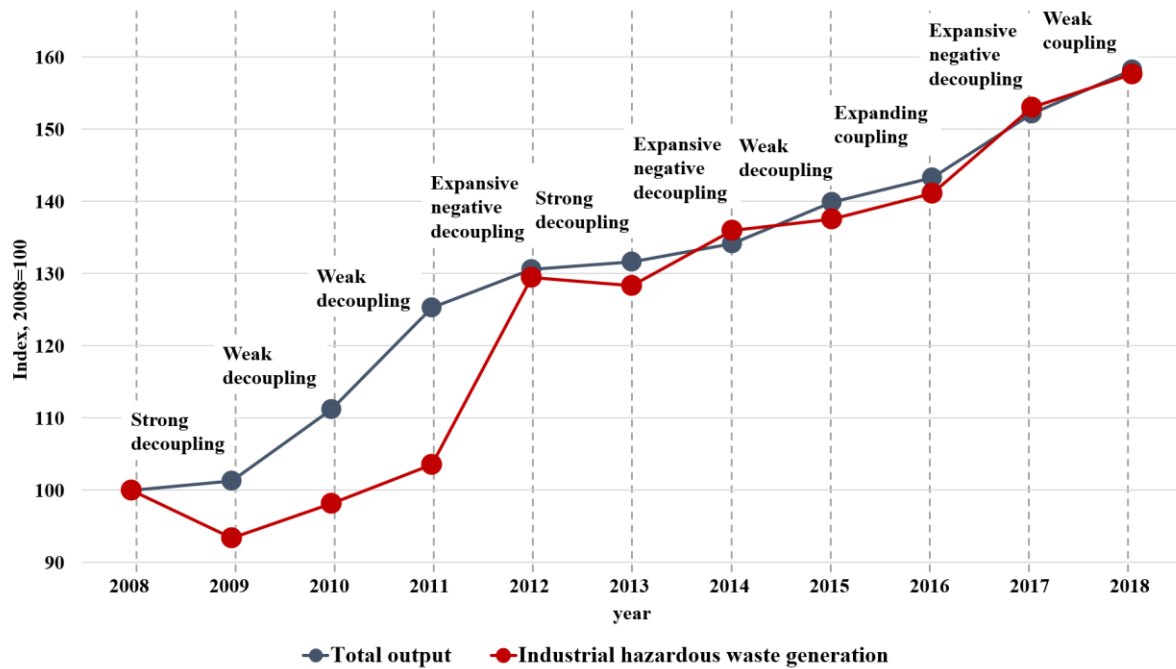


Figure 4-2. The decoupling of industrial hazardous waste generation from economic development in South Korea

Strong decoupling of IHW generation from economic growth happened 2008 -2009 and 2012-2013, and weak decoupling occurred 2009-2011, 2014-2015, and 2017-2018, and expansive negative decoupling happened 2011-2012, 2013-2014, and 2016-2017. However, non-decoupling (expanding coupling) occurred 2015-2016. In addition, the degree for the entire period of 2008-2018 shows the expanding coupling. As mentioned above, most periods show a decoupling pattern. Still, except for the strong decoupling in 2009-2009 and 2012-2013, they show a weak degree of decoupling (expansive negative decoupling, weak decoupling) or

non-decoupling (expanding coupling). Despite the efforts of issuing various waste-related laws and regulations, these unstable decoupling states imply that more practically customized IHW generation reduction measures and management are required. To devise the affective IHW generation reduction strategies and measures, it is crucial to analyze and comprehensively understand the IHW generation characteristics by industry.

4.2.3. Index decomposition analysis

To identify the IHW generation characteristics, the change of IHW generation of each industry sector between 2008 and 2018 was decomposed into three driving factors, which can reflect the effect of change in industrial output, industrial structure, characteristic of IHW generation, according to Eq 4-2 and Eq 4-3. The decomposition results are shown in Table 4-4. A positive value of the factor means that the factor affected the IHW increase. A negative value means that the factor affected the IHW decrease. As shown in Figure 4-3, we found that factors of industrial output and industrial characteristics of IHW generation were significantly influence the increase of IHW generation in most industries. In contrast, the industrial structure factor influences the decrease of IHW generation. ‘Chemicals and chemical products, rubber and plastic’, and ‘Basic metal’, which have been at the top of the IHW generation, are also in this case. This case means that the generation of IHW relative to total output increases despite the decrease in the industrial scale. It shows that IHW generation is not managed correctly in many industries. Also, eight industry sectors are exceptions to this case, and the degrees of affecting the IHW generation are different from industry to industry. So, for in-depth analysis, we focused on industrial sectors that exhibit exceptional characteristics.

Table 4-4. LMDI decomposition of industrial hazardous waste generation by industry

(Unit: tonnes)

Industry	ΔI	ΔP	ΔS	ΔT
Agriculture	-	-	-	-
Mining	6,656	1,260	-792	6,189
Food	3,647	9,460	-913	-4,900
Textile	-468	47,008	4,070	-51,546
Wood	36,152	13,531	-1,995	24,616
Coke	23,450	44,208	-39,128	18,369
Chemical	533,998	318,166	-53,122	268,954
Non-metallic mineral	82,348	27,436	-4,485	59,397
Basic metal	334,197	311,593	-510,593	533,196
Fabricated metal	-4,992	69,839	-4,245	-70,586
Electronic and electrical equipment	444,347	371,011	62,666	10,670
Machinery equipment	26,953	14,942	-1,863	13,875
Transport equipment	99,392	70,223	-38,293	67,463
Other manufacturing	27,620	8,827	23,187	-4,394
Electricity, gas, and water supply	45,637	23,862	9,163	12,612
Construction	157,889	13,921	-1,603	145,572
Wholesale and retail trade	22,875	5,662	4,124	13,089
Transport and storage	16,548	20,213	-7,888	4,223
Education, health, and social work	21,606	2,173	560	18,873
Other services	89,558	572,520	184,226	-667,189

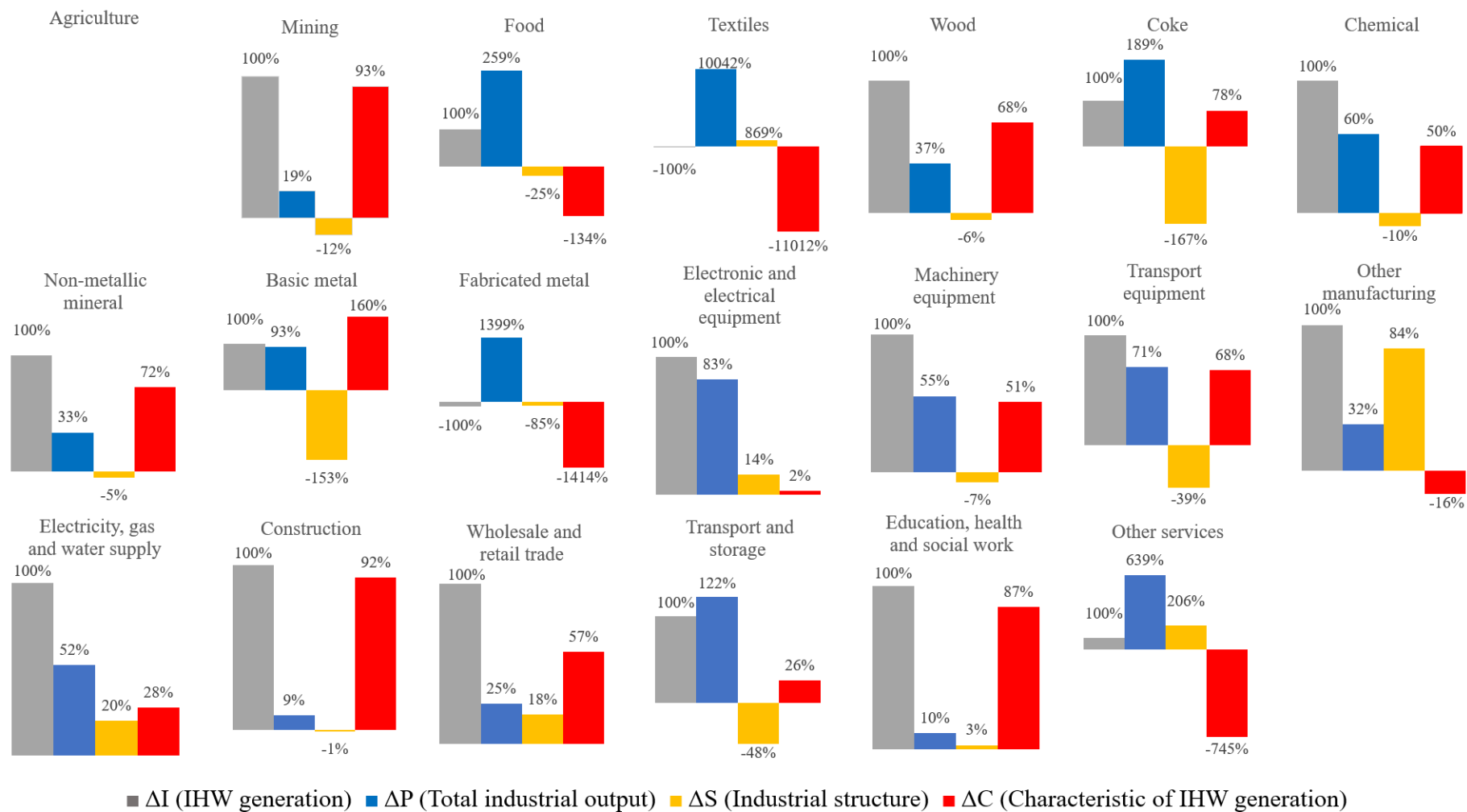


Figure 4-3. LMDI decomposition of industrial hazardous waste generation by industry

First of all, there is a case where only total industrial output affects the increase in IHW. The industrial structure and characteristics of IHW generation affect the reduction of IHW, including 'Food' and 'Fabricated metal'. 'Food' had the increase of IHW generation. Only total industrial output factor caused IHW generation increase. Industrial structure, and characteristics of IHW generation factors contributed to the IHW generation decrease. The industrial-scale of this industry is interrelated with 'Agriculture' sector, decreasing along with the decrease in the industrial scale of this primary industry (Gouk, 2012). In addition, the demand for tobacco continues to decrease in South Korea due to the increase in tobacco prices and strict regulations on smoking areas (D. J. Kim & Kim, 2017). However, as the amount of IHW increased as a result, it can be seen that the effect of total industrial output was much greater than the effect of reduction in industrial structure and characteristic of IHW generation. The 'Fabricated metal', which belongs to this case but has the opposite result, was affected by a decrease in IHW generation, an increase in the factor of total industrial output, the decreases in the factor of industrial structure and characteristic of IHW generation. The fact that the reduction in IHW generation had a much more significant effect than the reduction in industrial- scale can be interpreted as a decrease in the manufacturing of products, which mainly affected IHW generations. The LMDI analysis results for this case show that although management and support could be lacking to declining industry, IHW generation in the manufacturing process is well managed to maintain competitiveness.

The second case is that both the total industrial output and industrial structure factors affect the increase in IHW, while the characteristic of IHW generation affects the decrease in IHW; including 'Textile', 'Other manufacturing', and 'Other services'. Among them, 'Textile' is the industry in which IHW decreased due to the factor of the characteristic of IHW generation.

In contrast, the factors of total industrial output and industrial structure led to an IHW generation increase. 'Textile' is one of the industries that played a big role in South Korea's economic growth, and despite mass production and consumption due to rapid changes in fashion trends, waste treatment technology has been developed from the industry advancement and diversification of high-functional textiles, the government supports for high-valued textiles R&D and smart factory technology (Niinimäki et al., 2020; KIET, 2018). This case is the best case from a long-term of waste management point of view, where IHW generation characteristics are applied in the direction of IHW reduction and actually lead to IHW reduction although the industrial scale is growing. In 'Other manufacturing' and 'Other services', IHW increased, which was affected by an increase in the factors of total industrial output and industrial structure, and a decrease in factor of the characteristic of IHW generation. Especially in 'Other services', with the fourth industrial revolution, inter-industry convergence appears, and tertiarization is emerging as a new trend in the manufacturing industries (H. Kim, 2016). IHW is managed more efficiently due to the large enterprise of the service industry, showing a decreasing trend of IHW generation. However, the steadily increasing size of the 'Other services', resulting from the industry's advancement and diversification, requires systematic tailored IHW management. As a result, these two industries did not lead to a reduction in the amount of IHW, but it is interpreted that IHW reduction can be expected if IHW management policies for these industries is supported through the results that the factor of the characteristic of IHW generation affects IHW reduction, contrary to the growing trend of industrial structure.

The last one is the type where all factors of total industrial output, industrial structure, and characteristic of IHW generation affect the increase in IHW, including 'Electronic and electrical equipment', 'Electricity, gas and water supply', 'Wholesale and retail trade', and

‘Education, health and social work’. With the development of the semiconductor industry in South Korea, ‘Electronic and electrical equipment’ industry, which ranks the first in industrial output and IHW generation among secondary industries, has introduced and implemented environmental management certification system, but management of IHW generation is still insufficient (Samsung, 2020). It means that the current system is not working properly for IHW generation management, and an efficient new system is needed by analyzing the characteristics of the industry. ‘Electricity, gas, and water supply’ includes hydroelectric power generation, sewage, and waste treatment industries, and is an industry that has no choice but to increase in industrial size automatically as waste increases. To reduce IHW reduction in this industry, recycling waste as resources will be the only solutions. ‘Wholesale and retail trade’ and ‘Education, health, and social work’ are the increasingly growing services in South Korea. Although the amount of IHW is not large due to the characteristics of the tertiary industry, attention is required in the IHW management of these industries as the industrial scale is increasing.

In this chapter, we hypothesized factors affecting IHW generation and examined how much influence those factors have on the increase or decrease of IHW. It could have been thought that the amount of IHW generated in an industry with a large industrial total output and growing industrial scale would also increase proportionally. Still, it turned out not to be true. One critical finding was that the industrial total output factor was significantly influenced the increase of IHW generation in every industry, and the factors of industrial structure and characteristic of IHW generation and their degree of affecting the IHW generation are different by industry. Because IHW generation characteristics vary from industry to industry, integrated waste reduction plans would be ineffective to reduce IHW generation across all industry sectors.

Therefore, to design a sustainable national IHW management strategy, it is highly recommended to include customized IHW generation reduction targets and measures in consideration of industrial specific generation characteristics of the country.

Chapter 5 : Analysis of economic structure change

In this chapter, to improve understanding of the economic system of South Korea, the changes in Korea's industrial structure in terms of supply and demand using the input-output table of 2008 as the base year and 2018 as the comparative year were examined. Total output and imports sectors from the supply side, and consumption, investment, exports, and net exports sectors from the demand side are analyzed.

In total output sector, secondary industries such as 'Electronic and electrical equipment', 'Chemical', 'Basic metal', and 'Transport equipment' were oriented in 2008. Still, due to the growth of 'Wholesale and retail trade' and 'Education, health, and social work', it was changed to tertiary industries in 2018. Due to the impact of the tertiary industries-oriented total output growth, most of the secondary industries, especially 'Textile', 'Food', and 'Chemical', showed an increase in imports sector. Among the sectors on the demand side, consumption, investment, and export, investment showed an increase especially in the 'Other services', and both consumption and export sectors showed increases in the 'Electronic and electrical equipment' and 'Transport equipment'.

5.1. Overview on economic structure change

The results of analyzing the industrial structure of 2008 and 2018 in terms of total supply and total demand are shown in Figure 5-1 and Figure 5-2, respectively.

(Unit: million KRW)

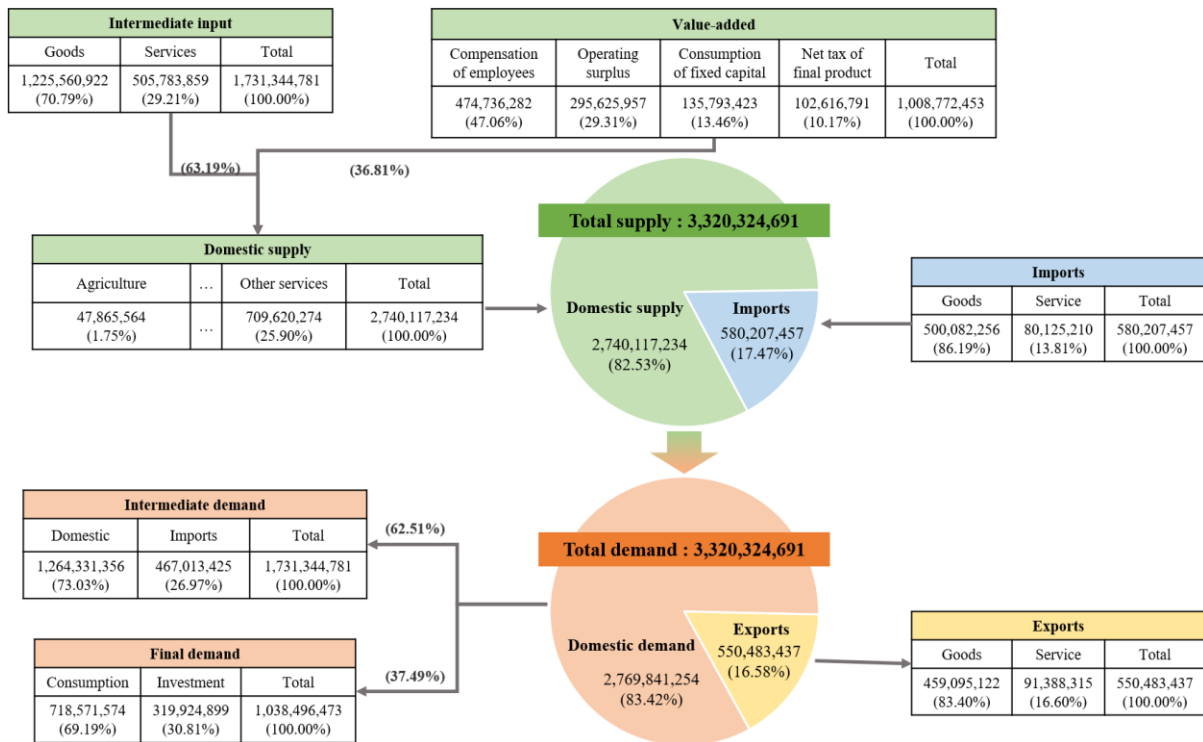


Figure 5-1. Economic structure of South Korea in 2008

In 2008, total supply consists of 82.53% of domestic supply and 17.47% of imports. Domestic supply comes from 63.19% of intermediate input and 36.81% of value-added. The amount of total demand must match the amount of total supply, which consists of 83.42% of domestic demand and 16.58% of exports.

(Unit: million KRW)

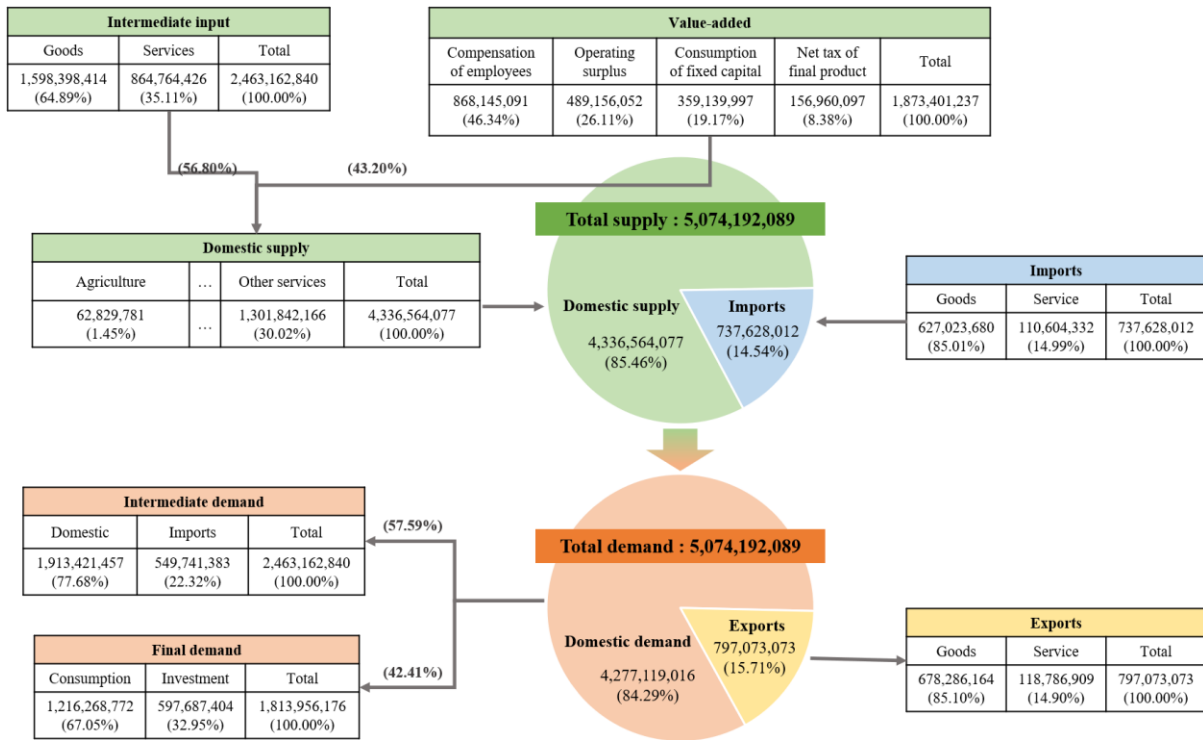


Figure 5-2. Economic structure of South Korea in 2018

In 2018, total supply consists of 85.46% of domestic supply and 14.54% of imports. Domestic supply comes from 56.80% of intermediate input and 43.20% of value-added. Total supply consists of 84.29% of domestic demand and 15.71% of exports.

This is analyzed in more detail by industry in terms of supply and demand.

5.2. Supply perspectives

The total supply in 2008 was 3,320 trillion KRW, and 82.53% (2,740 trillion KRW) of the total supply was produced from domestic and supplied (total output). The remaining 17.47% (580 trillion KRW) was imported and provided to South Korea. And 36.81% (1,009 trillion KRW) of total output was from added value, and 63.19% (1,731 trillion KRW) was from intermediate input such as raw materials. In 2018, the total supply was 5,074 trillion KRW. 85.46% (4,337 trillion KRW) of the total supply was produced and supplied domestically, and 14.54% (738 trillion KRW) was imported and supplied to South Korea. And 43.20% (1,873 trillion KRW) of total output was from added value, and the remaining 56.40% (2,463 trillion KRW) was from intermediate input. From 2008 to 2018, total supply increased by 52.82%, and total output and imports increased by 58.26% and 27.13%, respectively. In addition, added valued and intermediate input increased by 85.71% and 42.27%, respectively. It was analyzed by industry into total output and imports sector.

5.2.1. Total output

As shown in Figure 5-3 and Table 5-1, the top five industries of total output in 2008 are ‘Other services’, ‘Electronic and electrical equipment’, ‘Chemical’, ‘Basic metal’, and ‘Transport equipment’.

And in 2018, there are ‘Other services’, ‘Electronic and electrical equipment’, ‘Chemical’, ‘Wholesale and retail trade’, and ‘Education, health, and social work’ in top five industries of

total output. ‘Other manufacturing’ showed the most significant increase at 428.54%, followed by ‘Wholesale and retail trade’, ‘Electricity, gas, and water supply’, ‘Other services’, and ‘Education, health, and social work’ at 121.11%, 88.77%, 83.46%, 78.13%, respectively. The only industry that decreased is the ‘Basic metal’, which has the decreased rate of -25.41%. It shows that total output in South Korea is changing from manufacturing industry-oriented to service industry-oriented.

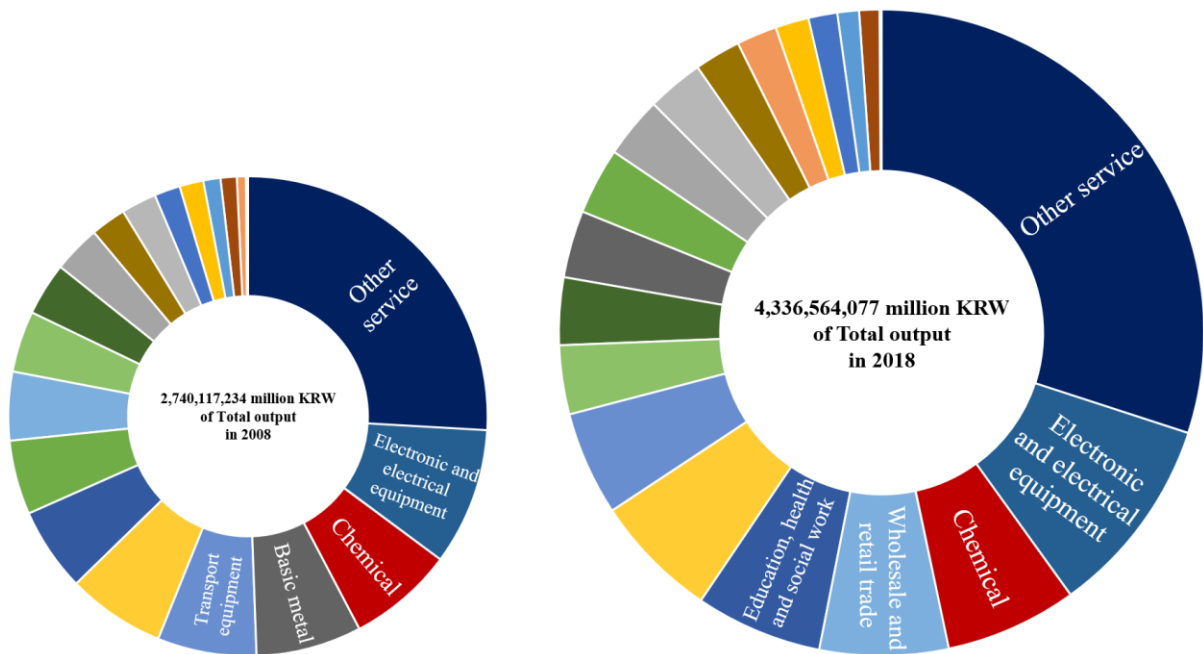


Figure 5-3. Total output in 2008 and 2018

Table 5-1. Total output of 2008 and 2018

(Unit : million KRW)

Industry sector		2008	2018
Primary industry	Agriculture	47,865,564	62,829,781
Secondary industry	Mining	3,811,611	4,519,229
	Food	87,729,106	132,822,086
	Textile	44,112,903	72,644,653
	Wood	31,799,468	47,032,314
	Coke	137,110,659	144,538,465
	Chemical	195,324,786	286,315,794
	Non-metallic mineral	29,942,931	43,962,144
	Basic metal	195,207,180	145,600,764
	Fabricated metal	65,296,040	100,495,199
	Electronic and electrical equipment	254,121,198	434,603,762
	Machinery equipment	97,828,849	146,210,491
	Transport equipment	183,219,338	225,748,464
	Other manufacturing	16,574,463	87,603,115
	Electricity, gas, and water supply	64,975,201	122,655,552
Construction	181,034,693	271,754,064	
Tertiary industry	Wholesale and retail trade	126,636,525	280,000,474
	Transport and storage	113,111,873	149,651,747
	Education, health, and social work	154,794,572	275,733,813
	Other services	709,620,274	1,301,842,166
Total		2,740,117,234	4,336,564,077

5.2.2. Imports

The top five industries of imports in 2008 are ‘Mining’, ‘Electronic and electrical equipment’, ‘Basic metal’, ‘Chemical’, and ‘Other services’. The detailed results are shown in Figure 5-4 and Appendix 2.

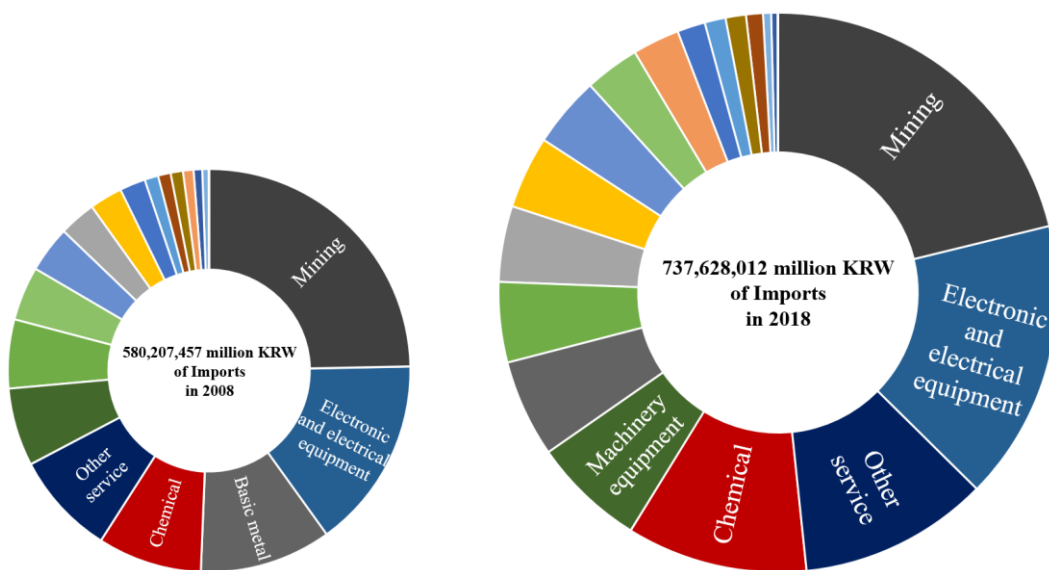


Figure 5-4. Imports in 2008 and 2018

In 2018, top five industries of imports in 2018 are ‘Mining’, ‘Electronic and electrical equipment’, ‘Other services’, ‘Chemical’, and ‘Machinery equipment’. The industry with the largest increased rate in imports is ‘Other manufacturing’ at 306.65%, followed by ‘Textile’, ‘Food’, ‘Other services’, and ‘Chemical’ at 102.28%, 88.72%, 68.85%, and 58.34%. At the same time as, total output increased mainly in the service industry, simple manufacturing industries are dependent on imports.

5.3. Demand perspectives

The final demand of total demand was 47.86% (1,589 trillion KRW), and intermediate demand was 52.14% (1,731 trillion KRW). Among final demand, consumption was 45.22% (719 trillion KRW), investment was 20.13% (320 trillion KRW), and exports were 34.64% (550 trillion KRW). In 2018, the final demand for total demand was 51.46% (2,611 trillion KRW), and intermediate demand was 48.54% (2,463 trillion KRW). Among final demand, consumption was 46.58% (1,216 trillion KRW), investment was 22.89% (598 trillion KRW), and exports were 30.53% (797 trillion KRW). From 2008 to 2018, final demand, intermediate demand, consumption, investment, and exports increased by 64.32%, 42.27%, 69.26%, 86.82%, and 44.80%, respectively. In addition, net exports, minus imports from exports, were -30 trillion KRW in 2008 and 59 trillion KRW in 2018. A negative value of net exports means that imports are higher than exports, and this shows that South Korea was a fairly imports-dependent industrial structure in 2008. Consumption, investment, and exports sectors of final demand were examined, and lastly, net exports were examined by industry.

5.3.1. Consumption

According to Figure 5-5 and Appendix 3, in both 2008 and 2018, ‘Other services’, ‘Education, health, and social work’, ‘Food’, ‘Wholesale and retail trade’, and ‘Textile’ accounted for the top five industries of consumption sector.

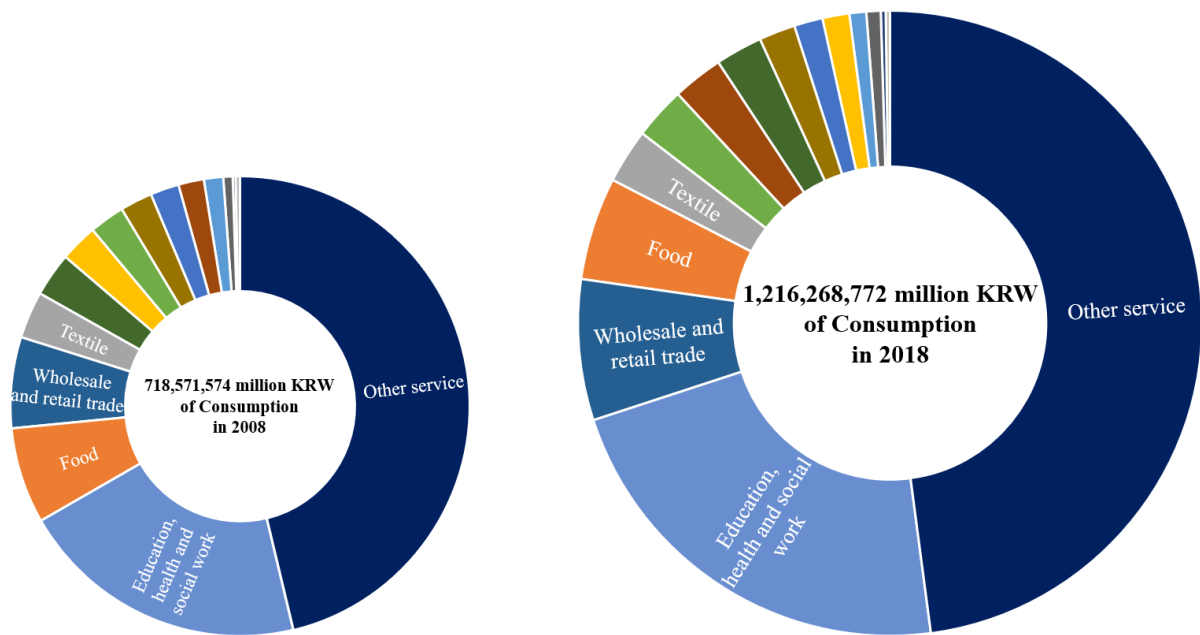


Figure 5-5. Consumption in 2008 and 2018

In addition, in the ‘Electronic and electrical equipment’ and ‘Transport equipment’ industries, it can be seen that consumption in these two industries is quite high in 2018 compared to 2008 due to high consumption growth rates.

5.3.2. Investment

In the investment sector, the top five industries in 2008 and 2018 were same as shown in Figure 5-6 and Appendix 4, including ‘Construction’, ‘Other services’, ‘Machinery equipment’, ‘Electronic and electrical equipment’, and ‘Transport equipment’.

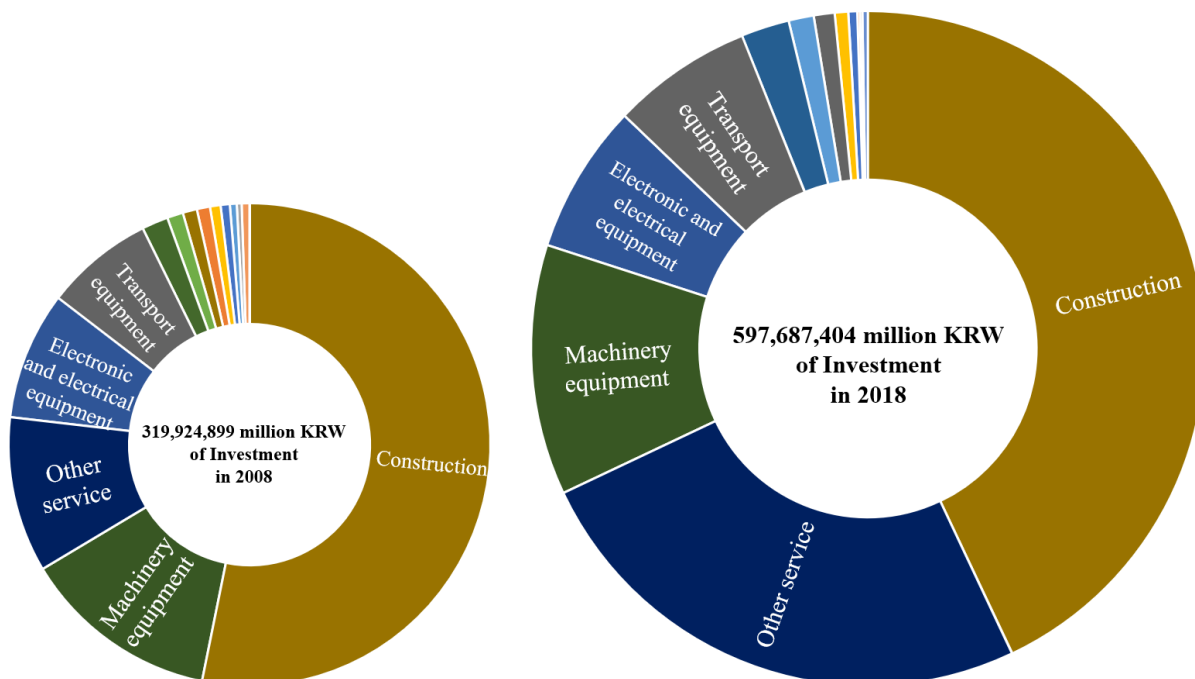


Figure 5-6. Investment in 2008 and 2018

In particular, ‘Construction’ and ‘Other services’ sectors are a large proportion of investment, with the sum of these sectors accounting for 68.17% of the total investment. Among them, the increased rate of 350.20% of investment in ‘Other services’ shows that South Korea is making considerable investments in developing the service industry.

5.3.3. Exports

In the exports sector as Appendix 5, ‘Electronic and electrical equipment’, ‘Transport equipment’, ‘Chemical’, ‘Transport and storage’, and ‘Coke’ were the top five industries in 2008.

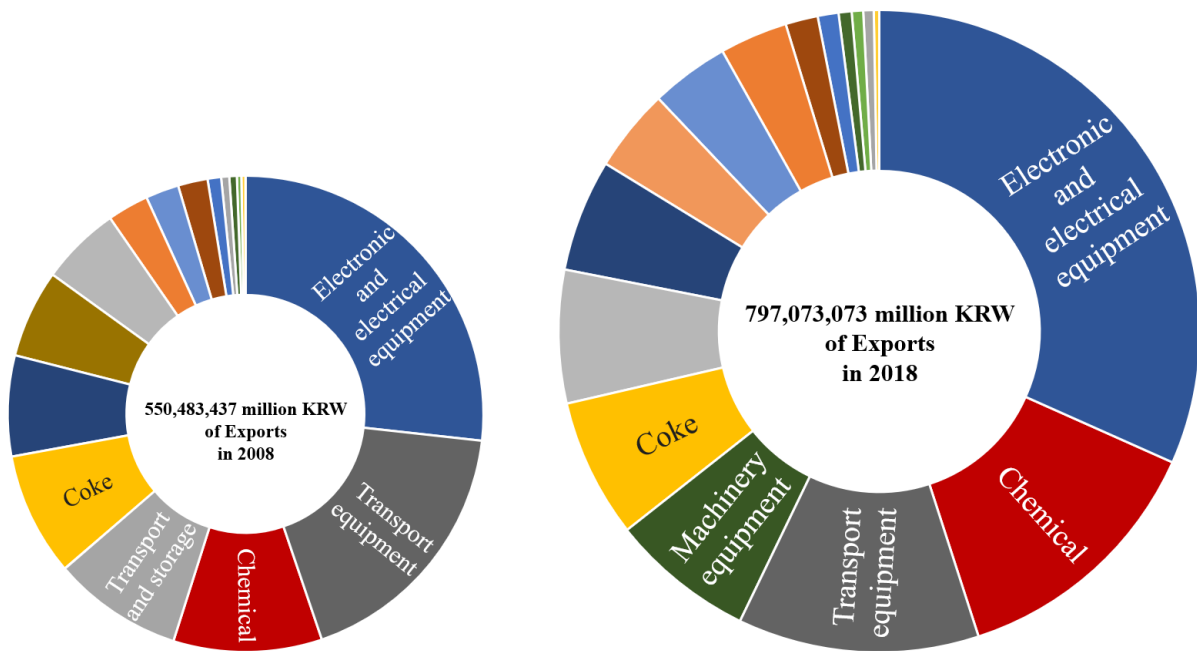


Figure 5-7. Exports in 2008 and 2018

Still, in 2018, it was partially changed to ‘Electronic and electrical equipment’, ‘Chemical’, ‘Transport equipment’, ‘Machinery equipment’, and ‘Coke’. The ‘Electronic and electrical equipment’ industry, which accounts for about 30% of South Korea’s total exports due to semiconductor exports, etc., is going smoothly with an increased rate of 71.04%, but the exports of the ‘Transport equipment’, the second largest industry in South Korea’s exports market, shows a declining trend with a decreased rate of -1.98%.

Chapter 6 : Waste footprint in industrial system

This chapter aimed to identify the industry's direct, indirect generation characteristics of industrial hazardous waste and generation inducement impacts by final demand. For this, waste-extended input-output table (WEIOT) was made using the 2008, 2018 IOT of South Korea and data on the amount of IHW generated by industry. The result showed that the 'Electronic and electrical equipment', 'Chemical', and 'Basic metal' industries contributed more than 50% of the total amount of direct generation, indicating that special management is required for these three industries. Furthermore, the industrial hazardous waste generation inducement impact results by final demand showed that consumption contributed more than 49% to the generation, implying that not only production process but also consumption aspects should be considered at the same time when the government establishes the waste policies and regulations.

6.1. Methodology

(Ruiz-Peñalver et al., 2019; Ruiz Peñalver et al., 2014; Salemdeeb et al., 2016) looked at waste generation by direct and indirect suppliers by assuming that direct suppliers as inputs required from other industries that supply the investigated industry and indirect suppliers as inputs required from the suppliers of the suppliers, and defining the waste generated by each supplier as direct waste and indirect waste. However, this assumption makes the error that the waste generated directly is counted more than the actual amount because even the waste from the primary supplier is included in the direct waste generation. Therefore, in this research, we defined direct waste as the waste generated by an industry's own on-site production process and indirect waste as the waste generated throughout the production processes of all industries in that supply chain underpinning the production of this final product. Figure 6-1 briefly shows the explanation and example of direct, indirect, and total waste generation.

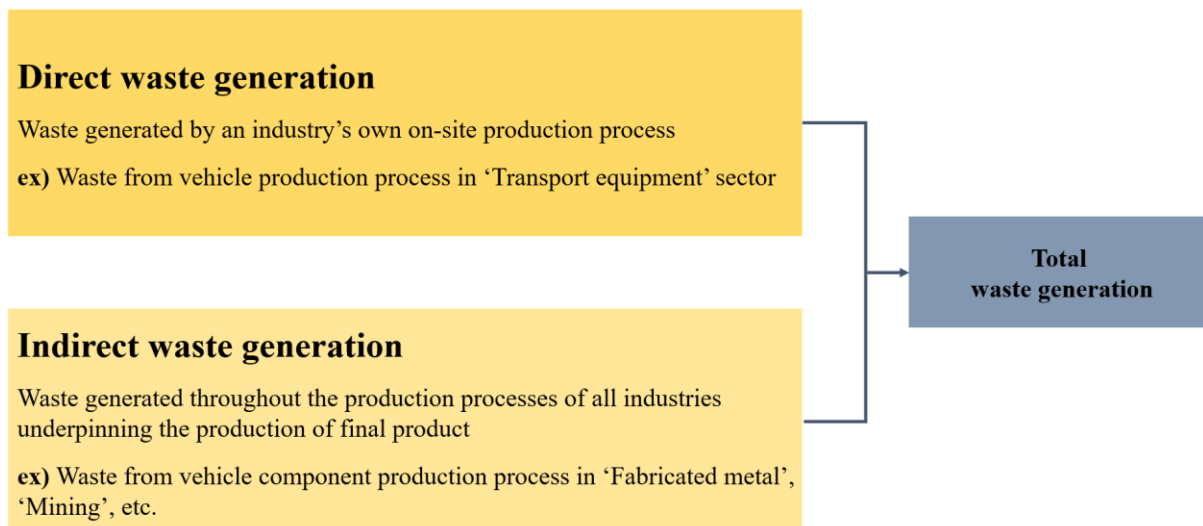


Figure 6-1. Direct, indirect, and total waste generation

We can calculate the direct IHW generation coefficients (L_{direct}) by dividing the total amount of IHW generation by sector (W) by total output (X), as Eq 6-1.

$$L_{direct} = \frac{W}{X} \quad \text{Eq 6-1}$$

The total IHW generation coefficients (L_{total}) can be computed by multiplying the diagonal matrix of the direct IHW generation coefficients ($L_{direct} = \hat{L}$) by the Leontief matrix, as Eq 6-2. It also includes the concept of an IHW generation inducement coefficient to meet one unit of demand.

$$L_{total} = \hat{L} \cdot (I - A)^{-1} \quad \text{Eq 6-2}$$

The indirect IHW generation coefficients ($L_{indirect}$) can be obtained as the difference between the total IHW generation coefficients (L_{total}) and the direct IHW generation coefficients (L_{direct}), as Eq 6-3.

$$L_{indirect} = L_{total} - L_{direct} \quad \text{Eq 6-3}$$

In terms of demand, the final demand Y is an exogenous sector consisting of consumption, investment, and exports as shown in Eq 6-4. This research analyzes it by dividing it into consumption, investment, and net exports.

$$Y = Y_C + Y_I + Y_E - M = Y_C + Y_I + Y_N \quad \text{Eq 6-4}$$

It is defined, Y_C as a vector of consumption including private consumption and government consumption, Y_I a vector of an investment including private fixed capital formation, gross fixed

capital formation, changes in inventories, and net acquisition of valuables, Y_E as a vector of exports, M as a vector of imports, and Y_N as a vector of net exports ($Y_E - M$).

The IHW generation inducement coefficients are computed as Eq 6-5, Eq 6-6, and Eq 6-7 by multiplying direct IHW generation coefficients by ratio of final demand sector, (i.e., the ratio of consumption, investment, and net exports to final demand).

$$L_C = \hat{L} \cdot (I - A)^{-1} \cdot \frac{Y_C}{Y} \quad \text{Eq 6-5}$$

$$L_I = \hat{L} \cdot (I - A)^{-1} \cdot \frac{Y_I}{Y} \quad \text{Eq 6-6}$$

$$L_N = \hat{L} \cdot (I - A)^{-1} \cdot \frac{Y_N}{Y} \quad \text{Eq 6-7}$$

Where L_C is the IHW generation inducement coefficients by consumption, L_I is the IHW generation inducement coefficients by investment, and L_N is the IHW generation inducement coefficients by net exports.

6.2. Results

6.2.1. Supply perspectives

The direct, indirect, and total IHW generation coefficients, one of the IHW generation characteristics in 2008 and 2018, were calculated by industry according to Eq 6-1, Eq 6-2, Eq 6-3 and summarized in Table 6-1 and Figure 6-1.

The averages of direct IHW generation coefficients are 0.92 kg/million KRW in 2008, and

1.26 kg/million KRW in 2018 with an increased rate of 36.98%. In both 2008 and 2018, there were six industries with above-average direct IHW generation coefficient: 'Textile', 'Chemical', 'Non-metallic mineral', 'Basic metal', 'Fabricated metal', and 'Electronic and electrical equipment'. Among them, 'Non-metallic mineral' and 'Basic metal' show high increased rates of 170.16%, 119.37%. Although it does not belong to the six industries with an above-average direct IHW generation coefficient, the 'Construction' and 'Education, health, and social work' industries show a remarkable increase of 12,060.58% and 5,298.65%, respectively. Currently, these two industries contribute little to the IHW generation, so we don't have to consider it much, but if they continue to increase steadily with huge increased rates, they will have to be included in the industries to be considered soon.

Table 6-1. Industrial hazardous waste generation coefficients by industry

(Unit: kg/million KRW)

Industry	Total IHW generation coefficients		Direct IHW generation coefficients		Indirect IHW generation coefficients	
	2008	2018	2008	2018	2008	2018
Agriculture	1.28	1.31	-	-	1.28	1.31
Mining	1.38	3.12	0.17	1.62	1.21	1.50
Food	1.61	1.63	0.21	0.17	1.40	1.47
Textile	5.30	4.29	2.33	1.41	2.98	2.88
Wood	2.53	3.25	0.47	1.09	2.06	2.17
Coke	1.92	3.11	0.62	0.75	1.30	2.36
Chemical	5.94	6.88	2.36	3.47	3.59	3.41
Non-metallic mineral	2.95	5.10	0.93	2.50	2.03	2.59
Basic metal	8.29	11.42	2.69	5.90	5.60	5.51
Fabricated metal	7.36	5.50	2.37	1.49	4.99	4.02
Electronic and electrical equipment	6.82	5.64	2.39	2.42	4.44	3.22
Machinery equipment	4.29	3.78	0.21	0.33	4.07	3.46
Transport equipment	4.64	5.04	0.59	0.92	4.05	4.12
Other manufacturing	3.87	2.67	0.52	0.41	3.35	2.26
Electricity, gas, and water supply	2.04	2.82	0.50	0.64	1.54	2.18
Construction	3.00	3.27	0.005	0.58	2.99	2.69
Wholesale and retail trade	1.10	1.19	0.03	0.10	1.07	1.09
Transport and storage	1.92	2.24	0.32	0.35	1.60	1.88
Education, health, and social work	1.20	1.41	0.001	0.08	1.20	1.33
Other services	3.05	2.04	1.70	0.99	1.36	1.05
Average	3.53	3.79	0.92	1.26	2.61	2.52

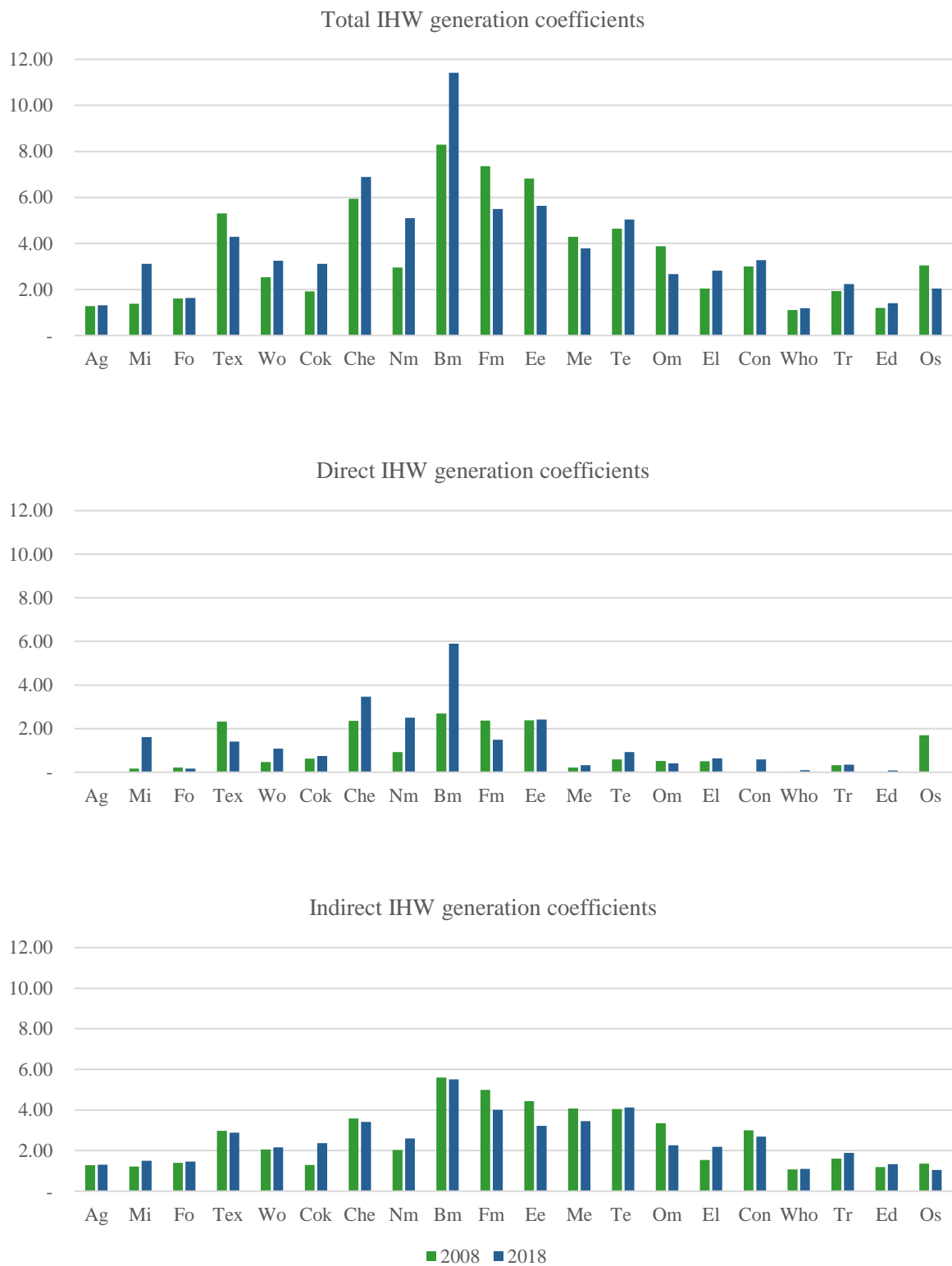


Figure 6-2. Industrial hazardous waste generation coefficients by industry

The averages of indirect IHW generation coefficients are 2.61 kg/million KRW in 2008 and 2.52 kg/million KRW in 2018, with a decreased rate of 3.08%. The industries have above-average indirect IHW generation coefficient in both 2008 and 2018 are 'Textile', 'Chemical', 'Basic metal', 'Fabricated metal', 'Electronic and electrical equipment', 'Machinery equipment', 'Transport equipment', and 'Construction'. Among them, only 'Transport equipment' industry shows a slight increased rate of 1.84%, and all others show a decreasing trend.

The averages of the total IHW generation coefficients are 3.53 kg/million KRW in 2008, and 3.79 kg/million KRW in 2018, and the increased rate is 7.38%. However, the indirect IHW generation coefficient shows a decreasing trend, a significant increase in the direct IHW generation coefficient results in an increase in the total IHW generation coefficient. The industries with above-average of total IHW generation coefficient in both 2008 and 2018 are 'Textile', 'Chemical', 'Basic metal', 'Fabricated metal', 'Electronic and electrical equipment' and 'Transport equipment'.

Through these overall results, we can confirm that direct, indirect, and total IHW generation coefficients are higher than average in five industries, including 'Textile', 'Chemical', 'Basic metal', 'Fabricated metal', and 'Electronic and electrical equipment', which implies that more attention to IHW generation and treatment in these five industries is required. In addition, the indirect IHW generation coefficients are high in 'Machinery equipment', 'Transport equipment', and 'Construction'. This result means that even though the amount of direct IHW generation aggregated by statistics in these industries is small, there is a lot of IHW generated within the supply chain, so caution for these industries is also needed. From an overall point of view, as the average value of the indirect IHW generation coefficient is almost

twice that of the direct IHW generation coefficient, it can be confirmed that there is a large amount of hidden IHW flows under the final statistics that are officially published. This means that when the government establishes waste policies, it is necessary to look at the entire supply chain beyond looking at the industries individually.

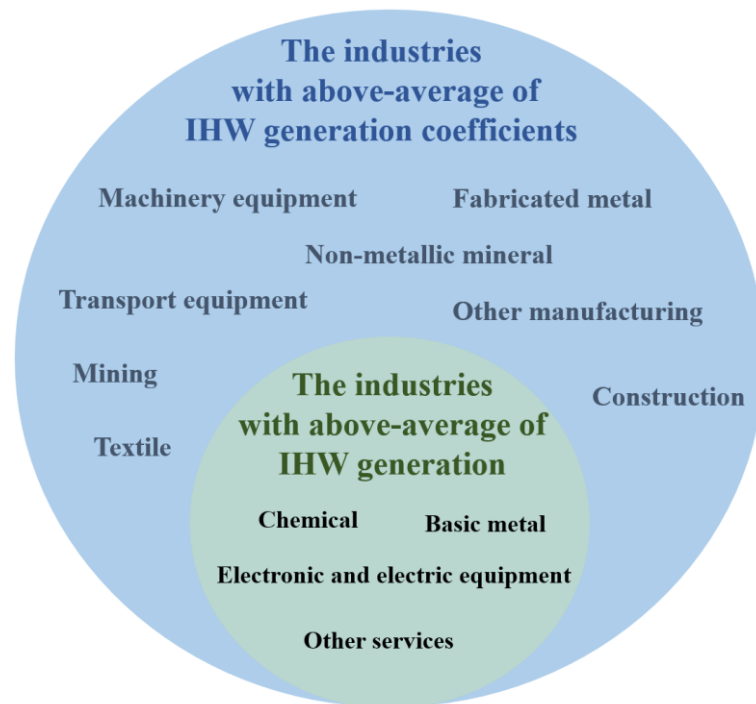


Figure 6-3. Selection of hotspots of Industrial hazardous waste generation

Table 6-2 is the results of the direct, indirect, and total IHW generation coefficients of ‘Chemical’, ‘Basic metal’, ‘Electronic and electrical equipment’, and ‘Other services’ in 2018, which are the industries were selected as shown in Figure 6-3. For these industries, among the 22 IHW types, six types of IHW contributing more than half of the total IHW were selected, and their direct, indirect, and total IHW generation coefficients were examined.

Table 6-2. Industrial hazardous waste generation coefficients by waste type (2018)

(Unit: kg/million KRW)

Industry	Waste organic solvent			Dust			Ash		
	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect
Chemical	3.20	1.96	1.24	0.17	0.00	0.17	0.17	0.00	0.17
Basic metal	0.43	0.03	0.41	4.41	2.67	1.74	0.24	0.01	0.23
Electronic and electrical equipment	1.63	0.80	0.83	0.41	0.00	0.40	0.10	0.00	0.10
Other services	0.31	0.08	0.23	0.09	0.02	0.07	0.34	0.22	0.12
Industry	Waste acid			Wastewater sludge			Waste oil		
	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect
Chemical	0.50	0.21	0.29	0.23	0.04	0.19	1.52	0.67	0.85
Basic metal	2.27	1.31	0.96	0.72	0.30	0.42	1.26	0.44	0.83
Electronic and electrical equipment	2.21	1.34	0.87	0.20	0.06	0.14	0.53	0.07	0.45
Other services	0.17	0.04	0.14	0.18	0.11	0.07	0.60	0.33	0.27

The most significant part of the IHW in 2018, which accounts for more total 50% of the total IHW of 5,378,553 tonnes, is 1,181,056 tonnes (21.96%) of waste organic solvent, followed by waste oil of 1,132,517 tonnes (21.06%), waste acid of 998,033 tonnes (18.56%), the dust of 576,898 tonnes (10.73%), ash of 376,010 (6.99%), and wastewater sludge of 253,399 (4.71%).

The results of analyzing the amount of IHW generated in the previously selected four industries focusing on the above six types of waste are as follows.

IHW generated from 'Other services' is 1,292,415 tonnes, accounting for 24.03% of the total IHW generation, and waste oil contributes the most (33.45%) among the above six types of waste, followed by ash (22.14%) and wastewater sludge (11.07%). However, due to the high indirect IHW generation coefficient of waste organic solvent, the total IHW generation coefficient is the largest in the order of waste oil (0.60), ash (0.34), and waste organic solvent (0.31). The amount of IHW from 'Other services' accounts for a large part, but it can be confirmed that all of the direct, indirect, and total IHW generation coefficients are relatively small compared to other industries. This result means that the amount of IHW generated by 'Other services' does not require special attention, such as strict regulations to this industry.

The 'Electronic and electrical equipment' industry generates 1,050,589 tonnes of IHW, accounting for 19.53% of the total IHW generation. And waste acid accounts for 55.33%, and waste organic solvent accounts for 33.04%. In addition, 58.25% of waste acid and 29.39% of waste organic solvent of all industries are generated from 'Electronic and electrical equipment', and it can be seen that their direct and indirect IHW generation coefficients also belong to a higher group than other industries. It can be confirmed that continuous and efficient

management of both wastes is necessary. Furthermore, the indirect IHW generation coefficients are higher than the direct IHW generation coefficients for every waste except waste acid, which means that the generation of IHW in the supply chain behind the site is higher than in the industry itself that produces ‘Electronic and electrical equipment’ products. It implies that to reduce the IHW generated by this industry, it is necessary to look at and regulate the entire supply chain, not just the workplaces of this industry itself.

The IHW generated from ‘Chemical’ is 994,000 tonnes (18.48%), of which more than half (56.48%) is formed from waste organic solvent and about 20% from waste oil. Approximately half of the waste organic solvent generated in all industries are from the ‘Chemical’, and the direct and indirect IHW generation coefficients of waste organic solvents are 1.96 and 1.24, respectively, which are very high compared to other industries and the direct IHW generation coefficients are usually larger than the indirect IHW generation coefficients. This means that the generation of waste organic solvent in the ‘Chemical’ industry itself is large, which implies that ‘Chemical’ workplaces require to manage the generation of waste organic solvent. In the ‘Electronic and electrical equipment’, another major cause of waste organic solvent, the indirect IHW generation coefficient was greater than the direct IHW generation coefficient. It can be seen that it is quite different whether the industry is directly or indirectly affected by industrial characteristics, even the same waste type.

‘Basic metal’ generated 859,488ton (15.98%) of IHW, and almost half of them (45.30%) are from dust, and 22.17% are from waste acid. 67.49% of dust generated in all industries and 19.09% of waste products are generated from the ‘Basic metal’, and the direct and indirect IHW generation coefficients are 2.78 and 1.74, which are quite high levels. The direct and indirect IHW generation coefficients of waste acid are 1.31 and 0.96, which are much higher

than that of other industries. In particular, the total IHW generation coefficient of the dust of 'Basic metal' is the highest coefficient in all industries and all waste types. It seems necessary to provide a practical solution to reduce the dust generation in the overall supply chain of the 'Basic metal'.

6.2.2. Demand perspectives

In the previous step, the direct, total, and indirect IHW generation coefficients from the production aspect were identified. However, since the occurrence of final demand induces production and added value is created through production activities, analysis in terms of consumption is also necessary. Therefore, in this step, we calculated the amount of IHW induced and IHW inducement coefficients generated by consumption, investment, and net exports to understand the effects of final demand on the IHW generation in terms of consumption in the economic system.

As shown in Table 6-3 and Table 6-4, the amounts of IHW induced from consumption, investment, and net exports in 2008 are 1,850,169 tonnes (54.24%), 1,171,433 tonnes (34.34%), and 389,571 tonnes (11.42%), respectively. And in 2018, the amounts of IHW induced from consumption, investment, and net exports are 2,591,582 tonnes (49.10%), 1,860,279 tonnes (35.25%), and 825,870 tonnes (15.65%), respectively. It means that IHW generated by consumption, investment, and net exports in 2018 increased by 40.07%, 58.80%, and 111.99% compared to 2008, respectively. Comparing the total output induced from the final demand, the total output from consumption, investment, and net exports in 2008 are 1,658,716,747 million

KRW (60.53%), 972,971,705 million KRW (35.51%), and 108,428,782 million KRW (3.96%), respectively. And in 2018, the total output from consumption, investment, and net exports are 2,605,795,350 million KRW (60.79%), 1,409,999,931 million KRW (32.89%), and 270,940,931 million KRW (6.32%), respectively.

Table 6-3. Total output induced by final demand

(Unit: million KRW (%))

Final demand sectors	Total output	
	2008	2018
Consumption	1,658,716,747 (60.53)	2,605,795,350 (60.79)
Investment	972,971,705 (35.51)	1,409,999,931 (32.89)
Net exports	108,428,782 (3.96)	270,940,931 (6.32)
Total	2,740,117,234 (100.00)	4,336,564,077 (100.00)

Table 6-4. Industrial hazardous waste generation induced by final demand

(Unit: tonnes (%))

Final demand sectors	IHW generation	
	2008	2018
Consumption	1,850,169 (54.24)	2,591,582 (49.10)
Investment	1,171,433 (34.34)	1,860,279 (35.25)
Net exports	389,571 (11.42)	825,870 (15.65)
Total	3,411,163 (100.00)	5,378,575 (100.00)

It can be confirmed that a large amount of IHW is induced compared to the total output generated by net exports. Also, we confirmed that more than half of the IHW generation is induced due to consumption, which implies that consumption is an important sector that must be considered unconditionally when managing IHW generation.

In addition, the IHW inducement coefficients from consumption, investment, and net exports, which were calculated by Eq 6-5, Eq 6-6, and Eq 6-7 and summarized in Table 6-5, were 1.83, 1.16, 0.39 in 2008 and 1.38, 1.05, 0.44 in 2018, respectively. This result means that 1.83 kg, 1.16 kg, and 0.39 kg of IHW were induced per one million KRW of consumption, investment, and net exports in 2008. The same concept works in 2018 as well.

Table 6-5. Industrial hazardous waste inducement coefficients by final demand

(Unit: kg/million KRW)

Final demand sectors	IHW generation inducement coefficients	
	2008	2018
Consumption	1.83	1.38
Investment	1.16	1.05
Net exports	0.39	0.44

This result shows that it is necessary to consider the consumption, investment, and exports sectors on the demand aspect and the supply aspect for a strategy to reduce and manage the IHW generation to achieve a circular economy.

Chapter 7 : Influence of industrial structure changes on IHW generation

This chapter analyzed the factors that increase or decrease the IHW generation during 2008-2018 using structural decomposition analysis methodology.

IHW generation increased 57.68% from 2008 to 2018. According to the analysis of each factor using the structural decomposition analysis method, the final demand change factor and imports substitution factor led the increase to +53.04%p and +13.79%p, respectively. On the other hand, the production technology factor acted as a factor of reduction to -9.16%p.

The secondary industry's contribution to IHW generation increase was +53.26%p, accounting for more than 90% of the total generation increase, which was led by exports demand expansion factor (+34.24%p) and waste generation coefficient change factor (+30.04%p). Among the factors of final demand change, the consumption expansion factor was +7.44%p, and the investment expansion factor was -7.41%p, offsetting each other, but it was seen that the significant effect of exports expansion contributed to the increase in IHW generation.

In the case of the tertiary industry, which is a service industry, the contribution of IHW generation increase was +4.41%p, accounting for only 10% of the total generation increase, which was led by consumption expansion factor +11.14%p.

7.1. Methodology

By multiplying the final demand vector of consumption, investment, and net exports by the waste generation inducement coefficient matrix obtained from the WEIO matrix, the waste generation inducement amount for each final demand can be obtained. And the waste generation inducement coefficient for each final demand can be obtained by dividing the waste generation inducement amount by each final demand sector. Furthermore, in this study, the SDA method was used to analyze the factors affecting the increase in IHW generation into demand-side factors accompanying economic growth and supply-side factors according to changes in production technology structure.

The amount of IHW generated is $W = \widehat{w} \cdot X$, and Eq 7-1 is the formula to express the change in the amount of IHW generation by dividing the base year and the comparative year.

$$\begin{aligned}\Delta W &= \widehat{w}_2 \cdot X_2 - \widehat{w}_1 \cdot X_1 \\ &= \widehat{w}_2 \cdot (X_2 - X_1) + (\widehat{w}_2 - \widehat{w}_1) \cdot X_1 \\ &= \widehat{w}_2 \cdot \Delta X + (\Delta \widehat{w}) \cdot X_1\end{aligned}\tag{Eq 7-1}$$

This research divides the final demand into consumption, investment, and exports to measure the imports substitution effect of intermediate goods and final goods. And the change in the technological structure is divided into changes in the input coefficient and changes in the IHW generation coefficient. Accordingly, a decomposition equation as in Eq 7-2 is derived. This equation is the Paasche equation based on the production inducement factor of the comparative year ($L_2 = (I - A_2)^{-1}$).

$$\begin{aligned}
\Delta W = & \widehat{w}_2 \cdot L_2 \cdot (I - \widehat{m}_2) \cdot \Delta C && \text{(Consumption expansion effect)} \\
& + \widehat{w}_2 \cdot L_2 \cdot (I - \widehat{m}_2) \cdot \Delta I && \text{(Investment expansion effect)} \\
& + \widehat{w}_2 \cdot L_2 \cdot \Delta E && \text{(Exports demand expansion effect)} \\
& + \widehat{w}_2 \cdot L_2 \cdot (\widehat{m}_1 - \widehat{m}_2) \cdot I_1 && \text{(Final goods imports substitution effect)} \\
& + \widehat{w}_2 \cdot L_2 \cdot (A_2^m - A_1^m) \cdot X_1 && \text{(Intermediate goods imports substitution effect)} \\
& + \widehat{w}_2 \cdot L_2 \cdot [\Delta A - (A_2^m - A_1^m)] \cdot X_1 && \text{(Technological structure change effect)} \\
& + (\widehat{w}_2 - \widehat{w}_1) \cdot X_1 && \text{(Waste generation coefficient change effect)}
\end{aligned} \tag{Eq 7-2}$$

Where, \widehat{m} is the diagonal matrix of the ratio of final goods imports to final domestic demand, C is the vector of consumption, I is the vector of investment, E is the vector of exports, A^m is the matrix of imports input coefficient, and A is the matrix of technical coefficient.

7.2. Results

IHW generation increased 57.68% from 2008 to 2018. According to the analysis of each factor using the structural decomposition analysis method, the final demand change factor and imports substitution factor led the increase to +53.04%p and +13.79%p, respectively. On the other hand, the production technology factor acted as a factor of reduction to -9.16%p.

Classified as the primary, secondary, and tertiary industries as shown in Table 7-1, the contribution of the primary industry, which is a manufacturing industry, to IHW generation increase was +53.26%p, accounting for more than 90% of the total IHW generation increase, which was led by exports expansion factor (+34.24%p) and waste generation coefficient change factor (+30.04%p). In aspects of final demand change factors, the consumption expansion factor was +7.44%p, and the investment expansion factor was -7.41%p, offsetting each other. Still, it can be seen that the large effect of the exports expansion factor contributed to the increase in IHW generation. The import substitution factors were the second factors that significantly contributed to the increase in IHW generation. Even though imports of intermediate goods contributed -9.21%p to the decrease in IHW generation, imports of final goods contributed +22.87%p, failing to lead to a reduction in IHW generations. Although the change in the input coefficient contributed by -24.72%p to the reduction of IHW generation, the change in the waste generation coefficient resulted in the increase of IHW by +5.33%p.

For tertiary industry, which is a service industry, the contribution to IHW generation growth was +4.41%p, accounting for less than 10% of the total IHW generation increase, and it was led by consumption expansion factor (+11.15%p). Looking at the factors that change the final demand, it can be seen that the consumption expansion factor contributed to the increase of IHW generation by +11.15%p, investment expansion by +4.76%p, and exports expansion by +2.85%p. In imports substitution factors, although the imports substitution of intermediate goods contributed -0.82%p to the reduction of IHW generation, it offset the imports substitution of final goods by +0.95%p and showed a low contribution of +0.13%p to the increase of IHW generation. On the other hand, in factors of technology change, input

coefficient factors contributed -0.57%p and -13.9%p, respectively, contributing to the reduction of IHW generation by -14.48%p totally.

Table 7-1. Results of structure decomposition analysis by primary, secondary, and tertiary industry

(Unit : %, %p)

Industry sectors		Primary industry	Secondary industry	Tertiary industry	Total
The factor of final demand expansion	Consumption	-	7.44	11.15	18.59
	Investment	-	-7.41	4.76	-2.65
	Exports	-	34.24	2.86	37.10
	Total	-	34.27	18.77	53.04
The factor of imports substitution	Final goods	-	22.87	0.95	23.82
	Intermediate goods	-	-9.21	-0.82	-10.03
	Total	-	13.66	0.13	13.79
The factor of technology change	Input coefficient	-	-24.72	-0.57	-25.28
	Waste generation coefficient	-	30.04	-13.92	16.13
	Total	-	5.33	-14.48	-9.16
Total		-	53.26	4.41	57.68

The results of the analysis by dividing them into the primary, secondary, and tertiary industries are subdivided and examined by industry. From 2008 to 2018, ‘Chemical’, ‘Electronic and electrical equipment’, and ‘Basic metal’, the top three industries with high

contribution to the increase in IHW generation, contributed by +15.65%p, +13.03%p, and +9.80%p, respectively, accounting for about 70% of the total IHW generation increase.

First of all, +11.20%p of the IHW increase factors of ‘Chemical’ was due to the expansion of the exports as shown in Figure 7-1. The factors of import substitution of intermediate goods and final goods, and input coefficient contributed to the IHW reduction by -1.60%p, -0.64%p, and -3.32%p, respectively, but it was far from enough to offset the impact of ‘Chemical’ industry’s exports market growth.

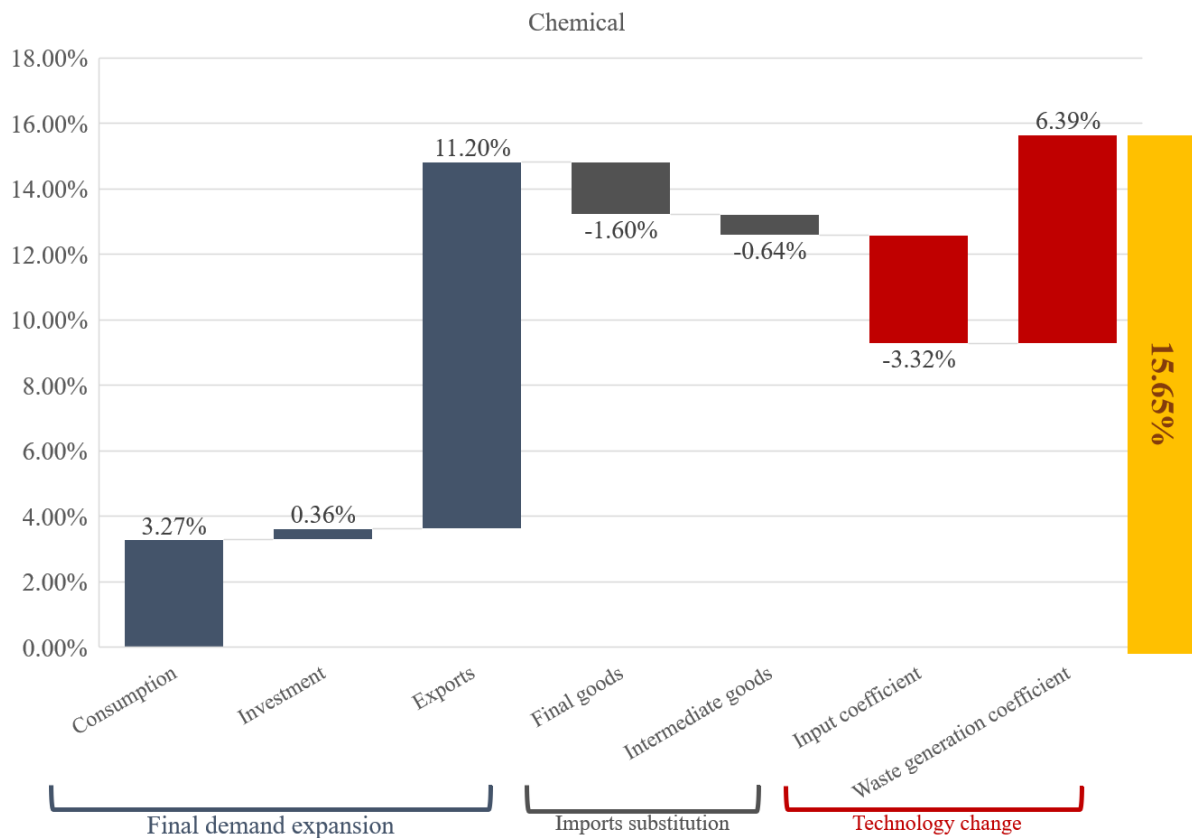


Figure 7-1. SDA result of ‘Chemical’ sector

Like the ‘Chemical’, the increase of IHW in ‘Electronic and electrical equipment’ industry was also due to the exports expansion of +11.49%p as shown in Figure 7-2. At the same time, imports substitution of intermediate goods contributed to the IHW reduction to only -2.02%p. This result seems to have occurred in the process of South Korea’s semiconductor export market growing steadily and significantly.

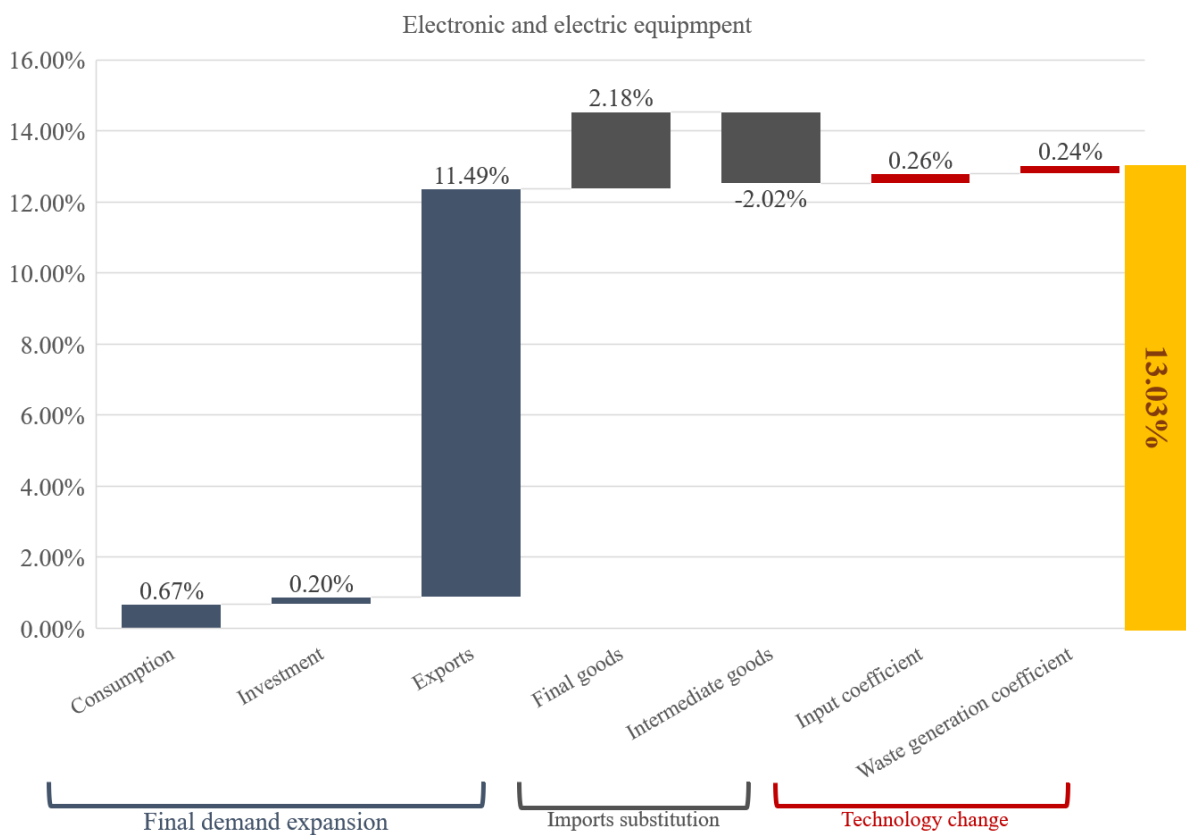


Figure 7-2. SDA result of ‘Electronic and electrical equipment’ sector

The increase in IHW in ‘Basic metal’ industry, as shown in Figure 7-3, is mainly due to +22.62%p of imports substitution of final goods and +18.38%p of change in waste generation

coefficient factor. Although -20.08%p of change in input coefficient factor and -11.82%p of investment expansion contributed to IHW decrease, substituting imports for final goods in ‘Basic metal’ rather affected IHW increase. It indicates that it is necessary to find a way to reduce the dependence of the ‘Basic metal’ industry’s imports for final goods and increase domestic manufacture.

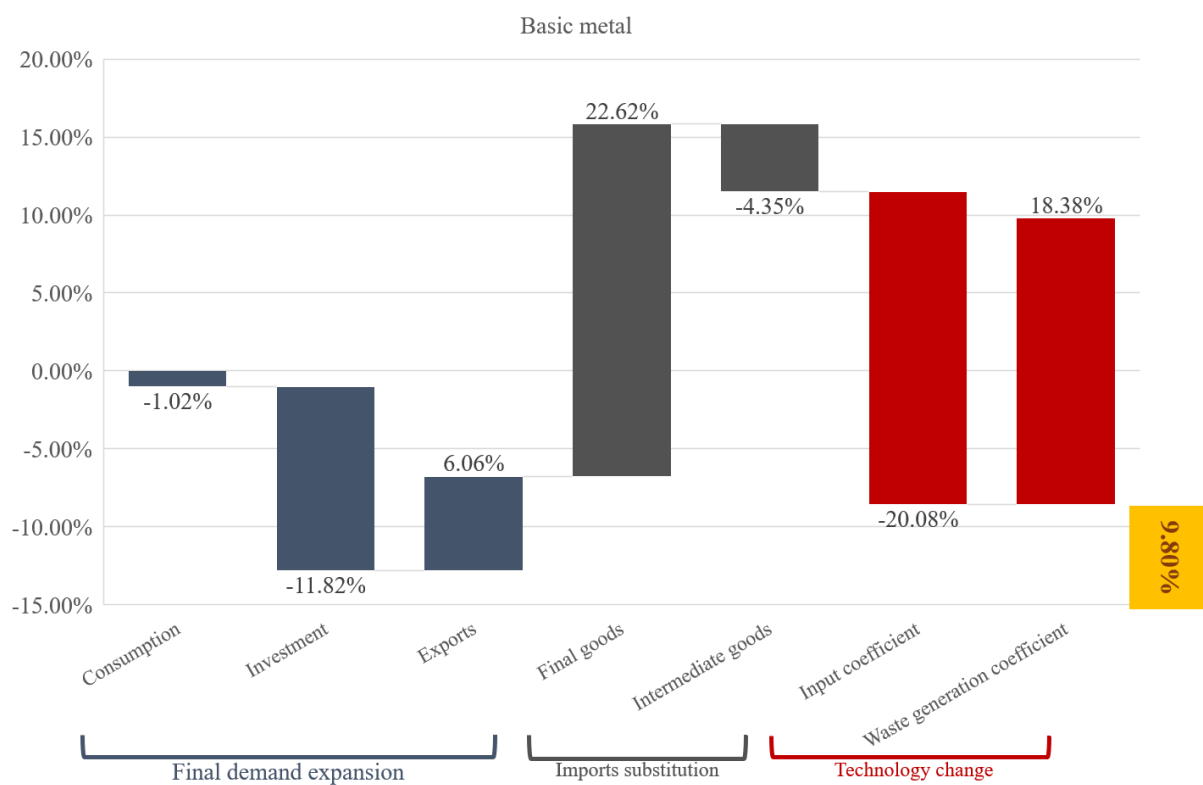


Figure 7-3. SDA result of ‘Basic metal’ sector

‘Other services’, which have a high contribution to the increase in IHW generation among the tertiary industries, contributed +2.64%p and accounted for about 4.55% of the total IHW generation increase. As shown in Figure 7-4, the factor that contributed the most to the IHW

increase in ‘Other services’ was consumption expansion by +10.43%p, while the change in waste generation coefficient factor contributed to the reduction of IHW reduction by -14.61%p.

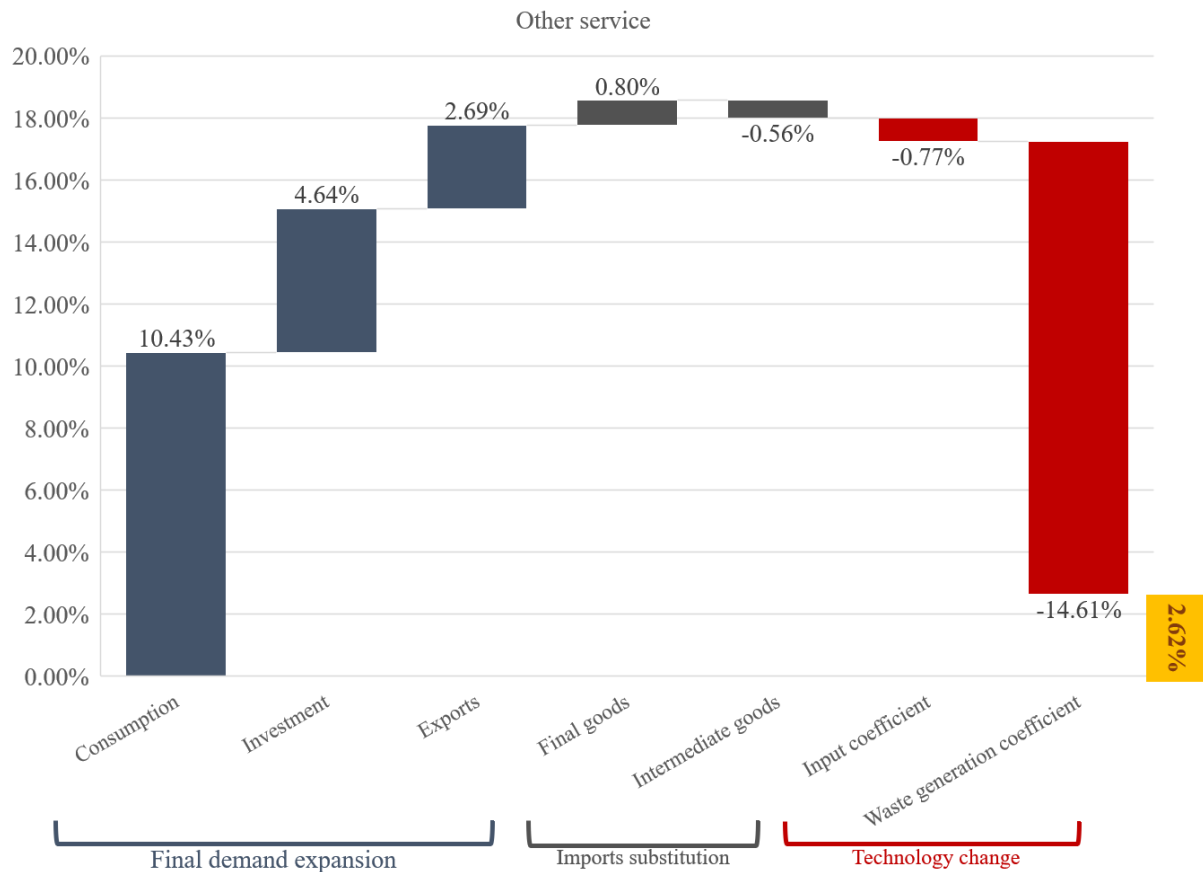


Figure 7-4. SDA result of ‘Other services’ sector

As seen from the above analysis, the increase in IHW generation in South Korea is driven by changes in final demand and import substitution. In particular, recently, the expansion of exports of ‘Electronic and electrical equipment’ and ‘Chemical’ and imports substitution of final goods of ‘Basic metal’ have had the most significant impact. The effect of the export expansion and import substitution on the IHW increase is not a simple matter that can be dealt with simply

by regulating and controlling products manufactured or waste disposal of exports and imports. The fact that exports are increasing means that the country's relevant industrial sector has been recognized through high competition in the global market, and it is undoubtedly a positive change at the national level that can enhance the nation's status through this. However, in terms of the environment, it is also true that it is a burden on the country. Considering the continued increase in exports of the relevant industry, research is needed on how to deal with waste generated from the industry in the long term. In other words, it is time to consider and prepare to increase the value of IHW affected by exports expansion, such as developing another industry through the conversion of waste into resources. Furthermore, in the case of industries where dependence on imports had negative consequences for increasing IHW, it is necessary to examine the background of how these industries became dependent on imports and to predict changes in industrial structure by considering economic and environmental factors' impacts at the same time.

The impressive finding from this chapter's overall result is that IHW generation is more affected by exports and imports than domestic production and consumption. That is, there are numerous hidden waste flows in international trade than in domestic manufacture. This result suggests that when we establish a waste policy, international trade considering the imports and exports characteristics by industry should be considered as important as domestic production activities.

Table 7-2. Results of SDA by industry

(Unit : %, %p)

Industry	The factor of final demand expansion				The factor of imports substitution			The factor of technology change			Total
	Consumption	Investment	Exports	Total	Final goods	Intermediate goods	Total	Input coefficient	Waste generation coefficient	Total	
Agriculture	-	-	-	-	-	-	-	-	-	-	-
Mining	1.01	0.39	1.50	2.91	-0.38	-0.76	-1.14	-1.74	0.16	-1.57	0.20
Food	0.16	0.04	0.05	0.25	-0.04	-0.06	-0.10	0.07	-0.12	-0.05	0.11
Textile	0.30	0.08	0.86	1.24	-0.35	0.05	-0.30	0.23	-1.19	-0.96	-0.01
Wood	0.19	0.12	0.26	0.56	0.11	-0.24	-0.12	0.05	0.57	0.62	1.06
Coke	0.45	0.11	0.66	1.22	-0.11	-0.39	-0.50	-0.57	0.52	-0.04	0.69
Chemical	3.27	0.36	11.20	14.82	-1.60	-0.64	-2.24	-3.32	6.39	3.07	15.65
Non-metallic mineral	0.80	0.44	0.59	1.83	-0.38	-0.15	-0.53	-0.27	1.38	1.11	2.41
Basic metal	-1.02	-11.82	6.06	06.78	22.62	-4.35	18.27	-20.08	18.38	-1.70	9.80
Fabricated metal	0.30	0.50	0.61	1.40	0.22	-0.13	0.09	0.05	-1.68	-1.64	-0.15

Electronic and electrical equipment	0.67	0.20	11.49	12.36	2.18	-2.02	0.16	0.26	0.24	0.50	13.03
Machinery equipment	0.05	0.16	0.36	0.57	0.12	-0.12	0.00	-0.11	0.33	0.22	0.79
Transport equipment	0.59	0.45	0.01	1.05	0.28	-0.39	-0.10	0.20	1.76	1.97	2.91
Other manufacturing	0.13	0.04	0.26	0.42	-0.04	0.09	0.05	0.39	-0.05	0.34	0.81
Electricity, gas, and water supply	0.47	0.01	0.32	0.80	0.22	-0.11	0.11	0.17	0.26	0.43	1.34
Construction	0.06	1.52	0.02	1.61	0.01	-0.01	0.00	-0.05	3.07	3.03	4.63
Wholesale and retail trade	0.19	0.05	0.12	0.36	0.02	-0.02	0.00	0.07	0.24	0.31	0.67
Transport and storage	0.24	0.07	0.05	0.35	0.13	-0.22	-0.09	0.12	0.11	0.23	0.49
Education, health, and social work	0.28	0.00	0.00	0.29	0.01	-0.02	-0.02	0.01	0.35	0.36	0.63
Other services	10.43	4.64	2.69	17.76	0.80	-0.56	0.24	-0.77	-14.61	-15.38	2.63
Total	18.59	-2.65	37.10	53.04	23.82	-10.03	13.79	-25.28	16.13	-9.16	57.68

Chapter 8 : IHW generation prospects by the changes of final demand, waste management method and cost - Scenario analysis

IHW is waste containing harmful components that require special management and is one of great interest to international organizations such as OECD. Therefore, it is important not only to regulate the generation of IHW but also to manage and treat it properly.

This chapter analyzes the scenarios for changes in final demand, changes in IHW treatment methods among incineration, landfill, and recycling, and changes in treatment costs for some types of IHW. The increase in exports of 'Chemical' and 'Electronic and electrical equipment' increased total output by 0.1283% and total IHW generation 0.2378%.

This scenario analysis using developed WIOT of IHW can be used as basic research data to verify the effectiveness of the current waste management system and establish a new waste management policy.

8.1. Methodology

8.1.1. Waste input-output modelling

To establish WIOT, data on waste management costs spent for incineration, landfill, and recycling by industry, the amount of IHW generated from the management process are required, but such data are not statistically and publicly available in South Korea. Therefore, it was necessary to estimate this data by making the most of the accessible public data.

First of all, data on the amount of waste treatment for each industry and waste type of IHW are well established. This research used data of No. 2015-500 of ‘Tipping fees of industrial hazardous waste at public treatment facility’ announced by the Ministry of Environment (MOE) of South Korea for incineration and landfill treatment to estimate the unit cost of treatment. And for recycling, I used data of management unit price of final recycling company from ‘Management unit price for each type of waste for calculation of performance guarantee insurance for neglected wastes’ according to Article 40 (5) of 「Waste Management Act」. Through the above process, the cost spent for waste management by industry was estimated by multiplying the collected management unit price data by the amount of IHW treated.

As with waste treatment costs, data on waste generated during the waste management process is also required to establish WIOT, but there are no publicly available data on this in South Korea.

In the case of the incineration treatment method, there is data on ash generation from incineration facilities. However, since data in 2016 is the most recent data, the amount of ash

generation in 2018 was estimated according to Eq 8-1.

$$Ash_{2018} = \frac{Incineration_{2016} \cdot Ash_{2016}}{Incineration_{2018}} \quad \text{Eq 8-1}$$

Where, Ash_{2016} , Ash_{2018} are the amount of ash generation from incineration facility in 2016, in 2018, respectively, and $Incineration_{2016}$, $Incineration_{2018}$ are the amount of IHW treated by incineration in 2016 and 2018, respectively.

In the case of the landfill management method, there is no IHW generated during this process because it is finally disposed of by landfilling.

Since no data on IHW generated during the recycling process has been established, I calculated it using ‘residue emission factor by waste type and management facility’, which is Appendix 3 of No. .2019-53 of ‘Announce on resource circulation performance management operation for business entities’ announced by the MOE of South Korea. It was estimated by multiplying the amount of IHW recycled by the residual emission factor for each type of waste and recycling type.

In this study, with the IOT and available and/or calculated IHW management related data, the WIOT is created through the following steps:

Step 1: Classification of industry sector of IOT and IHW data

Step 2: Estimation or reorganization of IHW management cost by industry, amount of IHW generated by industry, and amount of IHW generated from the IHW management process

Step 3: Deriving the allocation matrix

Step 4: Transformation of a non-square WIOT into a square WIOT through allocation matrix

8.1.2. Formulation of waste input-output table (WIOT)

The WIOT formed using these data is a non-square matrix. However, for WIOA, it is much easier to create and use a square matrix. To convert a non-square matrix into a square matrix, an allocation matrix is used. The allocation matrix ($S_{t \times k}$) is a matrix consisting of ‘waste management method \times waste type’. s_{tk} , a component of the S matrix, means the ratio of the amount of waste k treated by the waste management method t . Therefore, Eq 8-2 holds.

$$\sum_t s_{tk} = 1 \quad \text{Eq 8-2}$$

Where t is the waste management method and k is the waste type.

By multiplying the S matrix by the matrix at the lower of the WIO matrix, the non-square WIO matrix is converted into a square one like Figure 8-1.

	Production sector	Waste treatment sector	Final demand	Total output
Production sector	X_0	X_z	X_f	X
Waste treatment sector	$T \times N$	$T \times T$	$T \times 1$	$T \times 1$

Figure 8-1. Square shape of the waste input-output matrix

Each variable according to the structure of this WIO matrix model is expressed as follows:

$$X_i [= (N \times 1)] \quad \text{Eq 8-3}$$

: Output

$$Z_t [= (T \times 1)] \quad \text{Eq 8-4}$$

: The amount of waste treated by waste treatment method

$$X_{ij} [= N \times (N + T)] \quad (i = 1, \dots, N, \quad j = 1, \dots, N, N + 1, \dots, N + T) \quad \text{Eq 8-5}$$

: Input-output flow for each sector in a non-square input-output matrix

$$W_{kj} [= K \times (N + T)] \quad (k = 1, \dots, K, \quad j = 1, \dots, N, N + 1, \dots, N + T) \quad \text{Eq 8-6}$$

: The amount of waste generation from each industry and waste treatment sector

$$F_{X_i} [= (N \times 1)] \quad (i = 1, \dots, N) \quad \text{Eq 8-7}$$

: Final demand

Then, the following is established:

$$X_i = \left(\sum_{j=1}^{N+T} X_{ij} \right) + f_{X_i} \quad \text{Eq 8-8}$$

$$W_k = \left(\sum_{j=1}^{N+T} W_{kj} \right) + f_{W_k} \quad \text{Eq 8-9}$$

The lower part of the square WIO matrix transformed by S_{tk} and Eq 8-9 can be expressed as Eq 8-10.

$$Z_t = \sum_{j=1}^{N+T} \left[\sum_k S_{tk} (W_{kj} + f_{W_k}) \right] \quad \text{Eq 8-10}$$

Using each of the variables mentioned above, technical coefficients and waste input coefficients are obtained as in Eq 8-11, Eq 8-12, respectively.

$$a_{ij}^X = \frac{X_{ij}}{X_j} \quad (i, j = 1, \dots, N) \quad \text{Eq 8-11}$$

$$a_{ij}^Z = \frac{X_{it}}{Z_t} \quad (i = 1, \dots, N, \quad t = 1, \dots, T) \quad \text{Eq 8-12}$$

Moreover, waste generation coefficients and waste generation coefficients by waste treatment are obtained as in Eq 8-13, Eq 8-14, respectively.

$$g_{kj}^X = \frac{W_{kj}}{X_j} \quad (k = 1, \dots, K, \quad j = 1, \dots, N) \quad \text{Eq 8-13}$$

$$g_{kt}^Z = \frac{W_{kt}}{Z_t} \quad (k = 1, \dots, K, \quad t = 1, \dots, T) \quad \text{Eq 8-14}$$

Using these input coefficients and waste generation coefficients, the output and waste generation are expressed as Eq 8-15 and Eq 8-16.

$$X_i = \left(\sum_{j=1}^N a_{ij}^X X_j \right) + \left(\sum_{t=1}^T a_{it}^Z Z_t \right) + f_{X_i} \quad \text{Eq 8-15}$$

$$Z_t = \sum_{k=1}^K S_{tk} \left(\sum_{j=1}^N g_{kj}^X X_j + \sum_{t=1}^T g_{kt}^Z Z_t \right) + f_{W_k} \quad \text{Eq 8-16}$$

This can be expressed in matrix form as follows:

$$A_X = a_{ij}^X (= X_{ij}/X_j) \quad [= N \times N] \quad \text{Eq 8-17}$$

$$A_Z = a_{it}^Z (= X_{it}/Z_t) \quad [= N \times T] \quad \text{Eq 8-18}$$

$$G_X = g_{kj}^X (= W_{kj}/X_j) \quad [= K \times N] \quad \text{Eq 8-19}$$

$$G_Z = g_{kt}^Z (= W_{kt}/Z_t) \quad [= K \times T] \quad \text{Eq 8-20}$$

With those equations, the WIO matrix can be expressed as follows:

$$\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} A_X & A_Z \\ SG_X & SG_Z \end{pmatrix} \begin{pmatrix} X \\ Y \end{pmatrix} + \begin{pmatrix} f_X \\ Sf_W \end{pmatrix} \quad \text{Eq 8-21}$$

Eq 8-22 is derived by solving Eq 8-21 for the variables X and Y.

$$\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} I - A_X & -A_Z \\ -SG_X & I - SG_Z \end{pmatrix}^{-1} \begin{pmatrix} f_X \\ Sf_W \end{pmatrix} \quad \text{Eq 8-22}$$

The inverse matrix shown in Eq 8-22 is similar to the Leontief inverse matrix in IOA. Using this, we can analyze the effect of changes in various economic conditions output, etc. Schematic of the scenario analysis process using WIOT can be organized as shown in the below.

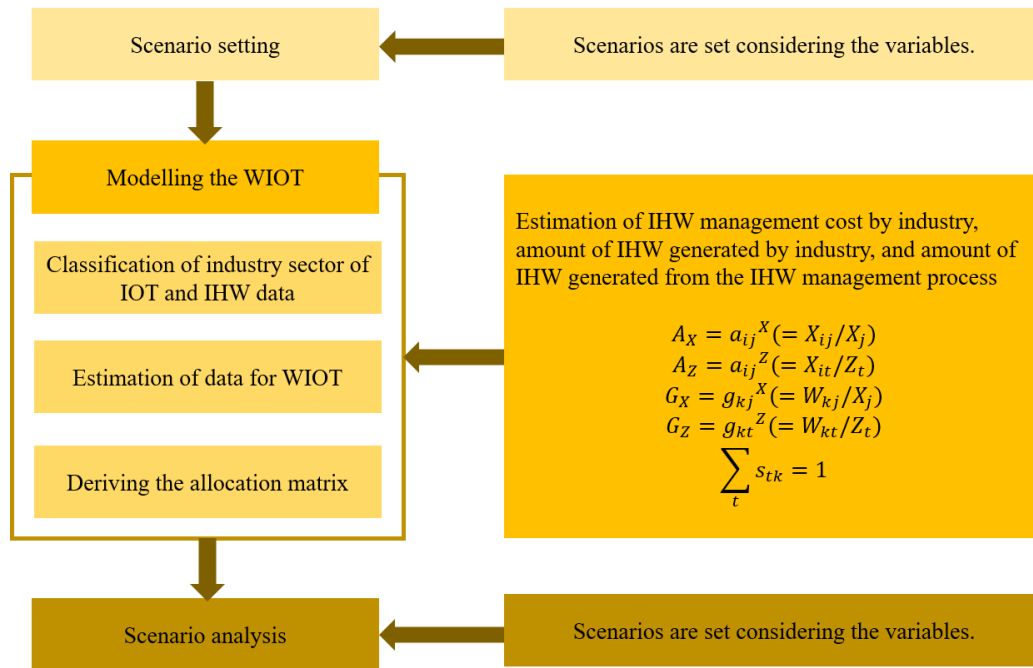


Figure 8-2. Schematic of the scenario analysis using WIOT

8.1.3. Scenario analysis

Using this modelled WIOT, I assumed an increase in exports, changes in waste treatment, changes in waste treatment unit costs, and looked at environmental and economic changes. Five scenarios are analyzed, and a description of each scenario is given in the Table 8-1.

Table 8-1. Description of scenario

Scenario	Description
Scenario 1	Changes in final demand : Assumption for exports expand of the ‘Chemical’ and ‘Electronic and electrical equipment’ by one unit
Scenario 2	Scenario 1 + 80% of Recycling
Scenario 3	Scenario 1 + 90% of Recycling
Scenario 4	Scenario 1 + 100% of Recycling
Scenario 5	Scenario 1 + 50% of increase of treatment unit cost in incineration and landfill

Scenario 1 was analyzed considering changes in final demand. Among the final demand, it was assumed that exports of the ‘Chemical’ and ‘Electronic and electrical equipment’ sectors, which contributed the most to the increase in IHW in particular, will expand by one unit (1 trillion KRW). Scenario 2, 3, 4 were analyzed by adding the assumption of 80%, 90%, 100% of IHW recycling respectively to the assumption of scenario 1. Scenario 5 was analyzed by adding the change in treatment unit price to Scenario 1. For this analysis, the treatment unit costs of incineration and landfill were applied in increments of 50%.

8.2. Results

8.2.1. Exports expansion

Table 8-2 shows the changes in output and the amount of IHW treatment according to changes in the final demand. Assuming that the output of the ‘the ‘Chemical’ and ‘Electronic and electrical equipment’ increases by one unit, the total output increases by 0.1283% and the amount of IHW treatment increases by 0.2378% as shown in Figure 8-3. The industry most affected by the increase in output was ‘Mining’ (6.3059%), followed by ‘Chemical’ (0.6093%), ‘Electronic and electrical equipment’ (0.3448%), ‘Coke’ (0.1975%), and ‘Other manufacturing’ (0.1523%). And in the waste treatment sector, incineration, landfill, and recycling showed an increase of 0.2788%, 0.1391%, and 0.2626%, respectively.

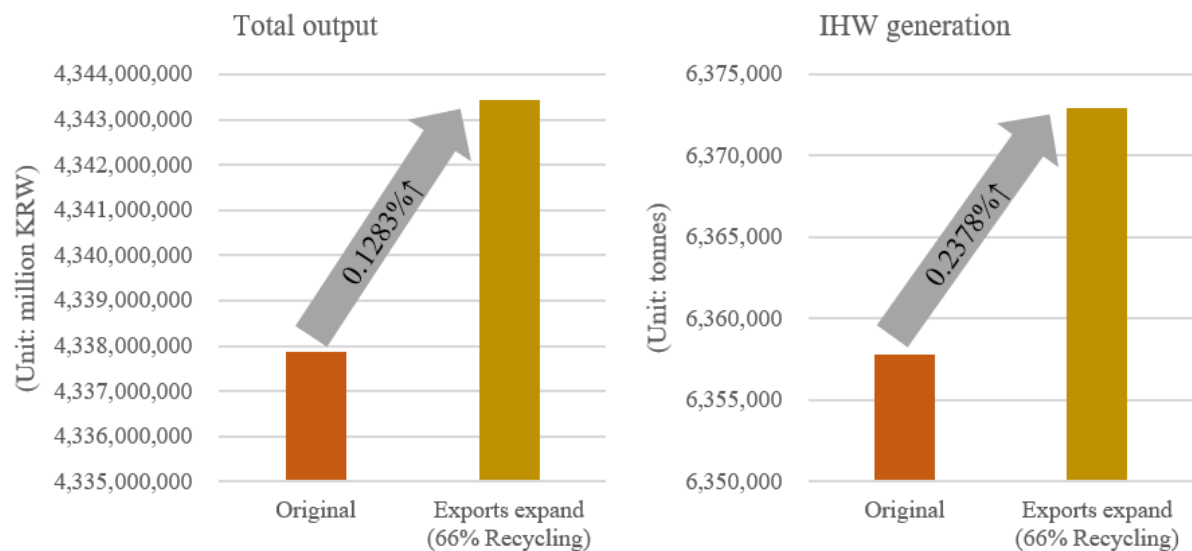


Figure 8-3. The total output and the amount of industrial hazardous waste generation of scenario 1

Table 8-2. The result of scenario 1

(Unit: million KRW, tonnes, %)

	Industry	Original	Scenario 1	Rate of change
Output	Agriculture	62,829,782	62,857,357	0.0439
	Mining	4,520,590	4,805,654	6.3059
	Food	132,826,872	132,872,994	0.0347
	Textile	72,672,986	72,709,788	0.0506
	Wood	47,042,604	47,092,693	0.1065
	Coke	144,563,068	144,848,563	0.1975
	Chemical	286,551,610	288,297,607	0.6093
	Non-metallic mineral	43,979,062	44,019,488	0.0919
	Basic metal	145,774,393	145,945,801	0.1176
	Fabricated metal	100,538,537	100,614,327	0.0754
	Electronic and electrical equipment	434,937,206	436,436,885	0.3448
	Machinery equipment	146,222,687	146,287,649	0.0444
	Transport equipment	225,803,713	225,836,721	0.0146
	Other manufacturing	87,607,952	87,741,414	0.1523
	Electricity, gas, and water supply	122,722,276	122,868,477	0.1191
	Construction	271,773,475	271,783,338	0.0036
	Wholesale and retail trade	280,008,073	280,186,811	0.0638
	Transport and storage	149,665,146	149,852,002	0.1248
	Education, health, and social work	275,736,326	275,744,806	0.0031
	Other services	1,302,090,857	1,302,632,007	0.0416
Industrial hazardous waste treatment	Incineration	732,380	734,422	0.2788
	Landfill	1,374,024	1,375,935	0.1391
	Recycle	4,251,404	4,262,566	0.2626
Total output		4,337,867,216	4,343,434,382	0.1283
Total industrial hazardous waste generation		6,357,808	6,372,923	0.2378

8.2.2. Treatment methods change

Table 8-3 shows the result of changes in output and the amount of IHW treatment according to changes in the S matrix. The change in output by industry in scenario 2 was not significantly different from scenario 1. But as a result, the total output, and the amount of IHW generation decreased slightly compared to scenario 1. In addition, the 80% of recycling treatment led to a decrease of -41.6599% and -9.6681% for incineration and landfill, respectively, and an increase of 10.6564% for recycling. It is interpreted that the result of reduction of the amount of the total IHW generation along with reduction of incineration and landfill amount was led to reduction of ash generated during incineration due to increase in recycling. Table 8-4 shows the changes in output and the amount of IHW treatment from scenario 3. In scenario 3, as in scenario 2, the output by industry is not different from scenario 1. However, the results of the total IHW generation of scenario 3 decreased quite significantly. The 90% of recycling treatment led to a decrease of -69.9338% and -22.1564% for incineration and landfill, respectively, and an increase of 19.5625% for recycling. Table 8-5 shows the changes in output and the amount of IHW treatment according to the change of treatment method to 100% recycling. The results of the total IHW generation of scenario 4 were significantly reduced compared to scenario 3. It led to -100% of incineration and landfill and increased recycling by 49.8842%. It means that, as in scenario 2 and 3, the total IHW generation decreased while the amount of recycling increased. An important finding here is that the increase in residue emissions due to increased recycling is sufficiently offset by decreased incineration ash that would not have been generated by incineration. 100% of recycling is unpractical, but this result can quantitatively explain that more government support and application of recycling business and research in IHW area is a reasonable alternative to sustainable resource circulation policy.

Table 8-3. The result of scenario 2

(Unit: million KRW, tonnes, %)

	Industry	Original	Scenario 2	Rate of change
Output	Agriculture	62,829,782	62,857,355	0.0439
	Mining	4,520,590	4,805,635	6.3055
	Food	132,826,872	132,872,986	0.0347
	Textile	72,672,986	72,709,806	0.0507
	Wood	47,042,604	47,092,703	0.1065
	Coke	144,563,068	144,848,634	0.1975
	Chemical	286,551,610	288,297,475	0.6093
	Non-metallic mineral	43,979,062	44,019,509	0.0920
	Basic metal	145,774,393	145,945,791	0.1176
	Fabricated metal	100,538,537	100,614,342	0.0754
	Electronic and electrical equipment	434,937,206	436,436,850	0.3448
	Machinery equipment	146,222,687	146,287,692	0.0445
	Transport equipment	225,803,713	225,836,664	0.0146
	Other manufacturing	87,607,952	87,741,581	0.1525
	Electricity, gas, and water supply	122,722,276	122,868,301	0.1190
	Construction	271,773,475	271,783,334	0.0036
	Wholesale and retail trade	280,008,073	280,186,816	0.0638
	Transport and storage	149,665,146	149,851,995	0.1248
	Education, health, and social work	275,736,326	275,744,934	0.0031
	Other services	1,302,090,857	1,302,631,846	0.0415
Industrial hazardous waste treatment	Incineration	732,380	427,271	-41.6599
	Landfill	1,374,024	1,241,182	-9.6681
	Recycle	4,251,404	4,704,450	10.6564
Total output		4,337,867,216	4,343,434,249	0.1283
Total industrial hazardous waste generation		6,357,808	6,372,903	0.2374

Table 8-4. The result of scenario 3

(Unit: million KRW, tonnes, %)

	Industry	Original	Scenario 3	Rate of change
Output	Agriculture	62,829,782	62,857,355	0.0439
	Mining	4,520,590	4,805,629	6.3053
	Food	132,826,872	132,872,985	0.0347
	Textile	72,672,986	72,709,804	0.0507
	Wood	47,042,604	47,092,701	0.1065
	Coke	144,563,068	144,848,629	0.1975
	Chemical	286,551,610	288,297,461	0.6093
	Non-metallic mineral	43,979,062	44,019,507	0.0920
	Basic metal	145,774,393	145,945,779	0.1176
	Fabricated metal	100,538,537	100,614,339	0.0754
	Electronic and electrical equipment	434,937,206	436,436,833	0.3448
	Machinery equipment	146,222,687	146,287,690	0.0445
	Transport equipment	225,803,713	225,836,662	0.0146
	Other manufacturing	87,607,952	87,741,577	0.1525
	Electricity, gas, and water supply	122,722,276	122,868,297	0.1190
	Construction	271,773,475	271,783,333	0.0036
	Wholesale and retail trade	280,008,073	280,186,812	0.0638
	Transport and storage	149,665,146	149,852,991	0.1248
	Education, health, and social work	275,736,326	275,744,933	0.0031
	Other services	1,302,090,857	1,302,632,827	0.0415
Industrial hazardous waste treatment	Incineration	732,380	220,199	-69.9338
	Landfill	1,374,024	1,069,592	-22.1563
	Recycle	4,251,404	5,083,084	19.5625
Total output		4,337,867,216	4,343,434,143	0.1283
Total industrial hazardous waste generation		6,357,808	6,372,874	0.2370

Table 8-5. The result of scenario 4

(Unit: million KRW, tonnes, %)

	Industry	Original	Scenario 4	Rate of change
Output	Agriculture	62,829,782	62,857,336	0.0439
	Mining	4,520,590	4,805,450	6.3014
	Food	132,826,872	132,872,951	0.0347
	Textile	72,672,986	72,709,753	0.0506
	Wood	47,042,604	47,092,647	0.1064
	Coke	144,563,068	144,848,445	0.1974
	Chemical	286,551,610	288,297,227	0.6092
	Non-metallic mineral	43,979,062	44,019,459	0.0919
	Basic metal	145,774,393	145,945,574	0.1174
	Fabricated metal	100,538,537	100,614,252	0.0753
	Electronic and electrical equipment	434,937,206	436,436,615	0.3447
	Machinery equipment	146,222,687	146,287,605	0.0444
	Transport equipment	225,803,713	225,836,618	0.0146
	Other manufacturing	87,607,952	87,741,350	0.1523
	Electricity, gas, and water supply	122,722,276	122,868,215	0.1189
	Construction	271,773,475	271,783,311	0.0036
	Wholesale and retail trade	280,008,073	280,186,726	0.0638
	Transport and storage	149,665,146	149,852,897	0.1248
	Education, health, and social work	275,736,326	275,744,798	0.0031
	Other services	1,302,090,857	1,302,632,419	0.0415
Industrial hazardous waste treatment	Incineration	732,380	-	-100.00
	Landfill	1,374,024	-	-100.00
	Recycle	4,251,404	6,372,182	49.8842
Total output		4,337,867,216	4,343,431,651	0.1283
Total industrial hazardous waste generation		6,357,808	6,372,182	0.2261

Figure 8-4 shows the results for scenarios 2,3 and 4 that increased the recycling rate. It was confirmed that the amount of IHW generation was slightly decreased while the total output showed little change. However, compared to the increase in the recycling rate, the decrease in the net IHW generation by subtracting the amount of recycling from the amount of IHW generation is much larger. It could be interpreted as a multiplier effect from the amount of residue generated during recycling would be smaller compared to the amount of residue generated during incineration.

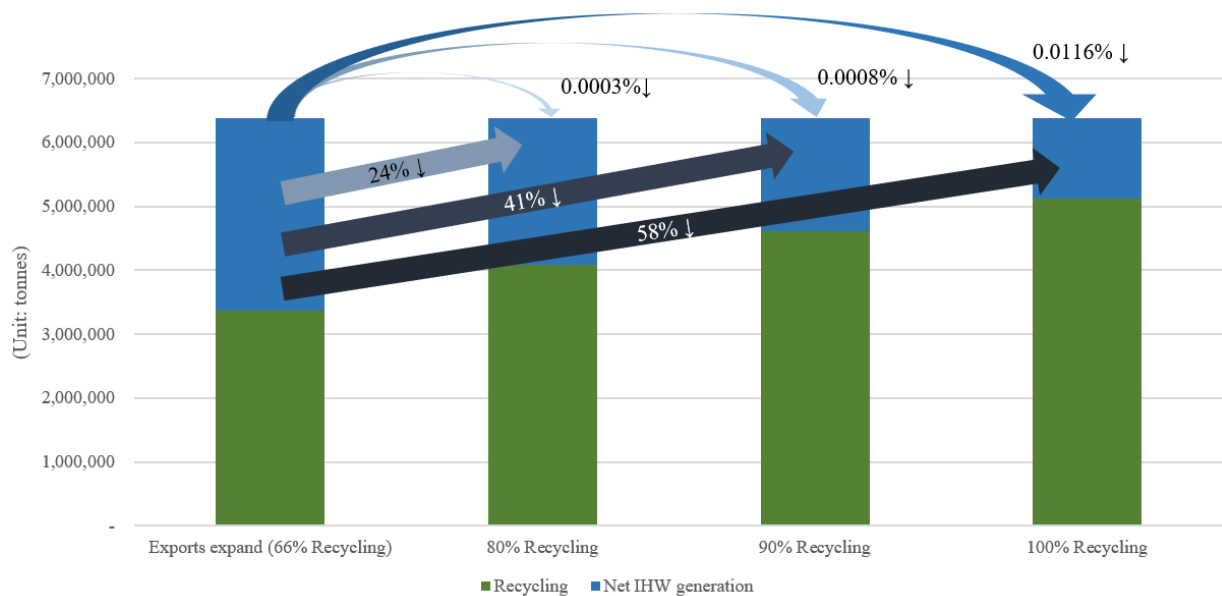


Figure 8-4. The amount of industrial hazardous waste generation of scenario 2, 3, 4

8.2.3. Treatment unit cost change

Table 8-6 and Figure 8-5 show the changes in the total output according to changes in treatment unit cost. Unlike the subtle changes in scenario 2, 3 and 4, the change in treatment unit cost in scenario 5 shows a relatively large increase in the total output, but little change in

the total IHW generation. The increase in the total output indicates that each industry spent more on waste treatment, and output from industries such as waste treatment industry was increased. These changes are expected to put a burden on industries to waste treatment cost and resulting in a reduction.

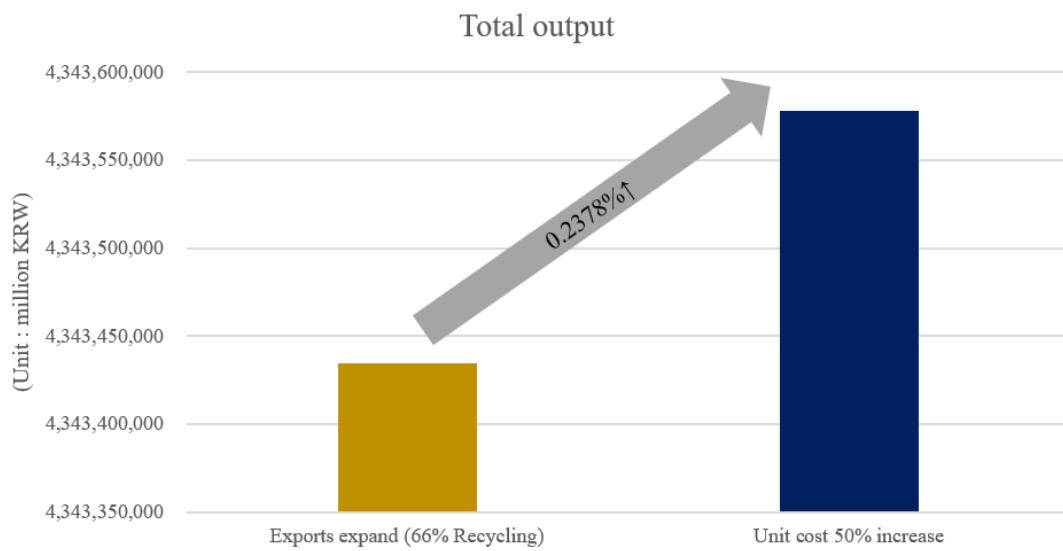


Figure 8-5. The total output of scenario 5

Table 8-6. The result of scenario 5

(Unit: million KRW, tonnes, %)

	Industry	Original	Scenario 5	Rate of change
Output	Agriculture	62,829,782	62,857,360	0.0439
	Mining	4,520,590	4,805,828	6.3098
	Food	132,826,872	132,873,625	0.0352
	Textile	72,672,986	72,710,138	0.0511
	Wood	47,042,604	47,095,427	0.1123
	Coke	144,563,068	144,851,022	0.1992
	Chemical	286,551,610	288,318,021	0.6164
	Non-metallic mineral	43,979,062	44,020,553	0.0943
	Basic metal	145,774,393	145,957,196	0.1254
	Fabricated metal	100,538,537	100,617,678	0.0787
	Electronic and electrical equipment	434,937,206	436,441,776	0.3459
	Machinery equipment	146,222,687	146,288,899	0.0453
	Transport equipment	225,803,713	225,844,664	0.0181
	Other manufacturing	87,607,952	87,742,352	0.1534
	Electricity, gas, and water supply	122,722,276	122,898,215	0.1434
	Construction	271,773,475	271,788,116	0.0054
	Wholesale and retail trade	280,008,073	280,187,281	0.0640
	Transport and storage	149,665,146	149,852,808	0.1254
	Education, health, and social work	275,736,326	275,745,882	0.0035
	Other services	1,302,090,857	1,302,681,394	0.0454
Industrial hazardous waste treatment	Incineration	732,380	734,422	0.2788
	Landfill	1,374,024	1,375,935	0.1391
	Recycle	4,251,404	4,262,566	0.2626
Total output		4,337,867,216	4,343,578,236	0.1317
Total industrial hazardous waste generation		6,357,808	6,372,923	0.2378

The WIOT developed through this research work is expected to be utilized as a framework that can consider both environmental and economic aspects when adjusting the unit price of waste treatment.

Chapter 9 : Conclusion

Throughout the previous chapters, a basic understanding of the intended research work and essential knowledge from literature reviews on the research subject has been well established, which ultimately leads to the methodological framework and development of the proposed solution to the problem. It is time to conclude this research work with the interpretation of the analyzed data.

This chapter explores the conclusions of this research work. The main findings obtained by each chapter through this research work, objectively examining how they can potentially contribute to this research field and presenting the limitations and future research, were summarized.

9.1. Summary of major features and findings

This dissertation started with a brief explanation of the IHW problem facing the world: the background of this research, the objective, questions, and tools used in this study in Chapter 1. After much discussion through the literature review in Chapter 2, it has become obvious that characteristics of IHW generation linking with economics and its flow are rarely reviewed from an ecosystem point of view. Compared to active research on greenhouse gas and CO₂, research on waste, especially IHW from an industrial ecological perspective, is insufficient. This research gap has given rise to fundamental research questions. The importance of identifying waste flows within the industrial system for circular economy and sustainable industrial development based on comprehensive research questions was emphasized. To answer the research questions, the processes of analyzing the characteristics of IHW generation and treatment using the industrial ecological tools, which is one of the ways to link the economy and the environment, were described in Chapter 3.

To address the research questions, a comprehensive analysis and understanding and analysis of the state and characteristics of IHW generation in industrial ecosystems is an important first step. It is because the reduction of IHW generated in the production process is one of the key tasks of the new resource recycling plan announced by the South Korean government in 2020. For efficient and sustainable IHW management, it is an essential task. By focusing on IHW generation from economic growth, the characteristics of IHW generation by industry were identified in Chapter 4. First of all, it was confirmed that the decoupling status between the IHW generation and economic growth was unstable, with the overall IHW generation in South Korea showing an upward trend. Most of the period of 2008-2018 showed

a pattern of decoupling, but with the exception of strong decoupling in 2008-2009 and 2012-2013, there is a weak degree of decoupling (expansive negative decoupling, weak decoupling) or non-decoupling (expanding coupling). One more critical finding was that the factor of total industrial output, among the factors of total industrial output, industrial structure, and characteristic of IHW generation, has a significant effect on the increase in IHW generation in all industries. In contrast, the factors and degrees of industrial structure and characteristics of IHW generation vary in each of industries. This result supports the fact that integrated initiatives across all industry sectors are ineffective. Therefore, to design a sustainable national IHW management strategy, it is strongly recommended to include customized IHW reduction targets and measures consideration the characteristics of industrial specific generations in the country.

In Chapter 5, the analysis of industrial structure in terms of supply and demand using input-output table was examined to improve understanding of the economic system of South Korea. In the total output sector, secondary industries were oriented in 2008. Still, due to the growth of ‘Wholesale and retail trade’ and ‘Education, health, and social work’, it was changed to tertiary industries in 2018. Due to the impact of the tertiary industries-oriented total output growth, most secondary industries showed an increase in the imports sector. Meanwhile, in demand side, consumption, investment, and export, investment showed an increase especially in the ‘Other services’, and both consumption and export sectors showed increases in the ‘Computer, electronic and optical equipment, electrical machinery, and apparatus’ and ‘Motor vehicles, trailers and semi-trailers, other transport equipment’. By understanding the overall flow and change of South Korea’s productions, imports, and exports, it was confirmed that South Korea’s industrial structure is changing from secondary industry-oriented to tertiary

industry-oriented.

In Chapter 6, the IHW generation flows, and hotspots were figured out by identifying the direct and indirect IHW generation coefficients by industry and the effects of IHW induced from final demand using South Korea's Waste-Extended Input-Output Table (WEIOT) of IHW. As a result, the 'Electronic and electrical equipment', 'Chemical' and 'Basic metal' industries contributed more than 50% of total amount of direct IHW generation as hot spots for direct IWH generation, indicating that special care is required for these three industries. In addition, it was found that consumption among the final demand sectors contributed more than 49% of the IHW generation, suggesting that the government should consider the production process and the consumption aspect when establishing waste policies.

The fact that both production and demand affect IHW generation led this research to analyze the factors that influence the increase or decrease of IHW generation during 2008-2018 using structural decomposition analysis methodology as shown in Chapter 7. Total IHW generation increased by 57.68% over the 10years from 2008 to 2018, with the contributions of final demand change and imports substitution by +53.04%p and +13.79%p, respectively. In contrast, the production technology acted as a factor to IHW reduction by -9.16%p. No IHW was generated in the primary industry. And the secondary industry's contribution to IHW generation increase was +53.26%p, accounting for more than 90% of the total generation increase, which was led by exports demand expansion factor (+34.24%p), waste generation coefficient change factor (+30.04%p), and imports substitution factor of final goods(+22.87%p). In the case of the tertiary industry, the contribution of IHW generation increase was +4.41%p, accounting for only 10% of the total generation increase, which was led by consumption expansion factor by +11.14%p. It is summarized that the exports expansion

and changes in waste generation efficiency in the secondary industry and consumption expansion in the tertiary industry affect the increase of IHW generation. Our findings are consistent with the previous results, highlighting that both production and consumption influence the increase of IHW generation and provide quantitative proof.

Lastly, Chapter 8 described the process of modelling the WIOT of IHW by using the IOT and national statistics about IHW in South Korea. And five scenarios were assumed and analyzed according to the exports expansion and the change in treatment method and treatment unit cost. The results showed that increasing of recycling rate led to a decrease in IHW generation. In particular, the change in treatment unit cost showed a relatively significant increase in total output compared to other scenarios. This scenario analysis using developed WIOT of IHW can be used as fundamental research data to verify the effectiveness of the current waste management system and establish a new waste management policy.

9.2. Potential contributions to the field

This research provides tools linking economic and environmental variables based on the industrial ecology and environmental engineering, and IHW flow footprint. It potentially contributes to environmental management/policy and industrial ecology in several ways.

First, in Chapter 4, this research analyzed the decoupling degree by linking the IHW generation with economic growth in South Korea and showed that the characteristics of IHW generation by industry are different, suggesting that it is necessary to establish a customized policy for each industry rather than an integrated waste policy. Second, in Chapter 5, through

industrial structure analysis using the IOT, trends in production and consumption in South Korea are comprehensively analyzed. It contributes to understanding how South Korea's total output, imports, consumption, investment, and exports in the industry system were changed. Third, Chapter 6 defines the direct and indirect IHW generation boundaries within the supply chain, links industrial activities and IHW generation to calculate direct and indirect IHW generation and identifies its hotspots. And also, in this chapter, the flow of IHW generation between consumption and production was analyzed. The results can be used to drive change in waste research and policy research related IHW that simultaneously considers both the supply and demand aspects. Forth, Chapter 7, which quantitatively evaluates which factors among changes in production technology, expansion of final demand, and import substitution factors affect the increase or decrease in IHW generation, is expected to suggest the direction for waste management and regulation. Lastly, in Chapter 8, scenarios of changes in waste treatment methods are assumed and applied by developing a WIOT of IHW that reflects the current situation of IHW generation and treatment in South Korea. These results are expected to be used as basic research material when establishing reasonable waste policies in the future.

9.3. Limitations and future recommendations

This research work has been carried out in compliance with the best efforts and honest practices in scientific research. Despite all efforts and accessible data materials, since it's the first evaluation version of IHW generation and treatment performed in South Korea, this research is still immature level. However, this study opens the way for South Korea and the world to collect, compile statistics specific environmental data in the waste field, and use them

for efficient and rational policymaking. Some limitations while conducting this research and some of the future recommendations are given below:

1. The different sector classifications of waste data and IOT forced us to reclassify industry sectors, merging several industries into one. Especially the service sector, while it is simplified in the waste data, it is more granular in the IOT. Due to the simplification of waste data, it is unfortunate that detailed analysis could not be done in service sector, which is a tertiary industry. In addition, some discrepancies may have occurred in reclassifying the industry of waste data and IOT data. Although this research has been reclassified and reassembled by focusing on the commonalities of each industry as much as possible, there are still limitations to propose the policy establishment due to data aggregation.
2. There is a limit to the availability of waste generation and treatment data. In particular, there is little data on waste treatment (e.g., less subdivided waste treatment methods (it's only classified into incineration, landfill, recycling, and others), treatment costs used for waste treatment by industry, waste generated during waste treatment process). WIOT of IHW was modeled by estimating those data based on the concept of environmental engineering. Still, it must be resolved at the national level in the future for more accurate analysis.
3. The detailed characteristics of the IHW and environmental hazardous were not considered in this research. If these components were included, a much richer analysis would be possible. Still, the process of building an inventory with only accessible data was not easy at all, so it was omitted to simplify the estimation task.
4. This research was conducted only on South Korea. It is expected that representative conclusions can be reached if more data worldwide are integrated and generalized.

Chapter 10 : Extended abstract (in French)

Les déchets industriels dangereux (DID) ont eu un impact négatif sur l'environnement et les humains et ont également causé des problèmes sociaux, tels que les transferts de déchets inégaux entre pays développés et en voie de développement. Pour éviter cela, la Convention de Basel a été signée pour réglementer les mouvements transfrontaliers et le commerce des DID. De plus, la Corée du Sud a annoncé le « grand plan de transition 2020 vers la circulation des ressources » et a fixé l'objectif de réduire le nombre des DID. Cependant, cette dernière a toujours du mal à établir une politique de gestion des déchets basée sur des motifs raisonnables. Par conséquent, dans cette recherche, basée sur le concept écologique industriel, le tableau entrées-sorties sud-coréen et la production et le traitement des DID ont été liés pour modéliser le tableau entrées-sorties des DID de la Corée du Sud. Grâce au tableau de développement, cette recherche a identifié les caractéristiques de la production des DID en termes de production et de demande par industrie et a analysé les facteurs affectant l'augmentation des DID parmi les facteurs de changement de la demande finale, les facteurs de substitution des importations et les facteurs de technologie de production. Cela a contribué à l'identification des points chauds de DID. Les résultats de cette étude, devraient contribuer à la recherche fondamentale pour établir une politique rationnelle de gestion des déchets qui reflète les caractéristiques de chaque industrie en évaluant quantitativement la production et la gestion des déchets.

10.1. Introduction

10.1.1. Fond

Après la révolution industrielle, la croissance démographique et l'industrialisation mondiale ont entraîné une augmentation constante du PIB mondial. L'industrialisation rapide a stimulé la croissance économique, augmentant les revenus, créant des emplois et réduisant la pauvreté. Cependant, cela a également causé des impacts environnementaux tels que l'épuisement des ressources, la pollution des milieux ou le changement climatique (Biskaborn et al., 2021; Cherniwchan, 2012; Mudakkar et al., 2013).

Au cours des dernières années, l'une de ces nombreuses charges environnementales, les déchets solides, sont une conséquence inévitable de la croissance économique, de l'industrialisation, de l'urbanisation et de l'élévation du niveau de vie humain (Alam & Ahmade, 2013; Hoornweg et al., 2013; Hoornweg & Bhada-Tata, 2012; Hossain et al., 2011). Comme les producteurs fournissent des produits utilisant des ressources naturelles par le biais d'activités industrielles, les consommateurs les achètent et les consomment, ce qui entraîne des déchets mixtes, tels que les déchets ménagers, les déchets agricoles, les déchets solides municipaux, les déchets industriels, etc. Parmi eux, les déchets industriels dangereux (DID), caractérisés par leur inflammabilité, leur corrosivité, leur réactivité et leur toxicité, sont directement liés aux activités industrielles et pourraient avoir des effets nocifs sur l'environnement, la santé humaine et la société (H. Guo et al., 2018; Moradi Hanifi et al., 2019; Ojha, 2020; Yi et al., 2011). Pour ces raisons, les pays du monde entier ont renforcé la gestion des DID et réglementé le commerce illégal des DID via la Convention de Bâle, un traité international qui contrôle le transfert et le commerce des déchets dangereux entre les pays (Khan, 2020; Rummel-Bulska & Basavaraj-Schroth, 1994; S. Yang, 2020).

Comme d'autres pays, la Corée du Sud a connu des problèmes croissants de déchets industriels en raison d'une industrialisation, d'une urbanisation et d'une croissance économique rapides et sans précédent. En 2020, le gouvernement sud-coréen a annoncé un nouveau plan de circulation des ressources pour surmonter les limites des lois et réglementations existantes relatives aux déchets. La première tâche clé de ce nouveau plan est de réduire la production de déchets en réduisant la quantité de DID générée au stade de la fabrication du produit. Pour cela, le gouvernement sud-coréen a élargi son soutien aux opportunités de conseil personnalisé et à l'amélioration des lieux de travail qui génèrent de grandes quantités de DID.

Récemment, les recherches sur la génération et la gestion des DID ont augmenté en Corée du Sud. Yoon et al. (2021) ont analysé les caractéristiques des déchets de poussière de 28 sites industriels de fabrication de métaux en Corée du Sud en termes de sécurité environnementale. Park et al. (2020) ont analysé la causalité entre les croyances et les comportements des consommateurs en Corée du Sud sur le plan social pour établir des stratégies de maximisation des flux de déchets d'équipements électriques et électroniques. Finalement, Choi et al. (2019) ont proposé une gestion avancée des DID en Corée du Sud d'un point de vue systémique en créant un lien entre l'industrie, les déchets, les produits chimiques dangereux, leurs caractéristiques néfastes et leurs méthodes de traitement. Cependant, pour autant que nous sachions, peu d'études se sont concentrées sur les caractéristiques de génération de DID, ce qui est un prérequis incontournable pour la conception d'une politique durable de gestion des déchets industriels dangereux en Corée du Sud.

10.1.2. Objectifs et questions de recherche

Cette étude se concentre, premièrement, sur l'identification des facteurs affectant la génération d'IHW en Corée du Sud, puis sur l'analyse quantitative de l'intensité de DID par

industrie et des facteurs affectant l'augmentation de la production de DID, et, finalement, sur la compréhension de l'impact des changements dans les méthodes de traitement de DID. Afin d'atteindre ces objectifs, cette étude applique et développe divers outils d'évaluation environnementale basés sur le concept d'écologie industrielle pour comprendre les caractéristiques de la production de DID en termes d'offre et de demande ainsi que l'effet multiplicateur des changements dans les méthodes de traitement des DID et le coût unitaire de traitement. L'ancien tableau entrées-sorties des déchets (TESD) établi pour les déchets industriels en Corée du Sud était insuffisant pour refléter la réalité. Pour combler cette lacune, cette étude se concentre sur le développement d'outils qui reflètent autant que possible la situation sud-coréenne grâce à des types de DID plus détaillés, des méthodes de traitement des déchets et une estimation des données basée sur une logique d'ingénierie environnementale.

L'objectif est de fournir un outil permettant d'analyser quantitativement le flux de production de DID et les effets des modes de traitement en modélisant le tableau entrées-sorties des déchets pour les DID en utilisant des données accessibles au public. Ces travaux visent à atteindre cet objectif de recherche

10.1.3. Outils et portée de l'évaluation

Les outils d'évaluation quantitative utilisés dans ce travail de recherche s'appuient sur l'ingénierie environnementale et l'écologie industrielle. Les méthodes utilisées dans cette recherche comprennent l'analyse de découplage, l'IPAT modifié, l'analyse de décomposition Log-mean Divisia Index (LMDI), l'analyse d'entrée-sortie étendue des déchets (AESED), l'analyse d'entrée-sortie des déchets (AESD) et l'analyse de décomposition structurelle (ADS).

L'étendue de cette étude porte sur la génération et le traitement de DID dans le système industriel de la Corée du Sud, et le cadre temporel est compris entre les années 2008 et 2018.

10.1.4. Le cadre du travail de recherche

Pour la première étape, cette étude considère comme frontière du système le système économique ainsi que les DID de la Corée du Sud. Dans la première analyse, la production de DID en Corée du Sud a été caractérisée par le biais d'une analyse de découplage et de décomposition de l'indice, cette analyse a été effectuée au niveau macro. Ensuite, la structure industrielle a été analysée du point de vue de l'offre et de la demande. Après cela, la caractérisation de la génération de DID et de l'ADS pour identifier les facteurs affectant l'augmentation de la génération de DID à travers AESED a été menée au niveau micro. Et pour la dernière étape, le TESD a été modélisé, et l'effet des changements de méthodes de traitement des déchets et des coûts unitaires a été analysé à travers AESD. Cette recherche a conclu en suggérant des implications politiques.

10.2. Revue de littérature

10.2.1. Revue de la théorie

L'écologie industrielle (EI) est un mot qui combine les mots « industrie » et « écologie » et est défini comme « un cadre large et holistique pour guider la transformation du système industriel vers une base durable » (E. A. Lowe & Evans, 1995). C'est un concept permettant aux activités industrielles de produire des biens en utilisant des ressources de manière naturelle comme sous la forme d'un écosystème naturel (L.W et al., 1992; S., 1997; T.E., 1996). L'objectif ultime de l'EI est de développer un écosystème industriel en boucle quasiment fermée afin d'améliorer la durabilité environnementale. Sur la base de ce concept, l'EI, en tant que champ d'étude interdisciplinaire, a été développée pour fournir un nouveau cadre conceptuel permettant de mieux comprendre les interactions entre les systèmes industriels et

les environnements et les sociétés à différentes échelles (Huber, 2000; E. Lowe, 1993).

L'approche de l'EI comprend de nombreux outils et méthodologies tels que l'Analyse du cycle de vie (ACV), l'analyse des flux de matières (AFM), l'analyse des entrées-sorties (AES), le système d'information géographique (SIG) et d'autres outils qui incluent des concepts de symbiose industrielle (J. Kim & Perez, 2015). Ces outils peuvent être utilisés pour étudier des réseaux spécifiques contenant des flux de ressources, d'énergie et de polluants (déchets, polluants atmosphériques, polluants de l'eau, polluants du sol, etc.) à différents niveaux (industrie, communauté, ville, région et nation, niveau mondial) (Horváth & Harazin, 2016; Schiller et al., 2014; Von et al., n.d.; G. Wang et al., 2014).

Le système économique linéaire de « production-consommation-élimination » de masse, qui visait principalement à accroître l'extraction de matières premières, la production et l'expédition de marchandises au début de l'industrialisation, a causé une variété d'impacts environnementaux, tels que la production de grandes quantités de déchets, le changement climatique et l'instabilité de l'offre et de la demande de ressources (Jackson, 2019; Sariatli, 2017; van den Bergh, 2017). Pour résoudre ces problèmes environnementaux mondiaux et parvenir à un développement durable, il est nécessaire de rompre avec la structure économique linéaire existante et de la transformer en une économie circulaire (EC) qui réduit l'utilisation des ressources naturelles et poursuit un cycle vertueux des ressources (Hartley et al., 2020; Korhonen et al., 2018; Moraga et al., 2019; Morseletto, 2020; Prieto-Sandoval et al., 2018). L'EC fournit aux systèmes économiques un modèle de flux alternatif circulaire en transformant les produits en fin de vie en ressources pour les acteurs économiques, en fermant les boucles des écosystèmes industriels et en minimisant les déchets (Korhonen et al., 2018; Cahya, 2016; International Reference Centre for the Life Cycle of Products, 2015). T Cette approche nécessite une

utilisation plus efficace et efficiente des matières premières, une augmentation de la durée de vie des produits et la réduction de la quantité de déchets produits. Contrairement au passé, où l'on se concentrait sur le traitement des déchets produits, l'EC se concentre sur la réduction de la production des déchets elle-même, en les traitant comme une ressource et en créant une circulation de ces ressources.

10.2.2. Revue des déchets industriels dangereux

Les déchets sont définis comme « les matériaux qui ne sont plus nécessaires à la vie humaine ou aux activités industrielles, tels que les ordures ménagères, les cendres de combustion, les boues, les huiles usées et les déchets acides, etc. ». En Corée du Sud, les déchets sont classés en deux différentes catégories : déchets ménager ou déchets industriels en fonction de leur origine de production. Les déchets industriels sont également classés en plusieurs catégories : déchets généraux, déchets de construction et déchets dangereux en fonction de leurs caractéristiques de production et de leurs propriétés nocives pour l'Homme et l'environnement.

Les déchets dangereux sont définis, par le biais d'un décret présidentiel, comme étant des substances nocives telles que les huiles usées, les déchets acides, etc. lorsqu'ils sont générés par des activités industrielles spécifiques et qu'ils sont rejetés dans l'environnement. Ils sont séparés en deux catégories : les déchets industriels dangereux et les déchets médicaux.

Les méthodes de traitement des déchets industriels dangereux diffèrent selon la source et les caractéristiques propres à chaque déchet, ils comprennent : l'incinération, l'incinération à haute température, la fusion à haute température, la solidification, la mise en décharge, le recyclage et le traitement physicochimique. Il existe différentes méthodes de traitement physicochimique des déchets : neutralisation, hydrolyse, oxydation, réduction, évaporation,

concentration, coagulation, précipitation et stabilisation, etc. Le recyclage des déchets industriels dangereux intègre le raffinage et la récupération de fioul. Le ministère de l'Environnement classe les méthodes de traitement des déchets industriels dangereux en incinération, enfouissement, recyclage et autres (incinération, enfouissement et recyclage) il publie les statistiques de traitement chaque année.

10.3. Méthodologie et données

10.3.1. Méthodologie

La théorie du découplage a été proposée pour la première fois par l'Organisation de coopération et de développement économique (OCDE) en 2002 (OECD, 2002). Il s'agit de rompre le lien entre « pression environnementale » et « production économique » (UNEP, 2011). En 2005, Tapio a introduit six types de découplage, notamment le découplage négatif expansif, le découplage faible, le découplage fort, le découplage récessif, le découplage négatif faible, le découplage négatif fort et deux types de couplage : le couplage expansif et le couplage récessif (Tapio, 2005).

La méthodologie de l'analyse de décomposition de l'indice (IDA) étudie l'effet des changements dans la structure industrielle, ou l'intensité énergétique par secteur depuis la fin des années 1970 (Ang, 2004). Deux principales méthodologies d'IDA existent : la méthodologie de l'indice Laspeyres et la méthodologie de l'indice Divisia. Parmi les méthodologies Divisia IDA, la méthodologie Log-Mean Divisia Index (LMDI) est considérée comme étant plus performante par rapport aux autres méthodologies IDA. Elle est ergonomique, simple à appliquer et facilite l'interprétation des résultats, après avoir utilisé cette méthodologie

il ne reste aucun résidu (Ang, 2005; Muller, 2006).

Dans le système économique national, chaque industrie a une relation directe et indirecte avec les autres à travers le processus d'achat et de vente de biens et de services nécessaires activités de production. Le tableau entrées-sorties (TES) est défini comme un tableau statistique complet de l'économie nationale. Les interrelations entre les industries pour une certaine période sont enregistrées dans un format matriciel selon certains principes. L'analyse quantitative de l'interrelation entre les industries utilisant un tel TES est appelée analyse des entrées-sorties (AES), qui peut être utilisée pour établir des politiques économiques et calculer les effets d'entraînement. La direction verticale du TES montre la structure d'entrée de chaque industrie, et la direction horizontale du TES montre la structure de distribution. La direction verticale (colonne) comprend le secteur des intrants intermédiaires, c'est-à-dire les détails d'achat des matières premières et des composants. Le secteur à valeur ajoutée correspond aux détails d'achat de main-d'œuvre ou de capital, et la somme correspond à l'intrant total. La direction horizontale (ligne) est divisée en deux secteurs : la demande intermédiaire, dans laquelle les produits de chaque secteur industriel sont vendus en tant que biens intermédiaires, et la demande finale, dans laquelle les produits sont vendus en tant que biens de consommation, biens d'équipement et biens d'exportation. Le secteur de la demande finale comprend la consommation, l'investissement et les exportations. La somme de la demande intermédiaire et de la demande finale est la demande totale, et la demande totale moins les importations est la production totale. L'entrée totale et la sortie totale, qui sont les sommes des deux directions, coïncident avec l'industrie, indiquant un équilibre offre-demande (Miernyk, 2020).

Il existe de nombreux liens entre l'environnement et l'économie, et l'AES a été utilisée pour quantifier et comprendre les problèmes environnementaux depuis l'introduction du

modèle ES environnemental (ESE) de Leontief (Leontief 1970) afin de tenir compte de la pollution, Converse (1971) étant le premier à étendre l'IOE vers la quantification et la compréhension des problèmes de génération de déchets. Une façon d'afficher ces liens est d'utiliser l'environnement "satellite" au bas du TES. Le tableau d'entrées-sorties étendu sur les déchets (TESED) relie la quantité de DID générés en unités physiques au TES indiqué en unités monétaires.

L'analyse de décomposition structurelle (ADS) est une méthodologie pour décomposer et analyser les facteurs de changement dans le temps des indicateurs socio-économiques. Cette méthode est basée sur la série chronologique TES (Peng et al., 2018). En outre, elle est basée sur une analyse statique comparative, qui décompose les changements historiques d'une variable politique en effets déterminants. La force de l'ADS est qu'elle est capable d'analyser en détail les changements de la structure économique. Puisqu'elle est basée sur le modèle entrées-sorties, il est possible de distinguer l'influence directe et indirecte de la demande finale et des changements de technologie d'entrée.

Le modèle ESE de flux de déchets nécessite une correspondance biunivoque entre les types de déchets et les méthodes de traitement pour faciliter le calcul du multiplicateur. Cette nécessité se traduit par un TES symétrique où les flux de déchets sont agrégés et simplifiés, garantissant une perte de détails. Pour surmonter ces lacunes, (Shinichiro Nakamura & Kondo, 2009) ont introduit une matrice distincte répertoriant l'allocation des déchets au secteur de traitement dans leur TESD afin que plusieurs types de déchets puissent être traités simultanément par différents secteurs de traitement. Pour refléter les activités de génération et de traitement de la pollution, les satellites environnementaux élargissent le TES avec des lignes et des colonnes supplémentaires (Shinichiro Nakamura & Kondo, 2009). Ce modèle ESD

introduit par S. Nakamura & Kondo (2002), a été développé pour relier les flux monétaires de produits et services aux flux physiques de déchets générés et traités.

10.3.2. Source d'information

Les sources de données sont présentées dans le Tableau 10-1.

Tableau 10-1. Data and the sources

Data	Sources
Input-Output Table (2018)	Bank of Korea (2018)
IHW generation and treatment (2018)	Korea Ministry of Environment (2018)
IHW treatment cost for incineration and landfill	No. 2015-500 of 'Tipping fees of industrial hazardous waste at public treatment facility'
IHW treatment cost for recycling	'Treatment unit price for each type of waste for calculation of performance guarantee insurance for neglected wastes' according to Article 40 (5) of 「Waste Management Act」
The amount of ash generated from incineration facility (2016)	「National waste statistical survey」 (2016)
Residue emission factor by waste type and treatment facility	'Appendix 3' of No. 2019-53 of 'Announce on resource circulation performance management operation for business entities'

10.4. Caractéristiques de la production de déchets industriels dangereux

10.4.1. Méthodologie

L'état de découplage peut être estimé par les valeurs d'élasticité de sortie de la pression environnementale (génération DID), qui montre dans Eq 10-1.

$$\text{Output elasticity of IHW generation} = \frac{\% \Delta IHW}{\% \Delta \text{Output}} \quad \text{Eq 10-1}$$

Dans cet article, nous avons effectué l'analyse de découplage de la production d'IHW (en tant que valeur de pression environnementale) de la croissance économique en calculant

l'élasticité de la production selon Eq 10-1.

L'équation de décomposition utilisée dans cette recherche multiplie les facteurs que le chercheur veut découvrir. L'identité de décomposition pour analyser les caractéristiques de la génération de DID en Corée est exprimée sous la forme Eq 10-2Eq 4-2, une identité IPAT modifiée.

$$I = Total\ output \times \frac{Output_{industry}}{Total\ output} \times \frac{WG_{industry}}{Output_{industry}} = P \times S \times C \quad \text{Eq 10-2}$$

Où I est un impact environnemental, $Output_{industry}$ est la production par industrie et $WG_{industry}$ est la quantité de production de DID par industrie. P est la production totale, S est la structure industrielle et C est caractéristique de la génération de DID.

Sur la base de Eq 10-2, les changements de chaque facteur peuvent être représentés dans Eq 10-3 comme suit :

$$\Delta I = I_{t,i} - I_{t,0} = \Delta P + \Delta S + \Delta C \quad \text{Eq 10-3}$$

$$\Delta P = \left(\frac{I_{t,i} - I_{t,0}}{\ln I_{t,i} - \ln I_{t,0}} \right) \times \ln \left(\frac{P_{t,i}}{P_{t,0}} \right)$$

$$\Delta S = \left(\frac{I_{t,i} - I_{t,0}}{\ln I_{t,i} - \ln I_{t,0}} \right) \times \ln \left(\frac{S_{t,i}}{S_{t,0}} \right) \quad \text{Eq 10-4}$$

$$\Delta C = \left(\frac{I_{t,i} - I_{t,0}}{\ln I_{t,i} - \ln I_{t,0}} \right) \times \ln \left(\frac{C_{t,i}}{C_{t,0}} \right)$$

Où $\frac{I_{t,i}-I_{t,0}}{\ln I_{t,i}-\ln I_{t,0}}$ est le facteur de pondération dans Eq 10-4. Changements dans le nombre

de I (ΔI) sont décomposés selon les changements dans les facteurs P, S et C.

10.4.2. Résultats

La quantité de production DID augmente régulièrement avec la croissance économique de la Corée du Sud. Pourtant, le résultat de l'analyse du découplage montre une forme de découplage pour la majeure partie de la période de 2008 à 2018. Un fort découplage de la production de DID de la croissance économique s'est produit en 2008-2009 et 2012-2013, et un faible découplage s'est produit en 2009-2011, 2014- 2015 et 2017-2018, et un découplage négatif expansif s'est produit en 2011-2012, 2013-2014 et 2016-2017. Cependant, un non-découplage (couplage en expansion) s'est produit en 2015-2016. De plus, le degré pour toute la période 2008-2018 montre le couplage en expansion. Comme mentionné ci-dessus, la plupart des périodes montrent un schéma de découplage. Pourtant, à l'exception du fort découplage en 2009-2009 et 2012-2013, ils présentent un faible degré de découplage (découplage négatif expansif, découplage faible) ou de non-découplage (couplage en expansion). Malgré les efforts déployés pour promulguer diverses lois et réglementations relatives aux déchets, ces états de découplage instables impliquent que des mesures et une gestion de la réduction de la production de DID plus adaptées à la pratique sont nécessaires. Pour concevoir les stratégies et les mesures de réduction de la génération de DID affectif, il est crucial d'analyser et de comprendre de manière exhaustive les caractéristiques de génération de DID par industrie.

Une découverte essentielle était que le facteur de production totale industrielle avait une influence significative sur l'augmentation de la production de DID dans chaque industrie, et que les facteurs de structure industrielle et les caractéristiques de la génération de DID et leur

degré d'incidence sur la génération de DID sont différents selon l'industrie. Étant donné que les caractéristiques de production de DID varient d'une industrie à l'autre, les plans intégrés de réduction des déchets seraient inefficaces pour réduire la production de DID dans tous les secteurs industriels. Par conséquent, afin de concevoir une stratégie nationale durable de gestion de DID, il est fortement recommandé d'inclure des objectifs et des mesures personnalisés de réduction de la production de DID en tenant compte des caractéristiques de production spécifiques à l'industrie du pays.

10.5. Analyse de l'évolution de la structure économique

10.5.1. Aperçu de la structure économique

En 2008, l'offre totale se compose de 82,53% de l'offre intérieure et de 17,47% des importations. L'offre intérieure est constituée de 63,19% d'intrants intermédiaires et de 36,81% de valeur ajoutée. Le montant de la demande totale doit correspondre au montant de l'offre totale, qui se compose de 83,42 % de la demande intérieure et de 16,58 % des exportations.

En 2018, l'offre totale se compose de 85,46% de l'offre intérieure et de 14,54% des importations. L'offre intérieure est constituée à 56,80% d'intrants intermédiaires et à 43,20% de valeur ajoutée. L'offre totale se compose de 84,29% de la demande intérieure et de 15,71% des exportations.

10.5.2. Perspectives d'approvisionnement

L'offre totale en 2008 était de 3 320 billions de KRW, et 82,53% (2 740 billions de KRW) de l'offre totale a été produite nationalement. Les 17,47 % restants (580 000 milliards de KRW) ont été importés et fournis à la Corée du Sud. Et 36,81% (1 009 billions de KRW) de la production totale provenaient de la valeur ajoutée, et 63,19% (1 731 billions de KRW)

provenaient d'intrants intermédiaires tels que les matières premières. En 2018, l'offre totale était de 5 074 billions de KRW. 85,46% (4 337 billions de KRW) de l'offre totale ont été produits et fournis sur le marché intérieur, et 14,54% (738 billions de KRW) ont été importés et fournis à la Corée du Sud. Et 43,20% (1 873 billions de KRW) de la production totale provenaient de la valeur ajoutée, et les 56,40% restants (2 463 billions de KRW) provenaient des intrants intermédiaires. De 2008 à 2018, l'offre totale a augmenté de 52,82 %, et la production totale et les importations ont augmenté de 58,26 % et 27,13 %, respectivement. En outre, la valeur ajoutée et les intrants intermédiaires ont augmenté respectivement de 85,71 % et 42,27 %. Il a été analysé par industrie dans la production totale et le secteur des importations.

10.5.3. Perspectives de la demande

La demande finale de la demande totale était de 47,86 % (1 589 billions de KRW) et la demande intermédiaire était de 52,14 % (1 731 billions de KRW). Parmi la demande finale, la consommation était de 45,22 % (719 000 milliards de KRW), l'investissement de 20,13 % (320 000 milliards de KRW) et les exportations de 34,64 % (550 000 milliards de KRW). En 2018, la demande finale pour la demande totale était de 51,46 % (2 611 billions de KRW) et la demande intermédiaire était de 48,54 % (2 463 billions de KRW). Parmi la demande finale, la consommation était de 46,58 % (1 216 billions de KRW), l'investissement de 22,89 % (598 billions de KRW) et les exportations de 30,53 % (797 billions de KRW). De 2008 à 2018, la demande finale, la demande intermédiaire, la consommation, l'investissement et les exportations ont respectivement augmenté de 64,32 %, 42,27 %, 69,26 %, 86,82 % et 44,80 %. En outre, les exportations nettes, moins les importations provenant des exportations, étaient de -30 000 milliards de KRW en 2008 et de 59 000 milliards de KRW en 2018. Une valeur négative des exportations nettes signifie que les importations sont supérieures aux exportations,

ce qui montre que la Corée du Sud avait une structure industrielle dépendante de l'importation en 2008. Les secteurs de consommation, d'investissement et d'exportation de la demande finale ont été examinés, et enfin, les exportations nettes ont été examinées par industrie.

10.6. Empreinte des déchets dans le système industriel

10.6.1. Méthodologie

Dans cette recherche, nous avons défini les déchets directs comme les déchets générés par le processus de production sur site d'une industrie et les déchets indirects comme les déchets générés tout au long des processus de production de toutes les industries de cette chaîne d'approvisionnement qui sous-tendent la production de ce produit final.

Nous pouvons calculer les coefficients de production directe de DID (L_{direct}) en divisant la quantité totale de production de DID par secteur (W) par la production totale (X), comme Eq 10-5.

$$L_{direct} = \frac{W}{X} \quad \text{Eq 10-5}$$

Les coefficients de génération DID totaux (L_{total}) peuvent être calculés en multipliant la matrice diagonale des coefficients de génération DID directs ($L_{direct} = \hat{L}$) par la matrice de Leontief, comme Eq 10-6. Il inclut également le concept d'un coefficient d'incitation à la génération IHW pour répondre une unité de demande.

$$L_{total} = \hat{L} \cdot (I - A)^{-1} \quad \text{Eq 10-6}$$

Les coefficients de génération DID indirects ($L_{indirect}$) peuvent être obtenus comme la différence entre les coefficients de génération DID totaux (L_{total}) et les coefficients de génération DID directs (L_{direct}), comme Eq 10-7.

$$L_{indirect} = L_{total} - L_{direct} \quad \text{Eq 10-7}$$

En termes de demande, la demande finale Y est un secteur exogène composé de la consommation, de l'investissement et des exportations comme la montre Eq 10-8. Cette recherche l'analyse en la divisant en consommation, investissement et exportations nettes.

$$Y = Y_C + Y_I + Y_E - M = Y_C + Y_I + Y_N \quad \text{Eq 10-8}$$

Il est défini, Y_C comme un vecteur de consommation incluant la consommation privée et la consommation publique, Y_I un vecteur d'un investissement incluant la formation privée de capital fixe, la formation brute de capital fixe, les variations de stocks et l'acquisition nette d'objets de valeur, Y_E comme vecteur d'exportations M comme vecteur des importations et Y_N comme vecteur des exportations nettes ($Y_E - M$).

Les coefficients d'incitation à la production de DID sont calculés comme Eq 10-9, Eq 10-10 et Eq 10-11 en multipliant les coefficients de production directe de DID par le ratio du secteur de la demande finale (c'est-à-dire le ratio de la consommation, de l'investissement et des exportations nettes à la demande finale).

$$L_C = \hat{L} \cdot (I - A)^{-1} \cdot \frac{Y_C}{Y} \quad \text{Eq 10-9}$$

$$L_I = \hat{L} \cdot (I - A)^{-1} \cdot \frac{Y_I}{Y} \quad \text{Eq 10-10}$$

$$L_N = \hat{L} \cdot (I - A)^{-1} \cdot \frac{Y_N}{Y} \quad \text{Eq 10-11}$$

Où L_C est les coefficients d'incitation de génération DID par consommation, L_I est les coefficients d'incitation de génération DID par investissement, et L_N est les coefficients d'incitation de génération DID par exportations nettes.

10.6.2. Résultats

Nous avons confirmé que les coefficients de production directe, indirecte et totale de DID sont supérieurs à la moyenne dans cinq industries, notamment « Textile », « Chimie », « Métal de base », « Fabrication métallique » et « Équipements électroniques et électriques », ce qui implique qu'il faut accorder plus d'attention à la production et au traitement des déchets ménagers dans ces cinq industries. De plus, les coefficients de génération indirecte de DIE sont élevés dans les « équipements de machines », les « équipements de transport » et la « construction ». Ce résultat signifie que même si la quantité de production directe de DID agrégée par les statistiques dans ces industries est faible, il y a beaucoup de DID générés au sein de la chaîne d'approvisionnement, donc la prudence est également de mise pour ces industries. D'un point de vue global, comme la valeur moyenne du coefficient de production indirecte de DID est presque le double de celle du coefficient de production directe de DID, on peut confirmer qu'il existe une grande quantité de flux cachés de DID sous les statistiques

finales qui sont officiellement publiées. Cela signifie que lorsque le gouvernement établit des politiques en matière de déchets, il est nécessaire d'examiner l'ensemble de la chaîne d'approvisionnement au-delà de l'examen des industries individuellement.

Dans l'étape précédente, les coefficients de génération directe, totale et indirecte de DID de l'aspect production ont été identifiés. Cependant, puisque l'apparition de la demande finale induit la production et que la valeur ajoutée est créée par les activités de production, une analyse en termes de consommation est également nécessaire. Par conséquent, dans cette étape, nous avons calculé le montant des coefficients d'incitation DID induits et DID générés par la consommation, l'investissement et les exportations nettes pour comprendre les effets de la demande finale sur la génération DID en termes de consommation dans le système économique.

Nous avons vu qu'une grande quantité de DID est induite par rapport à la production totale générée par les exportations nettes. De plus, nous avons confirmé que plus de la moitié de la production de DID est induite en raison de la consommation, ce qui implique que la consommation est un secteur important qui doit être considéré de manière inconditionnelle lors de la gestion de la production de DID.

10.7. Influence des changements de structure industrielle sur la production de déchets industriels dangereux

10.7.1. Méthodologie

En multipliant le vecteur de demande finale de consommation, d'investissement et d'exportations nettes par la matrice de coefficients d'incitation à la production de déchets obtenue à partir de la matrice ESED, le montant d'incitation à la production de déchets pour

chaque demande finale peut être obtenu. Et le coefficient d'incitation à la production de déchets pour chaque demande finale peut être obtenu en divisant le montant d'incitation à la production de déchets par chaque secteur de demande finale. En outre, dans cette étude, la méthode ADS a été utilisée pour analyser les facteurs affectant l'augmentation de la production de DID en facteurs de demande accompagnant la croissance économique et en facteurs d'offre en fonction des changements dans la structure de la technologie de production.

La quantité de DID générée est $W = \widehat{w} \cdot X$, and Eq 10-12 est la formule pour exprimer le changement dans la quantité de génération de DID en divisant l'année de base et l'année comparative.

$$\begin{aligned} \Delta W &= \widehat{w}_2 \cdot X_2 - \widehat{w}_1 \cdot X_1 = \widehat{w}_2 \cdot (X_2 - X_1) + (\widehat{w}_2 - \widehat{w}_1) \cdot X_1 \\ &= \widehat{w}_2 \cdot \Delta X + (\Delta \widehat{w}) \cdot X_1 \end{aligned} \quad \text{Eq 10-12}$$

Cette recherche divise la demande finale en consommation, investissement et exportations pour mesurer l'effet de substitution des importations des biens intermédiaires et des biens finaux. Et le changement de la structure technologique est divisé en changements du coefficient d'entrée et en changements du coefficient de génération IHW. En conséquence, une équation de décomposition comme dans Eq 10-13 est dérivée. Cette équation est l'équation de Paasche basée sur le facteur d'incitation à la production de l'année comparative ($L_2 = (I - A_2)^{-1}$).

$$\begin{aligned} \Delta W &= \widehat{w}_2 \cdot L_2 \cdot (I - \widehat{m}_2) \cdot \Delta C && \text{(Consumption expansion effect)} \\ &+ \widehat{w}_2 \cdot L_2 \cdot (I - \widehat{m}_2) \cdot \Delta I && \text{(Investment expansion effect)} \end{aligned} \quad \text{Eq 10-13}$$

$$+\widehat{w}_2 \cdot L_2 \cdot \Delta E \quad (\text{Exports demand expansion effect})$$

$$+\widehat{w}_2 \cdot L_2 \cdot (\widehat{m}_1 - \widehat{m}_2) \cdot I_1 \quad (\text{Final goods imports substitution effect})$$

$$+\widehat{w}_2 \cdot L_2 \cdot (A_2^m - A_1^m) \cdot X_1 \quad (\text{Intermediate goods imports substitution effect})$$

$$+\widehat{w}_2 \cdot L_2 \cdot [\Delta A - (A_2^m - A_1^m)] \cdot X_1 \quad (\text{Technological structure change effect})$$

$$+(\widehat{w}_2 - \widehat{w}_1) \cdot X_1 \quad (\text{Waste generation coefficient change effect})$$

Où \widehat{m} est la matrice diagonale du rapport des importations de biens finaux à la demande intérieure finale, C est le vecteur de la consommation, I est le vecteur de l'investissement, E est le vecteur des exportations, A^m est la matrice du coefficient des importations, et A est la matrice du coefficient technique.

10.7.2. Résultats

La production de DID a augmenté de 57,68 % de 2008 à 2018. Selon l'analyse de chaque facteur à l'aide de la méthode d'analyse de décomposition structurelle, le facteur de changement de la demande finale et le facteur de substitution des importations ont entraîné l'augmentation à +53,04 %p et +13,79 %p, respectivement. En revanche, le facteur technologie de production a joué un rôle de facteur de réduction à -9,16%p.

La contribution de l'industrie secondaire à l'augmentation de la production de DID a été de +53,26 %p, représentant plus de 90 % de l'augmentation de la production totale, qui a été entraînée par le facteur d'expansion de la demande d'exportations (+34,24 %p) et le facteur de changement du coefficient de production de déchets (+30,04 %). p). Parmi les facteurs de variation de la demande finale, le facteur d'expansion de la consommation était de +7,44 %p et

le facteur d'expansion de l'investissement était de -7,41 %p, se compensant, mais on a vu que l'effet significatif de l'expansion des exportations a contribué à l'augmentation de la génération de DID.

Dans le cas du secteur tertiaire, qui est une industrie de services, la contribution de l'augmentation de la production de DID a été de +4,41 %p, représentant seulement 10 % de l'augmentation de la production totale, qui a été entraînée par le facteur d'expansion de la consommation +11,14 %p.

10.8. Perspectives de production de DID par évolution de la demande finale, du mode de gestion des déchets et du coût – Scénario

10.8.1. Méthodologie

Pour établir le TESD, des données sur les coûts de gestion des déchets dépensés pour l'incinération, la mise en décharge et le recyclage par l'industrie, la quantité de DID générée à partir du processus de gestion sont nécessaires, mais ces données ne sont pas statistiquement et publiquement disponibles en Corée du Sud. Il était donc nécessaire d'estimer ces données en exploitant au mieux les données publiques accessibles.

Tout d'abord, les données sur la quantité de déchets traités pour chaque industrie et type de déchets de DID sont bien établies. Cette recherche a utilisé les données du n° 2015-500 des « Frais de déversement des déchets industriels dangereux dans les installations de traitement publiques » annoncées par le ministère de l'Environnement (MOE) de Corée du Sud pour l'incinération et le traitement des décharges afin d'estimer le coût unitaire du traitement. Et pour le recyclage, le doctorant a utilisé les données du prix unitaire de gestion de l'entreprise de

recyclage final du "Prix unitaire de gestion pour chaque type de déchet pour le calcul de l'assurance de garantie de performance pour les déchets négligés" conformément à l'article 40 (5) de la 「Loi sur la gestion des déchets」. Grâce au processus ci-dessus, le coût dépensé pour la gestion des déchets par l'industrie a été estimé en multipliant les données de prix unitaire de gestion recueillies par la quantité de DID traitée. Comme pour les coûts de traitement des déchets, les données sur les déchets générés au cours du processus de gestion des déchets sont également nécessaires pour établir le TESD, mais il n'y a pas de données publiquement disponibles à ce sujet en Corée du Sud. Dans le cas de la méthode de gestion des décharges, il n'y a pas de DID générés au cours de ce processus car ils sont finalement éliminés par enfouissement.

Étant donné qu'aucune donnée sur les DID générés lors du processus de recyclage n'a été établie, le doctorant a calculé à l'aide du « facteur d'émission de résidus par type de déchets et par installation de gestion », qui est l'annexe 3 du n° 2019-53 de l'« Annonce sur l'opération de gestion des performances de circulation des ressources pour les entités commerciales » publiée par le ministère de l'Éducation de Corée du Sud. Il a été estimé en multipliant la quantité de DID recyclée par le facteur d'émission résiduel pour chaque type de déchet et type de recyclage.

Dans cette étude, avec le TES et les données disponibles et/ou calculées relatives à la gestion de DID, le TESD est créé selon les étapes suivantes :

Étape 1 : Classification du secteur industriel des données TES et DID

Étape 2 : Estimation ou réorganisation des coûts de gestion du DID par industrie, quantité de DID générée par l'industrie et quantité de DID générée à partir du processus de gestion du DID

Étape 3 : Dérivation de la matrice d'allocation

Etape 4 : Transformation d'un TESD non carré en un TESD carré grâce à la matrice d'allocation

En utilisant ce TESD modélisé, le doctorant a supposé une augmentation des exportations, des changements dans le traitement des déchets, des changements dans les coûts unitaires de traitement des déchets et le doctorant a examiné les changements environnementaux et économiques. Cinq scénarios sont analysés et une description de chaque scénario est donnée dans le Tableau 10-2 Table 8-1.

Tableau 10-2. Description of scenario

Scenario	Description
Scenario 1	Changes in final demand : Assumption for exports expand of the 'Chemical' and 'Electronic and electrical equipment' by one unit
Scenario 2	Scenario 1 + 80% of Recycling
Scenario 3	Scenario 1 + 90% of Recycling
Scenario 4	Scenario 1 + 100% of Recycling
Scenario 5	Scenario 1 + 50% of increase of treatment unit cost in incineration and landfill

10.8.2. Résultats

En supposant que la production des « équipements chimiques » et « équipements électroniques et électriques » augmente d'une unité, la production totale augmente de 0,1283 % et la quantité de traitement DID augmente de 0,2378 %. L'industrie la plus touchée par l'augmentation de la production a été « Mines » (6,3059 %), suivie de « Chimie » (0,6093 %), « Équipements électroniques et électriques » (0,3448 %), « Coca » (0,1975 %) et « Autres fabrication » (0,1523%). Et dans le secteur du traitement des déchets, l'incinération, la mise en décharge et le recyclage ont enregistré une augmentation de 0,2788 %, 0,1391 % et 0,2626 %, respectivement.

Les résultats des scénarios 2, 3 et 4 qui ont augmenté le taux de recyclage ont montré que

la quantité de production de DID a légèrement diminué tandis que la production totale a peu changé. Cependant, par rapport à l'augmentation du taux de recyclage, la diminution de la production nette de DID en soustrayant la quantité de recyclage de la quantité de production de DID est beaucoup plus importante. Cela pourrait être interprété comme un effet multiplicateur de la quantité de résidus générés lors du recyclage qui serait plus faible par rapport à la quantité de résidus générés lors de l'incinération.

Contrairement aux changements subtils dans les scénarios 2, 3 et 4, le changement du coût unitaire de traitement dans le scénario 5 montre une augmentation relativement importante de la production totale, mais peu de changement dans la production totale de DID. L'augmentation de la production totale indique que chaque industrie a dépensé plus pour le traitement des déchets, et que la production d'industries telles que celle du traitement des déchets a augmenté. Il est attendu que ces changements deviennent une contrainte pour les industries concernant les coûts de traitement des déchets, et se traduisant ainsi par une réduction des déchets qu'elles produisent.

10.9. Conclusion

10.9.1. Résumé des principales caractéristiques et conclusions

Cette thèse a commencé par une brève explication du problème DID auquel le monde est confronté : le contexte de cette recherche, l'objectif, les questions et les outils utilisés dans cette étude au chapitre 1. Après de nombreuses discussions à travers la revue de la littérature au chapitre 2, il est devenu évident que les caractéristiques de la production de DID liées à l'économie et à son flux sont rarement examinées d'un point de vue écosystémique. Par rapport aux recherches actives sur les gaz à effet de serre et le CO₂, les recherches sur les déchets,

notamment les DID du point de vue de l'écologie industrielle, sont insuffisantes. Cette lacune de la recherche a donné lieu à des questions de recherche fondamentale. L'importance d'identifier les flux de déchets au sein du système industriel pour l'économie circulaire et le développement industriel durable sur la base de questions de recherche approfondies a été soulignée. Pour répondre aux questions de recherche, les processus d'analyse des caractéristiques de production et de traitement des DID à l'aide des outils écologiques industriels, qui est l'une des façons de lier l'économie et l'environnement, ont été décrits dans le chapitre 3.

Pour répondre aux questions de recherche, une analyse complète, une compréhension et une analyse de l'état et des caractéristiques de la génération de DID dans les écosystèmes industriels constituent une première étape importante, car la réduction des DID générés dans le processus de production est l'une des tâches clés du nouveau plan de recyclage des ressources annoncé par le gouvernement sud-coréen en 2020. Pour une gestion efficace et durable des DID, c'est une tâche essentielle. En se concentrant sur la production de DID à partir de la croissance économique, les caractéristiques de la production de DRI par industrie ont été identifiées au chapitre 4. Tout d'abord, il a été confirmé que l'état de découplage entre la production de DID et la croissance économique était instable, avec la production globale de DID en Corée du Sud montrant une tendance à la hausse. Une autre constatation critique était que le facteur de la production industrielle totale (parmi les facteurs de la production industrielle totale et de la structure industrielle et des caractéristiques de la production de DID) a un effet significatif sur l'augmentation de la production de DID dans toutes les industries. Ce résultat confirme le fait que les initiatives intégrées dans tous les secteurs de l'industrie sont inefficaces.

Au chapitre 5, l'analyse de la structure industrielle en termes d'offre et de demande à l'aide d'un tableau entrées-sorties a été examinée pour améliorer la compréhension du système économique de la Corée du Sud. En comprenant le flux global et l'évolution des productions, des importations et des exportations de la Corée du Sud, il a été confirmé que la structure industrielle de la Corée du Sud est en train de passer d'une industrie secondaire à une industrie tertiaire.

Dans le chapitre 6, les flux de production de DID et les hotspots ont été déterminés en identifiant les coefficients de production d'IHW directs et indirects par industrie et les effets de DID induits par la demande finale à l'aide du TESED de DID en Corée du Sud. En conséquence, les industries « Équipements électroniques et électriques », « Chimie » et « Métallurgie de base » ont contribué à plus de 50 % de la quantité totale de production directe de DID en tant que les hotspots pour la production directe de DID, ce qui indique qu'une attention particulière est requise pour ces trois industries. En outre, il a été constaté que la consommation parmi les secteurs de la demande finale contribuait à plus de 49 % de la production de DID, ce qui suggère que le gouvernement devrait tenir compte du processus de production et de l'aspect consommation lors de l'établissement de politiques en matière de déchets.

Le fait que la production et la demande affectent la production de DID a conduit cette recherche à analyser les facteurs qui influencent l'augmentation ou la diminution de la production de DID au cours de la période 2008-2018 en utilisant la méthodologie d'analyse de décomposition structurelle, comme indiqué au chapitre 7. La production totale de DID a augmenté de 57,68 % au cours de la 10 ans de 2008 à 2018, avec les contributions de la variation de la demande finale et de la substitution des importations de +53,04 %p et +13,79 %p, respectivement. En revanche, la technologie de production a agi comme un facteur

de réduction de DID de -9,16 %p. Nos résultats sont cohérents avec les résultats précédents, soulignant que la production et la consommation influencent l'augmentation de la production de DID et fournissent une preuve quantitative.

Enfin, le chapitre 8 décrit le processus de modélisation du TESD de DID en utilisant le TES et les statistiques nationales sur le DID en Corée du Sud. Et cinq scénarios ont été supposés et analysés en fonction de l'expansion des exportations et du changement de méthode de traitement et de coût unitaire de traitement. Les résultats ont montré que l'augmentation du taux de recyclage entraînait une diminution de la production de DID. En particulier, l'évolution du coût unitaire de traitement a montré une augmentation relativement significative de la production totale par rapport aux autres scénarios. Cette analyse de scénario utilisant le TESD développé de le DID peut être utilisée comme données de recherche fondamentale pour vérifier l'efficacité du système de gestion des déchets actuel et établir une nouvelle politique de gestion des déchets.

10.9.2. Contributions potentielles au domaine

Cette recherche fournit des outils reliant les variables économiques et environnementales basées sur l'écologie industrielle et l'ingénierie environnementale, et l'empreinte des flux DID. Il contribue potentiellement à la gestion/politique environnementale et à l'écologie industrielle de plusieurs manières.

Tout d'abord, au chapitre 4, cette recherche a analysé le degré de découplage en liant la production de DID à la croissance économique en Corée du Sud et a montré que les caractéristiques de la production de DID par industrie sont différentes, suggérant qu'il est nécessaire d'établir une politique personnalisée pour chaque industrie plutôt qu'une politique

intégrée des déchets. Deuxièmement, au chapitre 5, grâce à l'analyse de la structure industrielle à l'aide de la TES, les tendances de la production et de la consommation en Corée du Sud sont analysées de manière approfondie. Elle contribue à comprendre comment la production totale, les importations, la consommation, les investissements et les exportations de la Corée du Sud dans le système industriel ont été modifiés. Troisièmement, le chapitre 6 définit les limites de la production directe et indirecte de DID au sein de la chaîne d'approvisionnement, relie les activités industrielles et la production de DID pour calculer la production directe et indirecte de DID et identifie ses hotspots. Et aussi, dans ce chapitre, le flux de production de DID entre la consommation et la production a été analysé. Les résultats peuvent être utilisés pour conduire des changements dans la recherche sur les déchets et la recherche sur les politiques liées au DID qui considère simultanément les aspects de l'offre et de la demande. Quatrièmement, le chapitre 7, qui évalue quantitativement les facteurs parmi les changements de technologie de production, l'expansion de la demande finale et les facteurs de substitution des importations qui affectent l'augmentation ou la diminution de la production de DID, devrait suggérer l'orientation de la gestion et de la réglementation des déchets. Enfin, au chapitre 8, des scénarios de changements dans les méthodes de traitement des déchets sont supposés et appliqués en développant un TESD de DID qui reflète la situation actuelle de la production et du traitement des DID en Corée du Sud. Ces résultats devraient être utilisés comme matériel de recherche de base lors de l'établissement de politiques raisonnables en matière de déchets à l'avenir.

10.9.3. Limites et recommandations futures

Ce travail de recherche a été réalisé en respectant les meilleures pratiques en matière de recherche scientifique. Malgré tous les efforts et les données accessibles, puisqu'il s'agit de la première version d'évaluation de la génération et du traitement de DID réalisée en Corée du

Sud, cette recherche est encore immature. Cependant, cette étude ouvre la voie à la Corée du Sud et au monde vers la collection et la compilation des données statistiques spécifiques sur l'environnement dans le domaine des déchets, et à leur utilisation dans le cadre de l'élaboration de politiques efficaces et rationnelles. Certaines limites lors de la réalisation de cette recherche et certaines des recommandations futures sont données ci-dessous :

1. Les différentes classifications sectorielles des données sur les déchets et TES nous ont obligés à reclasser les secteurs industriels, fusionnant plusieurs industries en une seule. Surtout le secteur des services, s'il est simplifié dans les données sur les déchets, il est plus granulaire dans la TES. En raison de la simplification des données sur les déchets, il est regrettable qu'une analyse détaillée n'ait pas pu être effectuée dans le secteur des services, qui est une industrie tertiaire. De plus, certaines divergences peuvent s'être produites lors de la reclassification de l'industrie des données sur les déchets et des données TES. Bien que cette recherche ait été reclassée et réassemblée en se concentrant autant que possible sur les points communs de chaque industrie, il existe encore des limites pour proposer l'établissement de la politique en raison de l'agrégation des données.

2. Il y a une limite à la disponibilité des données sur la production et le traitement des déchets. En particulier, il existe peu de données sur le traitement des déchets (par exemple, sur les méthodes de traitement des déchets moins subdivisées – elles ne sont classées qu'en incinération, mise en décharge, recyclage et autres – les coûts de traitement utilisés pour le traitement des déchets par l'industrie, les déchets générés pendant le processus de traitement des déchets). Le TESD de DID a été modélisé en estimant ces données sur la base du concept d'ingénierie environnementale. Pourtant, il doit être résolu au niveau national à l'avenir pour une analyse plus précise.

3. Les caractéristiques détaillées des DID et des dangers environnementaux n'ont pas été prises en compte dans cette recherche. Si ces composantes étaient incluses, une analyse beaucoup plus riche serait possible. Pourtant, le processus de construction d'un inventaire ne comprenant que des données accessibles n'était pas facile du tout, la simplification de la tâche d'estimation a donc été omise.

4. Cette recherche a uniquement été menée sur la Corée du Sud. Nous nous attendons à ce que des conclusions représentatives puissent être atteintes si davantage de données mondiales sont intégrées et généralisées.

Chapter 11 : Extended abstract (in Korean)

산업 혁명 이후의 급격한 산업화와 도시화는 경제 성장, 일자리 창출 및 빈곤 감소 촉진과 동시에 자원 고갈, 환경오염 배출, 기후 변화 등의 환경문제를 야기하였다. 자원이 채굴, 생산, 소비 단계를 거쳐 버려지는 선형 경제로부터 발생하는 경제성장과 환경보호의 불균형을 해소하기 위해, 세계 각국이 쓰레기를 줄이고 자원을 최대한 활용하는 경제 시스템인 순환경제 체계로의 전환을 추진하고 있다. 이에 발맞춰 한국 또한 2020년 ‘자원순환 정책 대전환 계획’을 수립하며, 여러 계획 중 하나로 사업장폐기물 발생 감축을 목표로하였다. 사업장 폐기물 중에서도 지정폐기물은 환경과 인체에 유해한 성분을 함유한 폐기물로, 환경, 사회적으로 꾸준히 이슈가 되고 있는 물질이다. 유엔 환경계획 (UNEP)은 유해폐기물로부터 발생하는 지구 규모의 환경오염을 방지하기 위하여 유해폐기물 교역을 최소화하고 불법교역을 규제하는 바젤 협약을 체결하였다. 이러한 변화로 인해, 현재 각국의 국내 시스템 내에서 보다 효율적인 지정폐기물 관리 체계 구축에 대한 필요성이 부각되고 있다. 그럼에도 불구하고, 지정폐기물 발생 및 처리 부문에 대한 기초 연구가 많이 부족한 실정이다. 효율적이고 체계적인 자원 순환 정책 수립을 위해서는 지정폐기물의 발생 특성 파악과 처리에 따른 영향에 대한 분석이 선행되어야 한다.

본 연구는 탈동조화 지수 분석, 지수분해분석, 구조분해분석, 산업연관분석 등 다양한 산업생태학적 도구를 복합적으로 이용하여 지정폐기물 발생에 대한 분석 결과를 검토함으로써, 한국의 산업 시스템 내 지정폐기물 발생 특성에 대한 기초자료를 제공하고 지정폐기물 흐름에 대한 이해도를 높이고자 하였다. 또한, 국가 통계 자료를 활용하여 상호연결 되어있는 산업 시스템과 지정폐기물 흐름을 동시에 고려한 지정폐기물 산업연관표를 구축하고, 이를 활용하여 지정폐기물 처리 방법에 따른 영향을 분석함으로써 자원순환 정책 전략을 수립하는 과학적 근거를 제시하고자 하였다.

산업 시스템 내에서의 지정폐기물 발생에 대한 포괄적인 이해를 위한 탈동조화 지수 분석 방법을 제안하고, 2008년부터 2018년까지 한국의 산업생산량 및 지정폐기물 발생 데이터를 이용하여 경제 성장에 따른 환경영향 간의 탈동조화

지수를 평가하였다. 분석 결과, 2008년부터 2018년까지 대부분 기간동안 탈동조화(decoupling) 결과를 보이긴 했으나, 2008년~2009년과 2012년~2013년의 강한 탈동조화(strong decoupling)를 제외하고는 약한 정도의 탈동조화(expansive negative decoupling, weak decoupling)와 동조화(expanding coupling)를 보이는 등, 그 정도가 기간별로 상이하고 불안정한 결과를 보였다. 폐기물 발생에 영향을 미치는 요인으로 총 산업생산량, 산업구조, 지정폐기물 발생 특성을 가정하고 산업별로 지수분해분석을 수행한 결과, 대부분의 산업에서 총 산업생산량은 폐기물 발생 증가에 영향을 미치는 반면, 산업구조와 지정폐기물 발생 특성이 폐기물 발생 증감에 미치는 영향은 산업별로 상이한 것으로 나타났다. 이러한 결과는 한국이 안정적인 탈동조화 현상을 유지하도록 환경이 개선되어야 함을 수치적으로 보여주는 동시에, 모든 산업 부문에 걸친 통합된 폐기물 정책이 아닌 산업별 폐기물 발생 특성을 고려한 맞춤형 지정폐기물 감축 목표를 포함한 조치가 필요함을 의미합니다.

산업별 특성 파악에 앞서 한국의 산업 구조에 대한 이해를 높이기 위해 2008년과 2018년의 산업연관표를 이용하여 수요와 공급 측면에서 분석해보았다. 공급 측면의 총산출 부문에서 2008년에는 2차 산업 중심이었으나, 2018년이 되면서 '도소매업'과 '교육·보건·사회 산업'의 성장에 따라 3차 산업 중심으로 변화되고 있고, 이 영향으로 대부분의 2차 산업은 수입 부문에서 증가세를 보이는 것을 확인하였다. 한편, 수요 측면에서는 2008년 대비 2018년에 '기타 서비스'에서 투자 부문의 증가, '컴퓨터, 전자 및 광학 장비'와 '자동차, 트레일러 및 기타 운송 장비'에서 소비와 수출 부문 모두 증가 추세를 보였다. 생산, 수입, 수출의 전반적인 산업 흐름 분석을 통해 한국의 산업구조가 2차 산업 중심에서 3차 산업 중심으로 변화하고 있음과 '컴퓨터, 전자 및 광학 장비'와 '자동차, 트레일러 및 기타 운송 장비'의 수출 증가를 확인할 수 있었다.

지정폐기물 발생 특성과 산업 구조 변화에 대한 포괄적인 이해를 바탕으로, 한국의 지정폐기물 산업연관표를 구축하여 각 산업별 지정폐기물의 직간접 발생계수와 최종수요에 따른 지정폐기물 발생유발 영향을 좀 더 심층적으로 분석하여 지정폐기물 발생흐름과 핫스팟을 파악하였다. 그 결과, '컴퓨터, 전자 및 광학 장비', '화학 및 화학 제품, 고무 및 플라스틱', 그리고 '기초 금속' 산업이 직접 지정폐기물 발생량의 50% 이상을 기여하는 것으로 나타나, 이 세 산업에 대한 특별한 주의가 필요함을 확인했다. 또한, 간접 발생계수가 직접 발생계수의

2배에 가까움을 확인할 수 있었다. 이 결과는 산업체에서 직접적으로 발생하는 지정폐기물 뿐만 아니라 공급망 내에서 간접적으로 발생하는 숨은 지정폐기물 흐름이 많다는 것을 보여주며, 폐기물 발생을 관리하기 위해서는 해당 산업체뿐만 아니라 전체 공급망을 이해하고 분석하여 규제하는 전략이 필요함을 의미한다. 게다가, 최종수요에 따른 지정폐기물 발생유발 영향 분석 결과는 소비가 지정폐기물 발생에 49% 이상 기여하는 것으로 나타나, 정부가 폐기물 정책을 수립할 때 생산 과정뿐만 아니라 소비 측면도 동시에 고려해야 함을 시사한다.

생산과 수요의 여러 요인 중 지정폐기물 발생 증감에 영향을 미치는 요인을 구조분해분석을 이용하여 분석한 결과, 2차 산업의 기여도가 전체 지정폐기물 발생 증가분의 90% 이상을 차지했으며, 수출수요 확대, 폐기물 발생계수 변화, 최종재 수입대체 요인이 2차 산업의 지정폐기물 발생 증가에 큰 영향을 미치는 요인으로, 3차 산업의 경우, 소비확대 요인이 주요 요인으로 나타났다. 이 결과는 생산과 소비 측면 모두 지정폐기물 생성 증가에 영향을 미친다는 앞선 결과와 일치하며, 산업별, 요인 별 영향을 수치적으로 보여줌으로써, 보다 정량적인 근거를 제공한다.

마지막으로, 유해폐기물 산업연관표를 구축하여 수출 증가, 지정폐기물의 처리방법 및 처리단가 변화에 따른 다섯 가지 시나리오를 가정하여 분석하였다. 이 분석은 ‘컴퓨터, 전자 및 광학 장비’, ‘화학 및 화학 제품, 고무 및 플라스틱’, 산업의 수출 1단위 증가에 의해 유해폐기물 발생량이 0.2378% 증가하는 것을 보여주었다. 또한, 재활용 증가율에 비해 순폐기물 발생량 감소폭이 큰 결과를 통해, 소각 및 매립 시 발생하는 잔류물에 비해 재활용시 발생하는 잔류물의 양이 작아 폐기물 감소에 영향을 미치는 것을 확인할 수 있었다. 폐기물 재활용 처리를 높이기 위해서는 소각 및 매립 처리의 단가를 높여, 산업체에 폐기물 처리 비용에 대한 부담을 주는 방식이 필요할 것으로 예상되었다. 한국의 실정에 맞추어 개발된 지정폐기물 산업연관표를 이용한 시나리오 분석은 현행 폐기물 관리 시스템의 실효성을 검증하고 새로운 폐기물 관리 정책을 수립하기 위한 기초연구 자료로 활용될 수 있다.

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Appendices

Appendix 1. Classification 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		
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	

Appendix 2. Imports of 2008 and 2018

(Unit : million KRW)

Industry	2008	2018
Agriculture	12,023,564	11,945,757
Mining	143,173,748	156,148,249
Food	17,115,357	32,300,457
Textile	15,289,637	30,928,358
Wood	6,369,350	8,963,518
Coke	32,046,936	34,221,685
Chemical	48,698,342	77,110,599
Non-metallic mineral	5,901,523	7,207,468
Basic metal	61,432,612	41,539,398
Fabricated metal	5,723,253	8,696,834
Electronic and electrical equipment	89,298,318	119,641,839
Machinery equipment	36,273,619	47,986,316
Transport equipment	21,601,125	30,128,970
Other manufacturing	4,928,927	20,043,658
Electricity, gas, and water supply	174,398	153,669
Construction	31,547	6,905
Wholesale and retail social work	2,964,892	3,445,471
Transport and storage	25,143,376	23,389,887
Educations, health, and social work	4,008,969	2,705,542
Other services	48,007,964	81,063,432
Total	580,207,457	737,628,012

Appendix 3. Consumption of 2008 and 2018

(Unit : million KRW)

Industry	2008	2018
Agriculture	14,532,839	18,049,800
Mining	19,960	15,926
Food	48,565,275	64,654,628
Textile	23,713,528	34,241,164
Wood	633,185	1,324,311
Coke	19,073,747	16,956,284
Chemical	9,767,751	10,615,892
Non-metallic mineral	490,881	1,826
Basic metal	-290,366	-851,674
Fabricated metal	1,099,773	1,325,559
Electronic and electrical equipment	17,885,041	32,963,456
Machinery equipment	1,408,681	3,091,614
Transport equipment	12,921,666	31,956,368
Other manufacturing	4,749,545	9,026,260
Electricity, gas, and water supply	16,313,869	22,892,350
Construction	0	0
Wholesale and retail social work	45,989,296	88,658,074
Transport and storage	22,221,097	29,621,590
Educations, health, and social work	146,847,433	268,682,461
Other services	332,628,373	583,042,883
Total	718,571,574	1,216,268,772

Appendix 4. Investment of 2008 and 2018

(Unit : million KRW)

Industry	2008	2018
Agriculture	1,970,589	281,577
Mining	2,821,791	2,565,609
Food	1,039,044	736,291
Textile	470,824	220,195
Wood	347,907	694,704
Coke	97,471	232,963
Chemical	2,266,744	3,868,997
Non-metallic mineral	281,874	423,417
Basic metal	1,469,470	-1,957,500
Fabricated metal	3,432,571	7,238,695
Electronic and electrical equipment	27,464,925	43,170,306
Machinery equipment	42,323,444	71,905,791
Transport equipment	23,376,549	40,473,228
Other manufacturing	3,059,107	6,004,494
Electricity, gas, and water supply	0	0
Construction	170,072,517	257,552,448
Wholesale and retail social work	5,656,725	13,911,316
Transport and storage	476,199	459,706
Educations, health, and social work	0	0
Other services	33,297,148	149,905,167
Total	319,924,899	597,687,404

Appendix 5. Exports of 2008 and 2018

(Unit : million KRW)

Industry	2008	2018
Agriculture	594,917	828,561
Mining	179,825	95,007
Food	5,047,774	8,363,824
Textile	15,441,436	27,267,620
Wood	3,026,508	4,190,709
Coke	46,092,915	55,752,249
Chemical	55,651,333	106,046,540
Non-metallic mineral	1,659,001	4,589,290
Basic metal	37,638,572	45,035,366
Fabricated metal	11,107,463	12,996,513
Electronic and electrical equipment	147,641,991	252,526,361
Machinery equipment	32,941,048	57,811,268
Transport equipment	98,803,131	96,842,059
Other manufacturing	2,812,761	5,229,591
Electricity, gas, and water supply	70,116	528,455
Construction	386,331	182,751
Wholesale and retail social work	12,455,668	31,549,718
Transport and storage	48,820,334	33,243,259
Educations, health, and social work	287,057	596,031
Other services	29,825,256	53,397,901
Total	550,483,437	797,073,073

Appendix 6. S matrix of original and modified

	Original S			Modified S ₂ (Scenario 2)		
	Incineration	Landfill	Recycling	Incineration	Landfill	Recycling
Process sludge	0.03	0.86	0.11	0.02	0.77	0.21
Slag	-	0.92	0.08	-	0.84	0.16
Waste organic solvent	0.17	-	0.83	0.09	-	0.91
Dust	-	0.12	0.88	-	0.06	0.94
Ash	-	0.97	0.03	-	0.94	0.06
Stabilizing/ Solidification compound	-	1.00	-	-	1.00	--
Waste refractory/ piece of ceramic	-	1.00	-	-	1.00	-
Waste pesticide	1.00	-	-	1.00	-	-
Waste acid	-	-	1.00	-	-	1.00
Waste asbestos	-	1.00	-	-	1.00	-
Wastewater sludge	0.01	0.86	0.13	0.01	0.75	0.24
Waste alkali	0.06	0.01	0.93	0.03	-	0.97
Waste oil	0.25	0.02	0.73	0.14	0.01	0.85
Waste toxic substances	0.55	-	0.45	0.37	-	0.63
Waste molding sand/ sand	-	0.76	0.24	-	0.61	0.39
Waste catalysis	-	0.19	0.81	-	0.10	0.90
Waste paint and lacquer	0.57	-	0.43	0.39	-	0.61
Waste synthetic rubber	0.74	-	0.26	0.58	-	0.42
Waste synthetic resins	0.69	-	0.31	0.52	-	0.48
Waste absorbent/ adsorbent	0.42	0.47	0.11	0.38	0.42	0.20
Waste halogen organic solvent	0.37	-	0.63	0.22	-	0.78
Waste containing PCBs	1.00	-	-	1.00	-	-

	Modified S ₃ (Scenario 3)			Modified S ₄ (Scenario 4)		
	Incineration	Landfill	Recycling	Incineration	Landfill	Recycling
Process sludge	0.02	0.61	0.38	-	-	1.00
Slag	-	0.70	0.30	-	-	1.00
Waste organic solvent	0.04	-	0.96	-	-	1.00
Dust	-	0.03	0.97	-	-	1.00
Ash	-	0.87	0.13	-	-	1.00
Stabilizing/ Solidification compound	-	1.00	-	-	-	1.00
Waste refractory/ piece of ceramic	-	1.00	-	-	-	1.00
Waste pesticide	1.00	-	-	-	-	1.00
Waste acid	-	-	1.00	-	-	1.00
Waste asbestos	-	1.00	-	-	-	1.00
Wastewater sludge	0.01	0.58	0.41	-	-	1.00
Waste alkali	0.01	0.00	0.98	-	-	1.00
Waste oil	0.07	-	0.93	-	-	1.00
Waste toxic substances	0.21	-	0.79	-	-	1.00
Waste molding sand/ sand	-	0.41	0.59	-	-	1.00
Waste catalysis	-	0.05	0.95	-	-	1.00
Waste paint and lacquer	0.22	-	0.78	-	-	1.00
Waste synthetic rubber	0.38	-	0.62	-	-	1.00
Waste synthetic resins	0.33	-	0.67	-	-	1.00
Waste absorbent/ adsorbent	0.30	0.33	0.37	-	-	1.00
Waste halogen organic solvent	0.11	-	0.89	-	-	1.00
Waste containing PCBs	1.00	-	-	-	-	1.00

Appendix 7. Estimated IHW treatment unit cost

(Unit: million KRW/tonnes)

Waste type	Incineration	Landfill	Recycling
Process sludge	0.241	0.116	0.021
Slag	0.031	0.116	0.021
Waste organic solvent	0.180	0.053	0.018
Dust	0.031	0.116	0.021
Ash	0.031	0.116	0.021
Stabilizing / Solidification compound	0.031	0.116	0.021
Waste refractory / Waste piece of ceramic	0.031	0.116	0.021
Waste pesticide	0.983	0.053	0.018
Waste acid	0.027	0.111	0.018
Waste asbestos	0.046	0.154	0.031
Wastewater sludge	0.241	0.116	0.021
Waste alkali	0.027	0.111	0.018
Waste oil	0.198	0.053	0.018
Waste toxic substances	0.027	0.027	0.018
Waste molding sand / Waste sand	0.031	0.116	0.021
Waste catalysis	0.031	0.116	0.021
Waste paint and lacquer	0.433	0.083	0.028
Waste synthetic rubber	0.391	0.154	0.031
Waste synthetic resins	0.391	0.154	0.031
Waste absorbent / Waste adsorbent	0.031	0.116	0.021
Waste halogen organic solvent	0.402	0.027	0.018
Waste containing PCBs	21.645	0.062	0.021

Appendix 8. X_0 matrix of scenario 1, 2, 3, 4 and 5

Xo	Ag	Mi	Fo	Tex	Wo	Cok	Che	Nm	Bm	Fm	Ee	Me	Te	Om	El	Con	Who	Tr	Ed	Os
Ag	0.05546	0.00120	0.27224	0.00947	0.01842	0.00005	0.00365	0.00016	0.00010	0.00012	0.00004	0.00012	0.00004	0.00489	0.00010	0.00189	0.00033	0.00016	0.00434	0.00846
Mi	0.00002	0.00068	0.00024	0.00005	0.00057	0.57776	0.02347	0.08787	0.15651	0.00024	0.00008	0.00009	0.00002	0.00030	0.33039	0.00110	0.00000	0.00000	0.00002	0.00003
Fo	0.14374	0.00208	0.18349	0.00890	0.00146	0.00042	0.00510	0.00087	0.00056	0.00073	0.00020	0.00066	0.00022	0.00618	0.00048	0.00033	0.00359	0.00170	0.00842	0.03918
Tex	0.01175	0.00337	0.00134	0.29138	0.00803	0.00065	0.00563	0.00409	0.00194	0.00430	0.00136	0.00168	0.00511	0.03812	0.00254	0.00145	0.00669	0.00994	0.00463	0.00467
Wo	0.01093	0.00296	0.02116	0.01162	0.31819	0.00113	0.00691	0.01127	0.00215	0.00808	0.00324	0.00335	0.00116	0.02976	0.00321	0.01930	0.01054	0.00881	0.00482	0.00821
Cok	0.02595	0.03036	0.00363	0.00509	0.00583	0.04409	0.11938	0.04715	0.00532	0.00740	0.00195	0.00367	0.00421	0.01172	0.03555	0.00891	0.02409	0.16742	0.01617	0.00948
Che	0.07214	0.03197	0.02804	0.10232	0.06624	0.01684	0.32824	0.04812	0.01272	0.05014	0.07425	0.03761	0.06952	0.05929	0.02381	0.03904	0.01355	0.01297	0.08939	0.01216
Nm	0.00035	0.00197	0.00586	0.00054	-0.00027	0.00061	0.00432	0.15054	0.01797	0.00494	0.01303	0.00358	0.00612	0.00464	0.00057	0.09062	0.00024	0.00075	0.00048	0.00097
Bm	0.00085	0.00170	0.00003	0.00022	0.00073	0.00150	0.00805	0.01842	0.36682	0.19371	0.04293	0.08414	0.07541	0.03107	0.00192	0.06231	-0.00026	0.00058	0.00060	0.00034
Fm	0.00115	0.01655	0.01356	0.00405	0.00661	0.00893	0.00708	0.01260	0.00858	0.14032	0.01629	0.10146	0.06417	0.03154	0.00763	0.07290	0.00203	0.00537	0.00138	0.00320
Ee	0.00356	0.00659	0.00123	0.00173	0.00340	0.00413	0.00298	0.00575	0.00436	0.01178	0.30216	0.08386	0.08424	0.04434	0.02409	0.04818	0.00894	0.01909	0.01927	0.02154
Me	0.00350	0.02113	0.00171	0.00136	0.00136	0.00701	0.01029	0.00787	0.00678	0.02604	0.01019	0.19455	0.03217	0.02240	0.00888	0.02280	0.00133	0.00268	0.00129	0.00172
Te	0.00318	0.01278	0.00022	0.00028	0.00106	0.00086	0.00104	0.00493	0.00099	0.00212	0.00032	0.00829	0.28837	0.01060	0.00186	0.00041	0.00157	0.05583	0.00101	0.00648
Om	0.00497	0.03199	0.03232	0.18855	0.03588	0.00260	0.02256	0.02452	0.02152	0.04119	0.03013	0.04243	0.02621	0.08589	0.00564	0.01210	0.00323	0.00265	0.01952	0.00663
El	0.01490	0.02677	0.01360	0.01521	0.04043	0.01774	0.03248	0.04740	0.07343	0.02203	0.01194	0.01265	0.00683	0.01391	0.13538	0.00393	0.01354	0.01852	0.03058	0.01856
Con	0.00141	0.00399	0.00063	0.00031	0.00061	0.00047	0.00076	0.00088	0.00119	0.00098	0.00059	0.00070	0.00036	0.00059	0.00413	0.00031	0.00101	0.00139	0.00094	0.00872
Who	0.03814	0.01411	0.07449	0.08461	0.04845	0.01185	0.03738	0.03144	0.02208	0.03137	0.03328	0.03703	0.04732	0.04714	0.00964	0.03183	0.04333	0.01925	0.04644	0.02765
Tr	0.01510	0.13578	0.03598	0.02595	0.04521	0.00720	0.02909	0.10995	0.02858	0.02415	0.01665	0.02418	0.01683	0.02011	0.01387	0.00838	0.07358	0.14855	0.00373	0.01104
Ed	0.00204	0.00290	0.00098	0.00076	0.00172	0.00056	0.00120	0.00161	0.00136	0.00227	0.00078	0.00187	0.00101	0.00329	0.00153	0.00168	0.00544	0.00160	0.00331	0.00260
Os	0.06272	0.17312	0.05524	0.04645	0.07201	0.04344	0.08142	0.08007	0.07627	0.07056	0.04833	0.06185	0.05873	0.10805	0.07530	0.13531	0.24933	0.16580	0.12953	0.22827

Appendix 9. X_z matrix of scenario 1, 2, 3, 4 and 5

Xz	Scenario 1			Scenario 2			Scenario 3			Scenario 4			Scenario 5		
	Incineration	Landfill	Recycle	Incineration	Landfill	Recycle	Incineration	Landfill	Recycle	Incineration	Landfill	Recycle	Incineration	Landfill	Recycle
Ag	-	0.00000	-	0.00049	0.00000	-	0.00095	0.00000	-	-	-	-	-	0.00000	-
Mi	0.00029	0.00008	0.00025	0.00207	0.00008	0.00022	0.00401	0.00010	0.00021	-	-	0.00016	0.00043	0.00011	0.00025
Fo	0.00120	0.00027	0.00083	0.00122	0.00030	0.00075	0.00236	0.00034	0.00070	-	-	0.00056	0.00180	0.00040	0.00083
Tex	0.00071	0.00013	0.00650	0.00815	0.00014	0.00589	0.01582	0.00017	0.00545	-	-	0.00435	0.00106	0.00019	0.00650
Wo	0.00474	0.00144	0.00114	0.01133	0.00159	0.00103	0.02198	0.00185	0.00096	-	-	0.00076	0.00712	0.00215	0.00114
Cok	0.00659	0.00006	0.00463	0.08596	0.00007	0.00420	0.16678	0.00008	0.00388	-	-	0.00310	0.00989	0.00010	0.00463
Che	0.05001	0.00301	0.04588	0.00276	0.00334	0.04157	0.00536	0.00387	0.03847	-	-	0.03068	0.07501	0.00452	0.04588
Nm	0.00161	0.00069	0.00348	0.01854	0.00076	0.00315	0.03597	0.00088	0.00292	-	-	0.00233	0.00241	0.00103	0.00348
Bm	0.01079	0.01079	0.03550	0.01218	0.01196	0.03216	0.02364	0.01388	0.02976	-	-	0.02374	0.01618	0.01618	0.03550
Fm	0.00709	0.00108	0.00862	0.02141	0.00120	0.00781	0.04154	0.00139	0.00723	-	-	0.00577	0.01063	0.00162	0.00862
Ee	0.01246	0.00045	0.07614	0.00565	0.00050	0.06899	0.01096	0.00058	0.06385	-	-	0.05092	0.01868	0.00067	0.07614
Me	0.00329	0.00006	0.00228	0.03585	0.00006	0.00207	0.06956	0.00008	0.00191	-	-	0.00153	0.00493	0.00009	0.00228
Te	0.02086	0.00040	0.00927	0.00227	0.00044	0.00840	0.00440	0.00051	0.00778	-	-	0.00620	0.03129	0.00060	0.00927
Om	0.00132	0.00066	0.00070	0.13169	0.00073	0.00063	0.25553	0.00084	0.00059	-	-	0.00047	0.00198	0.00098	0.00070
El	0.07662	0.00232	0.00175	0.00341	0.00257	0.00158	0.00662	0.00298	0.00147	-	-	0.00117	0.11493	0.00347	0.00175
Con	0.00199	0.00588	0.00232	0.00192	0.00652	0.00210	0.00372	0.00757	0.00195	-	-	0.00155	0.00298	0.00883	0.00232
Who	0.00112	0.00008	0.00157	0.00330	0.00009	0.00142	0.00640	0.00010	0.00132	-	-	0.00105	0.00168	0.00012	0.00157
Tr	0.00192	0.00014	0.00278	0.00101	0.00016	0.00251	0.00195	0.00018	0.00233	-	-	0.00186	0.00288	0.00021	0.00278
Ed	0.00059	0.00125	0.00009	0.10912	0.00139	0.00008	0.21172	0.00161	0.00007	-	-	0.00006	0.00088	0.00188	0.00009
Os	0.06348	0.03785	0.03533	-	0.04196	0.03201	-	0.04869	0.02962	-	-	0.02362	0.09522	0.05678	0.03533

Appendix 10. SX₀ matrix of scenario 1, 2, 3, 4 and 5

Scenario 1																				
SX ₀	Ag	Mi	Fo	Tex	Wo	Cok	Che	Nm	Bm	Fm	Ee	Me	Te	Om	El	Con	Who	Tr	Ed	Os
Incineration	-	0.00021	0.00003	0.00023	0.00009	0.00016	0.00070	0.00008	0.00018	0.00018	0.00018	0.00007	0.00027	0.00009	0.00009	0.00002	0.00002	0.00008	0.00000	0.00011
Landfill	-	0.00071	0.00003	0.00004	0.00054	0.00003	0.00021	0.00025	0.00148	0.00021	0.00009	0.00001	0.00004	0.00005	0.00026	0.00033	0.00001	0.00002	0.00007	0.00047
Recycle	-	0.00070	0.00011	0.00114	0.00045	0.00056	0.00257	0.00218	0.00423	0.00110	0.00215	0.00025	0.00062	0.00028	0.00028	0.00024	0.00007	0.00026	0.00001	0.00041
Scenario 2																				
SX ₀	Ag	Mi	Fo	Tex	Wo	Cok	Che	Nm	Bm	Fm	Ee	Me	Te	Om	El	Con	Who	Tr	Ed	Os
Incineration	-	0.00012	0.00002	0.00012	0.00006	0.00009	0.00041	0.00005	0.00012	0.00011	0.00010	0.00004	0.00017	0.00005	0.00007	0.00001	0.00001	0.00004	0.00000	0.00006
Landfill	-	0.00064	0.00003	0.00003	0.00052	0.00002	0.00018	0.00013	0.00121	0.00018	0.00008	0.00001	0.00003	0.00004	0.00025	0.00031	0.00000	0.00002	0.00007	0.00044
Recycle	-	0.00085	0.00012	0.00125	0.00051	0.00064	0.00288	0.00232	0.00457	0.00120	0.00224	0.00028	0.00073	0.00032	0.00032	0.00027	0.00008	0.00029	0.00001	0.00049
Scenario 3																				
SX ₀	Ag	Mi	Fo	Tex	Wo	Cok	Che	Nm	Bm	Fm	Ee	Me	Te	Om	El	Con	Who	Tr	Ed	Os
Incineration	-	0.00006	0.00001	0.00006	0.00003	0.00004	0.00021	0.00002	0.00007	0.00006	0.00005	0.00002	0.00009	0.00003	0.00005	0.00001	0.00000	0.00002	0.00000	0.00003
Landfill	-	0.00054	0.00002	0.00003	0.00048	0.00001	0.00015	0.00007	0.00092	0.00014	0.00006	0.00001	0.00002	0.00004	0.00023	0.00029	0.00000	0.00001	0.00007	0.00040
Recycle	-	0.00101	0.00013	0.00132	0.00058	0.00070	0.00311	0.00241	0.00491	0.00129	0.00231	0.00030	0.00081	0.00035	0.00036	0.00029	0.00009	0.00032	0.00001	0.00056
Scenario 4																				
SX ₀	Ag	Mi	Fo	Tex	Wo	Cok	Che	Nm	Bm	Fm	Ee	Me	Te	Om	El	Con	Who	Tr	Ed	Os
Incineration	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Landfill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Recycle	-	0.00162	0.00017	0.00141	0.00109	0.00075	0.00347	0.00250	0.00590	0.00149	0.00242	0.00033	0.00092	0.00041	0.00064	0.00058	0.00010	0.00035	0.00008	0.00099
Scenario 5																				
SX ₀	Ag	Mi	Fo	Tex	Wo	Cok	Che	Nm	Bm	Fm	Ee	Me	Te	Om	El	Con	Who	Tr	Ed	Os
Incineration	-	0.00021	0.00003	0.00023	0.00009	0.00016	0.00069	0.00008	0.00018	0.00018	0.00018	0.00007	0.00027	0.00009	0.00009	0.00002	0.00002	0.00008	0.00000	0.00011
Landfill	-	0.00071	0.00003	0.00004	0.00054	0.00003	0.00021	0.00025	0.00148	0.00021	0.00009	0.00001	0.00004	0.00005	0.00026	0.00033	0.00001	0.00002	0.00007	0.00047
Recycle	-	0.00070	0.00011	0.00114	0.00045	0.00056	0.00257	0.00218	0.00423	0.00110	0.00215	0.00025	0.00062	0.00028	0.00028	0.00024	0.00007	0.00026	0.00001	0.00041

Appendix 11. SX_Z matrix of scenario 1, 2, 3, 4 and 5

		Scenario 1		
SXz		Incineration	Landfill	Recycle
Incineration		-	-	0.02500
Landfill		0.20669	-	0.01509
Recycle		0.00687	-	0.15346

		Scenario 2		
		Incineration	Landfill	Recycle
Incineration		-	-	0.01271
Landfill		0.34342	-	0.00970
Recycle		0.02366	-	0.15295

		Scenario 3		
		Incineration	Landfill	Recycle
Incineration		-	-	0.00576
Landfill		0.61667	-	0.00606
Recycle		0.09559	-	0.15047

		Scenario 4		
		Incineration	Landfill	Recycle
Incineration		-	-	-
Landfill		-	-	-
Recycle		-	-	0.12942

		Scenario 5		
		Incineration	Landfill	Recycle
Incineration		-	-	0.02500
Landfill		0.20669	-	0.01509
Recycle		0.00687	-	0.15346

Daye LEE

Doctorat : Systèmes SocioTechniques

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Analyse du lien économie-activité industrielle-déchets industriels dangereux en Corée du Sud par des approches multi-niveaux

Les déchets industriels dangereux (DID) ont eu un impact négatif sur l'environnement et les humains et ont également causé des problèmes sociaux, tels que les transferts de déchets inégaux entre pays développés et en voie de développement. Pour éviter cela, la Convention de Basel a été signée pour réglementer les mouvements transfrontaliers et le commerce des DID. De plus, la Corée du Sud a annoncé le « grand plan de transition 2020 vers la circulation des ressources » et a fixé l'objectif de réduire le nombre des DID. Cependant, cette dernière a toujours du mal à établir une politique de gestion des déchets basée sur des motifs raisonnables. Par conséquent, dans cette recherche, basée sur le concept écologique industriel, le tableau entrées-sorties sud-coréen et la production et le traitement des DID ont été liés pour modéliser le tableau entrées-sorties des DID de la Corée du Sud. Grâce au tableau de développement, cette recherche a identifié les caractéristiques de la production des DID en termes de production et de demande par industrie et a analysé les facteurs affectant l'augmentation des DID parmi les facteurs de changement de la demande finale, les facteurs de substitution des importations et les facteurs de technologie de production. Cela a contribué à l'identification des points chauds de DID. Les résultats de cette étude, devraient contribuer à la recherche fondamentale pour établir une politique rationnelle de gestion des déchets qui reflète les caractéristiques de chaque industrie en évaluant quantitativement la production et la gestion des déchets.

Mots clés : écologie industrielle – économie circulaire – déchets dangereux – analyse entrée-sorties.

Analysis of Economic Growth-Industrial Activities-Industrial Hazardous Waste Nexus in South Korea by Multi-level Approaches

Industrial hazardous waste (IHW) had a negative impact on the environment, humans and caused social problems, such as waste transactions between countries in unequal locations from developed countries to less developed countries. To prevent this, the Basel Convention has been signed to regulate the transboundary movements and trade of IHW. Under this convention, the world was required to have the capacity to manage industrial hazardous wastes in the domestic level efficiently. However, South Korea still struggles to establish a waste policy based on reasonable grounds, and there are few studies for this. Therefore, in this research, based on the industrial ecological concept, the South Korean input-output table, and IHW generation and treatment were linked to model the IHW input-output table of South Korea. Through the developing table, this research identified the characteristics of IHW generation in terms of production and demand by industry. It analyzed the factors affecting IHW increase among final demand change factors, import substitution factors, and production technology factors. This part contributed to the identification of IHW hot spots. Finally, we focused on analyzing the effects of changes in IHW treatment methods. The results of this study, based on the industrial ecological concept, are expected to contribute to the basic research of establishing a rational waste policy that reflects the characteristics of each industry by quantitatively evaluating the generation and management of waste.

Keywords: industrial ecology – circular economy – hazardous waste – input-output analysis.

Thèse réalisée en partenariat entre :

