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Resource Cyclical Dynamics Focused on the Waste of Electric and Electronic Equipment

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Abstract

As a practical means to upgrade urban sustainability, this paper focuses on resource cyclical systems concerned with the waste of electric and electronic equipment (WEEE) in Korea. Borrowing System Dynamics concepts and approaches, it examines behavioral changes of WEEE dynamics to observe whether the existing management methods can be readjusted. The measurement is based upon both reuse and material and thermal recycle simulation works in the individual stage of WEEE discharge, collection, and treatment, going beyond the traditional recycle-only customs. This research estimates that the newly introduced Extended Producer Responsibility (EPR) system would definitely exert a significant impact on the final stage of WEEE treatment, decreasing the final treatment volume in the first half of the research period. The trend, nonetheless, would be reversed in the second half, mainly owing to the additional waste volume originated from the local government and recycling center. Sensitivity analysis poses, among others, that the local government-supported reuse center should take charge of a pivotal role in the long run. The research also shows that sufficientand necessary conditions for the WEEE management and treatment should be given to the combined efforts, both from the private sectors and the public domains. Based on these research findings, the paper recommends that key stakeholders including the producer and the public organizations should devise how to jointly carry out specific agenda centered around partnership or network buildings.

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Keywords: Resource Cyclical Systems, System Dynamics, Waste of Electric and Electronic Equipment (WEEE), Extended Producer Responsibility (EPR)

Ⅰ. Introduction

This study examines treatment characteristics focused on the waste of electric and electronic equipment (hereafter WEEE), borrowing concepts derived from the System Dynamics (SD) which is well exposed in McGarvey and Hannon {1} and Sterman {2}. The existing documents stressing the resource cyclical society system have provided theoretical tools or practical means. For example, Mashayekhi {3}, Sudhir, Srinivasan, and Muraleedharan {4}, Ulli-Beer {5}, and Ulli-Beer, Richardson, and Anderson {6} used SD modeling to analyze treatment issues centered around solid waste. Ford in his Modeling the Environment also suggested various SD models related to the environment system {7}. These studies which trie to go beyond thestatistical data analyses point out structural relationships embedded in feedback, time delay, and non-linearity.

As the WEEE discharge and collection channels are complicatedly mingled, it is essential to understand the system as a whole, ahead of suggesting any specific treatment method. Research questions are hinged on how causal relationships are formed throughout the WEEE life cycles and discuss what types of variables and feedbacks should be strengthened or not. The research covers both explicit andimplicit factors in dealing with the WEEE management in Korea. The former emphasizes in-depth analysis of the current status quo and unresolvedtasks. In contrast, the latter stresses diagram formation and scenario experiment, reflecting bottleneck and time delay factors. All of them would contribute to reassigning appropriate roles among the key stakeholders.

Following the introduction, the WEEE conceptual models are proposed as the cornerstones for the causal map and flow-stock modeling works. After quantitative model building and calibration, sensitivity analyses are carried out to test models' robustness. In order to develop policy leverages, policy feasibility and applicability are experimented in both quantitative and qualitative manners. Finally, thekey research findings and discussion topics are highlighted as the conclusion of this research.

Ⅱ. WEEE Loops and Dynamics

1. Status Quo

The electric and electronic equipment refers to the typical household durable goods including televisions, washing machines, refrigerators, and air conditioners. These equipment life cycles are usually composed of a series of activities, covering material input, production, delivery, consumption, discard and treatment. Related to the last stage, both the local government, reuse center, and distributors in lieu of equipment producers in Korea are main bodies to handle most waste of electric and electronic equipment [8]. With a few exceptions, the local government which supports reuse center may collect due fee from the individual WEEE discharger.In the case of illegal dumping, the local government is the first organization to take care of illegally dumped waste within its jurisdiction. At the same time, if a buyer who purchases brand-new equipment requests, wholesale or retail distributors directly related to the producers have to recollect the used equipment and packing materials without charge [9].

In June 2000, Korea Electronics Association (KEA) [10] concluded a voluntary agreement with the Korean Ministry of Environment (KMOE). Under the agreement, KMOE may impose duty to recollect and recycle the WEEE upon KEA, who would be exempt from the discharge deposit. Since then, KMOE has expanded bilateral partnership with private sectors and finally it could adopt the Extended Producer System (EPR) [11] in January 2003. After a series of legal and institutional arrangement, electric and electronic equipment producers may have to take charge of heavier discharge duties than the public domains. For example, if the legal requirements are not satisfied, non-compliance fee may be levied on the industry. Whilst KMOE hopes to continuously extend the EPR items of manufacture, the industry points out the prerequisite conditions that the government has to provide an appropriate recollecting infrastructure. [12]

[Table 1] Major WEEE Volume Treated

Categories		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Electric and Electronic Industry (1,000 units)	Subtotal	467	638	594	514	536	625	714	844	1,237	1,231	1,520
	Television	35	96	101	130	167	254	168	221	370	326	404
	Refrigerator	225	256	212	190	171	213	275	343	433	476	542
	Washer	204	286	281	189	183	154	270	278	421	410	547
	Air Conditioner	3	0	0	5	15	4	1	2	13	19	27
Local Government (1,000 units)	Subtotal	479	532	674	403	505	581	342	662	610	495	506
	Television	99	116	187	123	161	178	95	193	172	103	87
	Refrigerator	234	268	294	175	204	238	170	288	268	254	288
	Washer	146	145	187	99	130	155	74	169	165	130	120
	Air Conditioner	0	3	6	6	10	10	3	12	5	8	11
Recycling Center (1,000 units)	Subtotal	25	76	93	100	75	51	225	251	178	137	114
	Television	8	25	32	36	27	18	76	72	46	58	52
	Refrigerator	10	29	35	37	27	18	85	105	62	42	36
	Washer	7	21	25	25	19	13	57	68	67	30	25
	Air Conditioner	0	1	1	2	2	2	7	6	3	7	1
Total (1,000 units)	Subtotal	971	1,246	1,361	1,017	1,116	1,257	1,281	1,757	2,025	1,863	2.140
	Television	142	237	320	289	355	450	339	486	588	487	543
	Refrigerator	469	553	541	402	402	469	530	736	763	772	866
	Washer	357	452	493	313	332	322	401	515	653	570	692
	Air Conditioner	3	4	7	13	27	16	11	20	21	34	39

Sources: Internal data from the Korean Association of Electronics Environment.

As shown in Table 1, the major WEEE volume recollected becomes more than doubled over a decade or so, from 0.971 million units in 1995 to 2.14 million units in 2005. Among household durable goods, refrigerator, washer, and television are the three major recollection items. [13] In general, it has shown an abrupt increasing trend in the 2000s, reflecting the explicit target set up by both the government and the industry during the same period. Still, the total volume handled by the recycling center is comparatively smaller than that of the industry and the local government

Table 2 presents the WEEE volume treated by the private and public organizations. In Korea, the final treatment based on material recycling has overwhelmed other methods including reuse and incinerating and landfill. The aggregate ratio of thematerial recycling has rather expanded over time, from 66% in 1999 up to 84% in 2005, running counter to the resource cyclical social system. It is specially noteworthy that the whole quantity recollected by the electric and electronic producers has been crushed without a single exception. Here, the only available option is given to the material recycling [14].

[Table 2] Major WEEE Volume Treated

Categories		Total		Reuse		Material Recycling		Incinerating And Landfill	
		Units (1,000)	%	Units (1,000)	%	Units (1,000)	%	Units (1,000)	%
1999	Total	1,116	100	258	23	736	66	122	11
	Electric and Electronic Industry	537	100	0	0	537	100	0	0
	Local Government	504	100	201	40	199	39	104	21
	Recycling Center	75	100	57	76	0	0	18	24
2000	Total	1,257	100	220	18	841	67	196	16
	Electric and Electronic Industry	625	100	0	0	625	100	0	0
	Local Government	581	100	179	31	216	37	186	32
	Recycling Center	51	100	41	80	0	0	10	20
2001	Total	1,281	100	186	15	821	64	274	21
	Electric and Electronic Industry	714	100	0	0	714	100	0	0
	Local Government	341	100	19	6	107	31	215	63
	Recycling Center	226	100	167	74	0	0	59	26

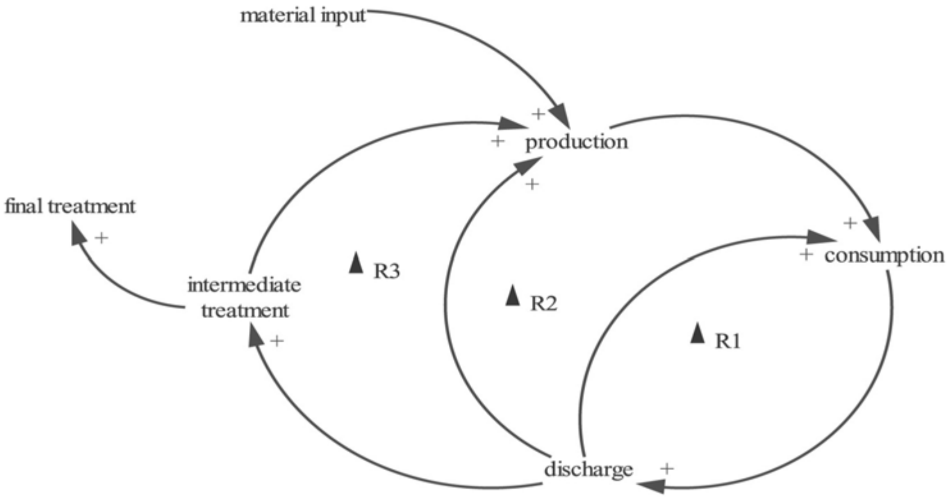
2002	Total	1,757	100	204	12	1,214	69	339	19
	Electric and Electronic Industry	843	100	0	0	843	100	0	0
	Local Government	662	100	57	9	307	46	298	45
	Recycling Center	252	100	147	58	64	25	41	16
2003	Total	2,025	100	170	8	1,617	80	238	12
	Electric and Electronic Industry	1,237	100	0	0	1,237	100	0	0
	Local Government	610	100	24	4	361	59	225	37
	Recycling Center	178	100	146	82	19	11	13	7
2004	Total	1,863	100	163	9	1,540	83	160	9
	Electric and Electronic Industry	1,231	100	0	0	1,231	100	0	0
	Local Government	495	100	65	13	309	62	121	24
	Recycling Center	137	100	98	72	0	0	39	28
2005	Total	2,140	100	152	7	1,801	84	187	9
	Electric and Electronic Industry	1,520	100	0	0	1,520	100	0	0
	Local Government	506	100	66	13	268	53	172	34
	Recycling Center	114	100	86	75	13	11	15	13

Note: The waste volume in the table only covers 4 major household durable goods such as televisions, washing machines, refrigerators, and air conditioners.

Sources: Internal data from the Korean Association of Electronics Environment.

2. WEEE Conceptual Loops

The resource cyclical social system in this study aims at minimizing the discard volume per se. That is, if reuse and recycle methods were adopted, it would definitely contribute to minimizing the final treatment volume. Reuse exemplifies the most appropriate type for the resource cyclical social system [15] [16]. It implies the fact that consumer(s) may reuse the old product or its components, which have been discharged by the aboriginal owners. Material and thermal recycles are also essential for the resource cyclical social system, as raw materials and energy, all of which are extracted from the discharged electric and electronic components, are again put into production-consumption processes. If these circular flows work, it would be possible for both producers and consumers to save money.

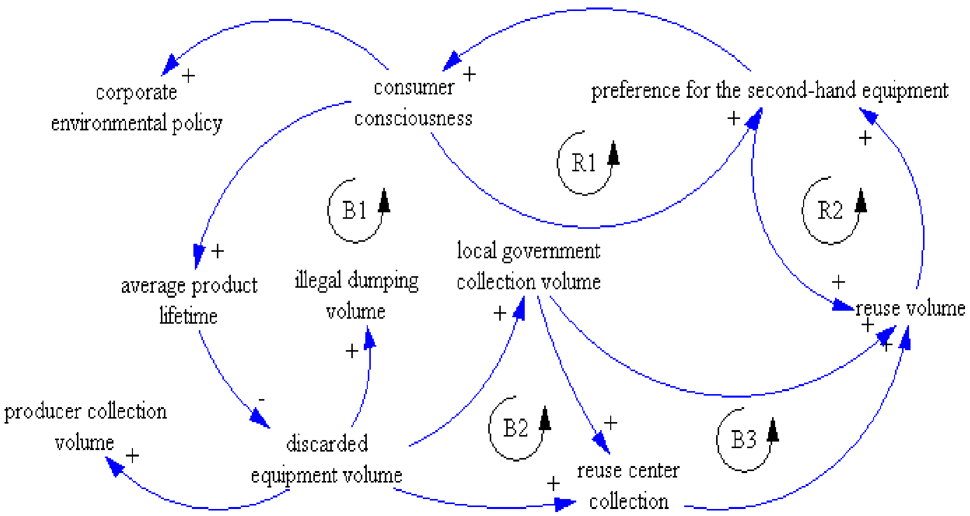


[Figure 1] Basic WEEE Loops

From this perspective, [Figure 1] presents the basic WEEE structure for the resource cyclical social system. It shows how the key variables interact in the processes of equipment production, consumption, discharge, and treatment. R1 focuses on continuous reuse of the discharged product as the second-hand product. In contrast, R2 simply means component reuse. Lastly, the R3 loop explains recycle circulation derived from the intermediate treatment. As mentioned above, the shortest route for the resource cyclical social system should be given to strengthening both R1 and R2 loops. If recycle-oriented policy resorts to a convenient and inexpensive alternative to satisfy the pre-allocated volume, as prescribed in the Extended Producer Responsibility (EPR) rules, it might result in a dilemmatic situation: The raw material input has to be increased over time, which would produce the increased volume of the final treatment.

3. WEEE Causal Loops

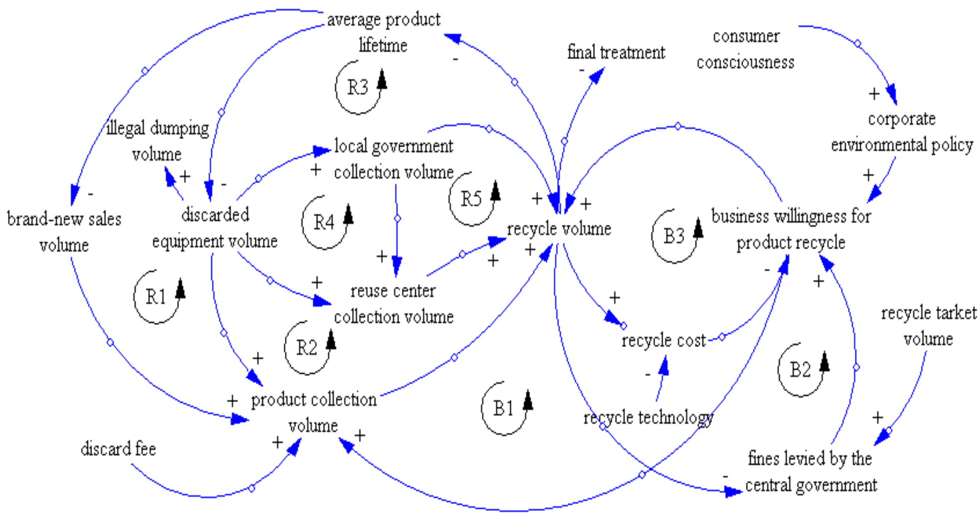
The reuse causal loops in [Figure 2] are composed of 2 reinforcing and 3 balancing loops. Higher consumer consciousness on the reuse and recycle leads to enlargement of the second-hand electric and electronic equipment in the market, which also increases the total reuse volume (R1 and R2). In contrast, as consumer consciousness expands the average product lifetime, it reduces the discarded quantity, which in turn lowers collection activities in the local government and reuse center (B1, B2, and B3).



[Figure 2] WEEE Reuse Loops

Secondly, [Figure 3] presents the basic recycle causal loops. Here 5 reinforcing and 3 balancing loops are interrelated to each other. The recycled product and components exert negative impacts on the average product lifetime. If the product lifetime becomes longer, it would dampen the brand-new sales volume, reducing the producer-collected waste volume

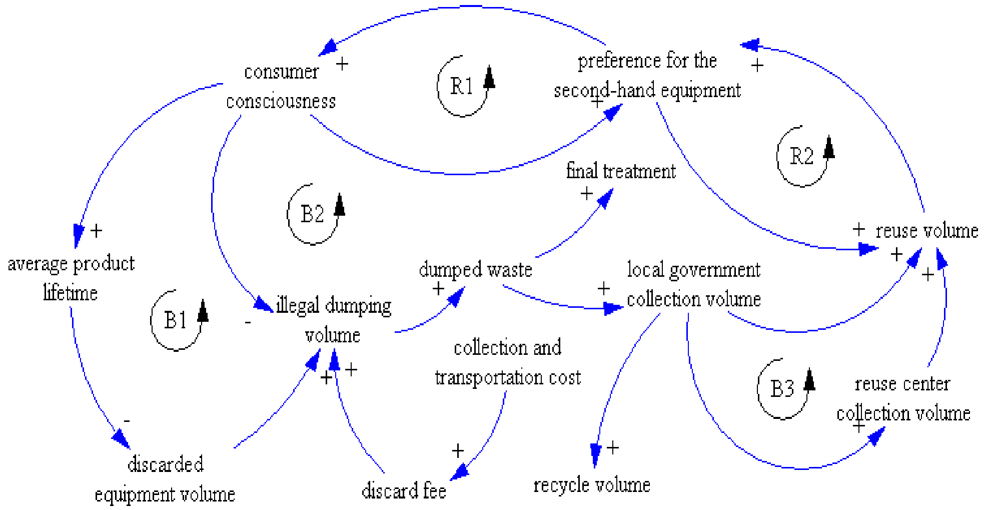
(R1). If the producer has to increase the replacement demand, the recycled volume would be expanded (R2). In a similar context, there also exists a positive relationship between the discharged product and components and the collection volume by the local government unit or the reuse center. Therefore, the recycle volume would be increased if the local government unit or local reuse center has to handle more electric and electronic waste (R3, R4, and R5). Reflecting the corporate environmental policy, however, the business willingness for the product recycle would yield a couple of balancing loops. First of all, the producer has to deal with the extra burden originated from the recycle cost. In addition, as the government may levy a huge amount of fines when the prearranged recycle target number is not achieved, the producer's top priority is given on how to minimize the recycle volume (B1, B2, and B3).



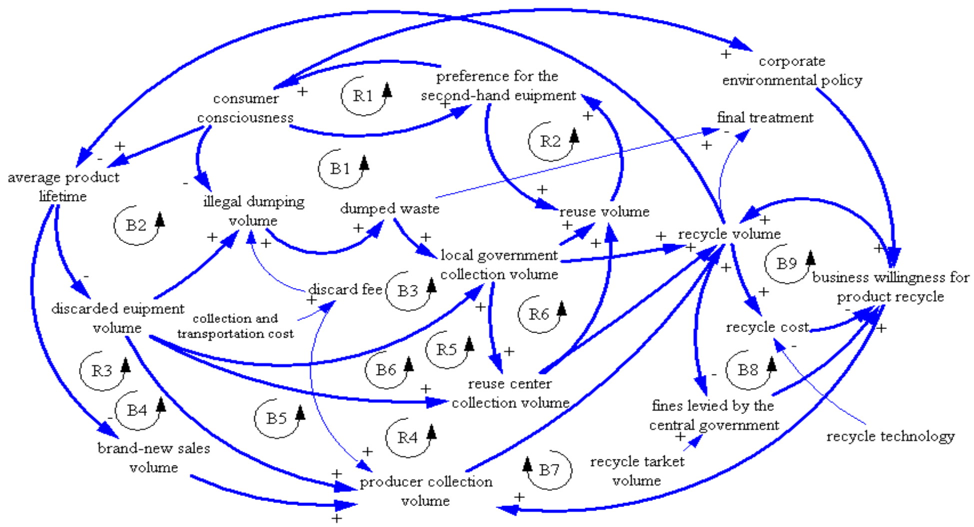
[Figure 3] WEEE Recycling Loops

Thirdly, illegal dumping in [Figure 4] reveals 2 reinforcing and 3 balancing loops. In fact, the reinforcing loops are the same as shown in [Figure 2] Up to now, the illegally dumped electric and electronic waste has been handled either by the individual consumer or the local government. To reduce illegal dumping, of course, consumer consciousness should be upgraded. In addition, if the average product lifetime is expanded and if both the local government and reuse center facilitate product and component transaction in the second-hand market, it would also contribute to the reduction of the illegally dumped volume (B1, B2, and B3).

In sum, [Figure 5] represents the resource cyclical system, in which the WEEE treatment processes are synthesized.



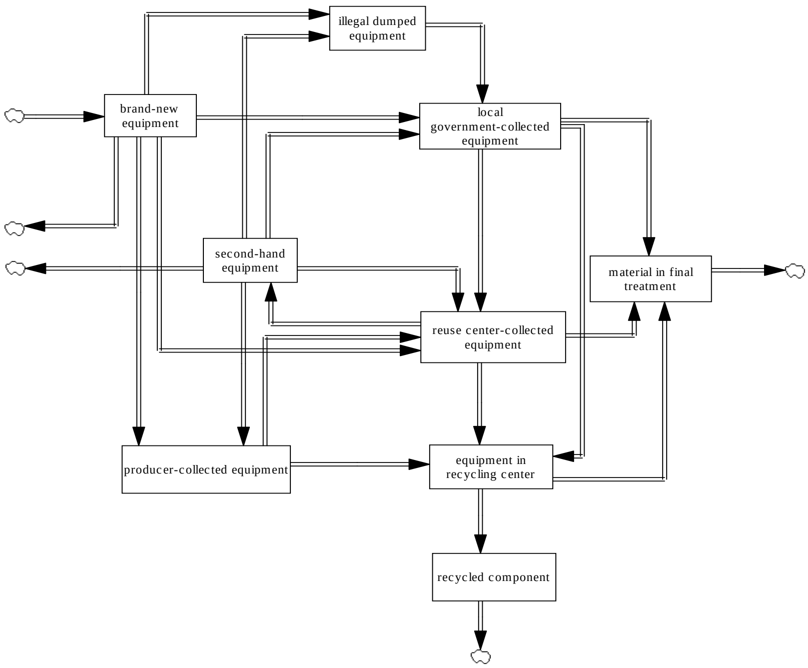
[Figure 4] WEEE Illegal Dumping Loops



[Figure 5] Synthesized WEEE Loops

4. WEEE Stock-Flow Dynamics

Not like the previous figures based on the causal loops, [Figure 6] highlights the resource cyclical dynamics, representing the lifecycle of electric and electronic equipment with stock and flow components [17]. First of all, the aggregation of domestic and imported product decides the total volume of brand-new supply. Commonly, consumers use these durable goods for a certain period of time. Once a consumer discharges the electric and electronic equipment and its components, the law and ordinances make sure that the used product should be properly collected either by the local government unit, reuse center or producer in Korea.



[Figure 6] WEEE Stock-Flow Model for the Resource Cyclical Social System

If the collected product is reused by the local government unit, reuse center, or producer, it once again follows the same routes. Even though the local government joins the collection processes, the actual reuse works are usually intermediated by the reuse center, with a few exceptions. As mentioned above, the total volume of the electric and electronic waste collected by the producer has been directed to the recycling processes, without exception. For the policy experiment based on the reuse-oriented alternative, however, the model also presupposes that the producer-collected electric and electronic equipment would be on the reuse circle [18].

Lastly, the material in final treatment implies the residual quantity for incinerating and landfill. Similar to the case of the dumped waste, the local government and reuse center in its jurisdiction is the primary organizations to handle the final stage.

Ⅲ. ModelingBuildingandPolicyExperiment

1. Major variables

Using the theoretical frames derived from the previous researches, this research puts emphasis on dynamic analyses based on various data. The major variables in the model cover electric and electronic sales volume, supply ratio, and collection volume from the local government unit, reuse center, and producer. It also tries to figure out the reused and recycled volume originated from diverse collection activities,

[Table 3] Major Variables and Their Contents

Major Variables	Contents
Equipment supply ratio	- Household supply ratio of major equipment in 2002 (TV: 1.35, refrigerator: 1.25, washing machine: 1.15, air conditioner: 0.26 units/household, respectively) - Non-household equipment in 2002: 20 % of household volume
Imported equipment sales	- Imported equipment sales (1989-2003)
Domestic equipment sales	- Domestic equipment sales (1985-2003)
Producer collection	- Producer-collected waste data (1995-2002)
Exporting	- Exported volume as the second-hand product or treated useless industrial waste (70.1% of the total discard volume in 2002)
Reuse center collection	- Volume collected by the reuse center (1995-2002)
Local government collection	- Volume collected by the local government (1995-2002)

Local government reuse	- Reused volume collected by the local government (1999-2002)
Local government recycle	- Recycled volume collected by the local government (1999-2002)
Reuse center reuse	- Reused volume collected by the reuse center (1999-2002)
Reuse center recycle	- Recycled volume collected by the reuse center (1999-2002)
Reuse center treatment	- Incinerating or landfill volume among the reuse center-collected waste (1999-2002)
Local government treatment	- Incinerating or landfill volume among the local government-collected waste (1999-2002)
Illegal dumping	- Illegally dumped volume (5.2% of the local government-collected volume in 2000)
Recycle	- Volume recycled by the local government, reuse center, and producer (1999-2002)
Final treatment	- Volume treated by local government and reuse center or untreated materials from the recycling center (9.1% of the total WEEE measured by the weight average)
Recycle ratio	- 90.9% of the total WEEE measured by the weight average (metals: 49.2%, nonferrous metals: 13.4%, plastics: 22.4%, others: 15.0%)
Producer collection recycle	- Recycled volume collected by producer (1995-2002)

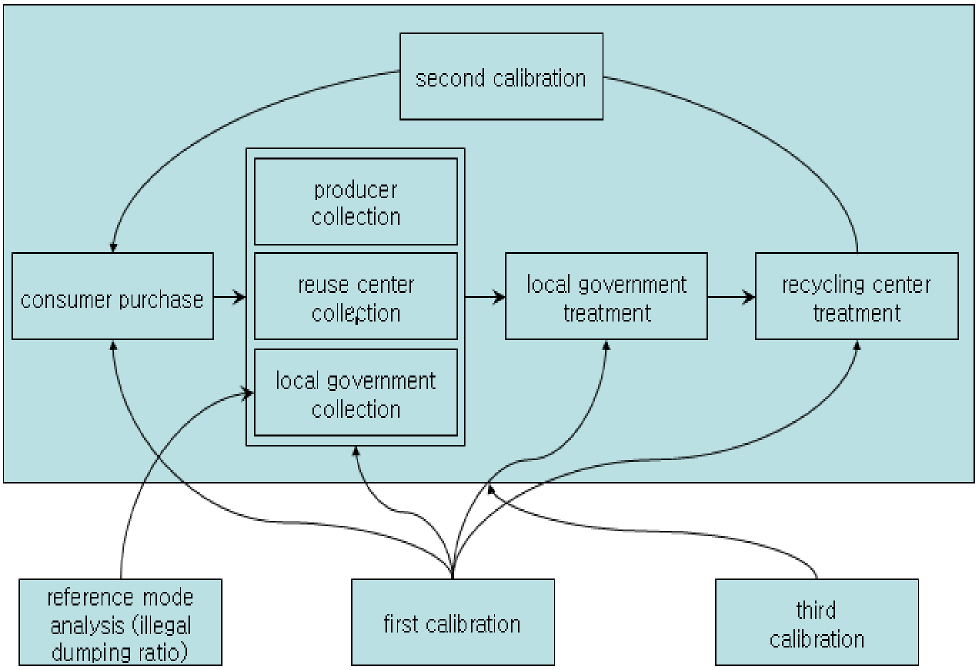
Note: Purely modeling purposes, this research depends on internal data from the Korean Association of Electronics Environment.

Due to questions on data availability, a handful of variables depend on the estimated figures. For example, using internal documents kept at Korea Electronics Association, the model recalculates the illegal dumping volume. Judging from the existing household supply ratio, the model also assumes that non-households such as administrative units, hospitals, schools, and other types of offices would account for almost 20 percent of the household supply ratio. In the same manner, the collected waste volume would be around 30 percent of the estimated waste volume in a given period. Table 3 summarizes key variables and their attributes.

2. Model Calibration

Model calibration works for the waste of electric and electronic equipment are carried out in three steps. As diagramed in {Figure 7} the first job is concerned with data input and the second with feedbacks. The third loop in the figure symbolizes the synthesized calibration for the WEEE model.

In order to increase model's robustness, the extended Bass models, which represent the aggregation of both external and internal factors, have been used for the auxiliary variables. Table 4 shows a list of the calibrated variables. In order to minimize the gap between real data and the prototype scenario-based data, the model tries to calculate innovation and imitation coefficients of each constraint.



[Figure 7] Calibration of WEEE Dynamic Model

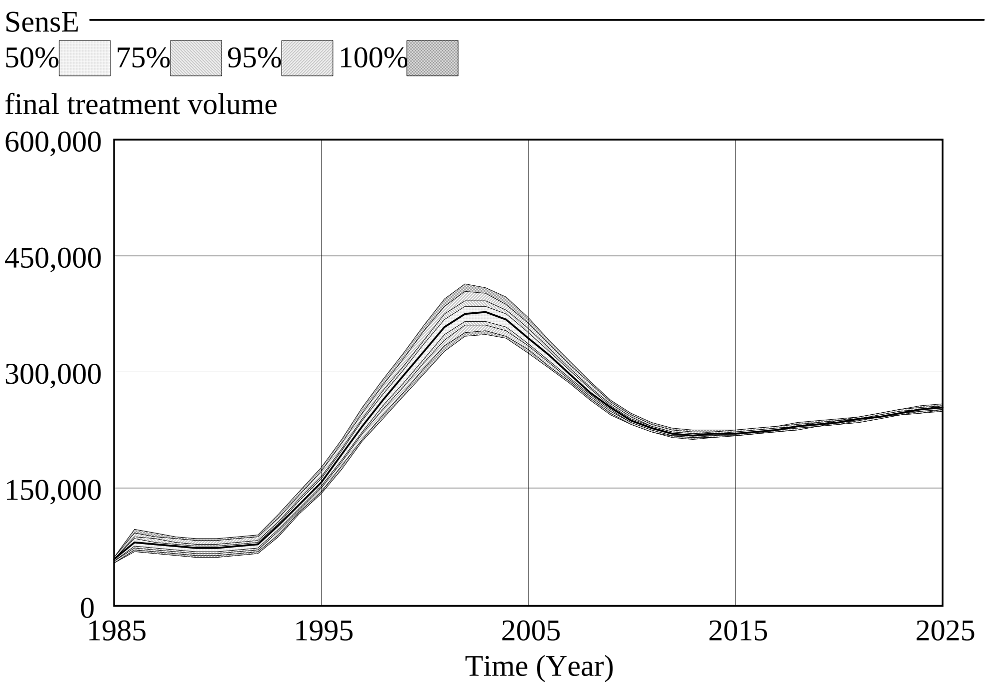
[Table 4] Calibrated Variables and Attributes

Variables and Constraints	Contents
Objective variable	minimize (model itself – model inputted data)2
Constraints	0≤purchase, word of mouse coefficient=0.0399004≤0.1 0≤purchase, word of mouse coefficient·income coefficient=0.412232 0≤purchase imitation coefficient≤1 0≤income-purchase delayed period=0.00662686 0≤maximization supply volume by purchase=1.11816e+008 0≤brand-new purchase weight in 1985=0.8≤1 0≤discard weight advertisement coefficient by purchase of brand-new product=0≤1 0≤discard weight, word of mouse coefficient by purchase of brand-new product=0.118582≤1 0≤discard maximization weight by purchase of brand-new product=0.194669≤1 0≤reuse center, recycle weight of collection volume=0.518219≤1 0≤reuse center, delayed period=0.111493≤1 0≤reuse center, final treatment weight=0.434356≤1 0≤reuse center, ratio of second-hand to brand-new=0≤1 0≤weight per reuse center=0.000887322 0≤reuse center, advertisement coefficient=1.17894 0≤reuse center, word of mouse coefficient=9.91629e-005 0≤decreasing rate of collection by local government=9.12077e-005≤1 0≤collection by local government, dumping weight=0.0296964≤0.1 2≤collection by local government, ratio of second-hand to brand-new=19.9448≤20 0.05≤collection by local government, weight of charged portion 1985=0.0564076≤1 0≤reuse base weight by local government=0.129754≤1 0≤reuse by local government, collection base weight of brand-new product by reuse center=0.0258447 0≤reuse by local government, coefficient of second-hand product weight=0≤1 0≤reuse by local government, reuse center coefficient=0.830288 0≤weight per final treatment of local government=0.0046249≤1 0≤local government, final treatment facility imitation coefficient=0.3331122 0≤local government, number of final treatment facility 0≤local government, final treatment facility innovation coefficient=0.0008321 0≤local government, recycle base weight≤1 0≤local government, sense coefficient for recycle

3. Sensitivity Analysis on Illegal Dumping

Illegal dumping data derived from the existing documents at Korea Electronics Association require a sensitivity analysis to measure the degree of their impact on the system. Specifically, this study focuses on measuring the impact on brand-new purchase, final treatment, and ferrous material volumes. It covers a time span from 1985 to 2025.

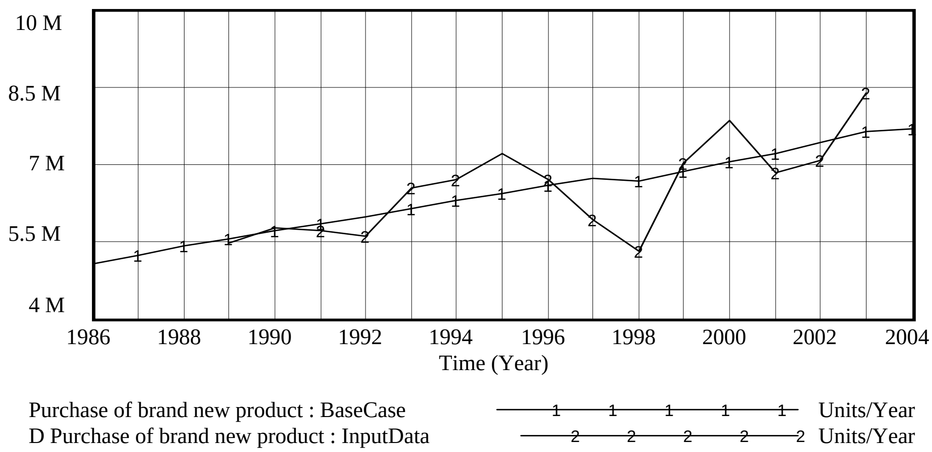
After repeated experiments, the study confirms that the illegal dumping exerts minimal impact on both brand-new purchase and final treatment volumes, even though the recycled ferrous materials yield a relatively high degree of impact. Among them, {Figure 8} represents the sensitivity result on the final treatment volume.



[Figure 8] Sensitivity Results on the Final Treatment Volume by the Illegal Dumping

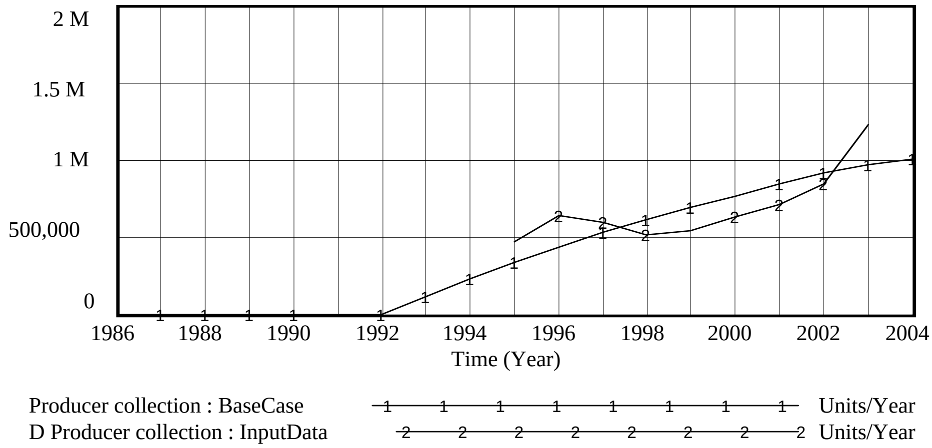
4. Base Models

Base models are derived from the dynamic movement of key variables. First of all, purchase behavior (1989-2003) is represented in [Figure 9]. The purchase volume dropped abruptly during the so-called 'Asian foreign exchange crisis' period. Aside from this, the ever-increasing trend in the purchase pattern has been observed.



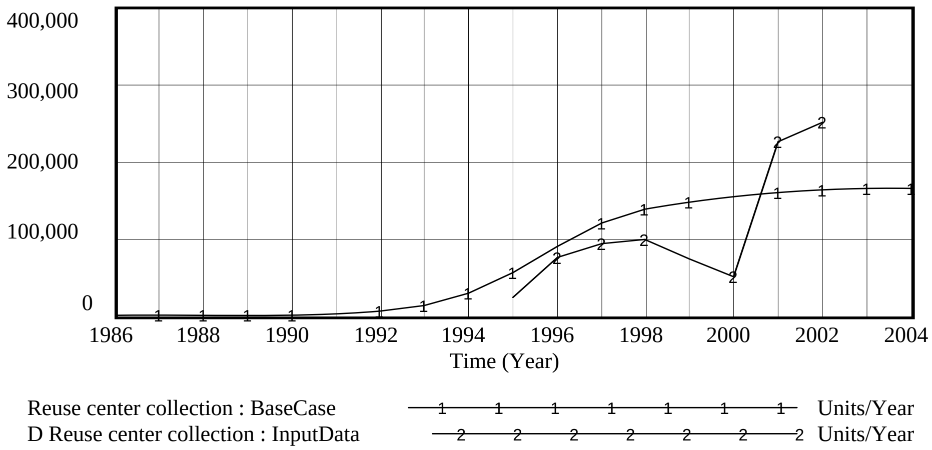
[Figure 9] Electric and Electronic Equipment Purchase Pattern

[Figure 10] presents the movement of producer collection (1995-2003). Even though any producer collection activity did not exist until 1992, its movement has shown a skyrocketing pattern since the adoption of the Extended Producer Responsibility (EPR) in 2000. It is expected that producer collection will be accelerated in the near future as the consumer is entitled to trading of the old product without any charge when she/he purchases a brand-new one.



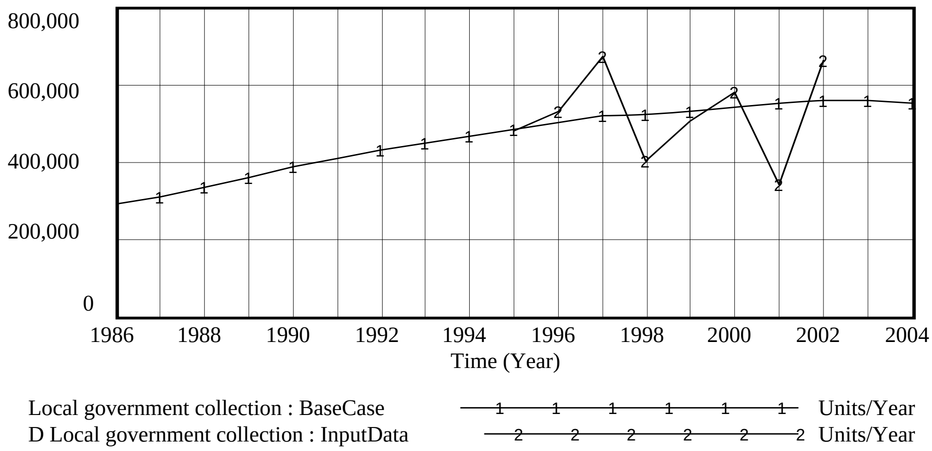
[Figure 10] WEEE Producer Collection

In Korea, many local governments run the reuse center or financially support it. [Figure 11] yields the collection volume handled by the reuse center, from 1995 to 2002. Even though the reuse center has been under heavy pressure to expand its capacity, the increase rate has become rather weakened over time.



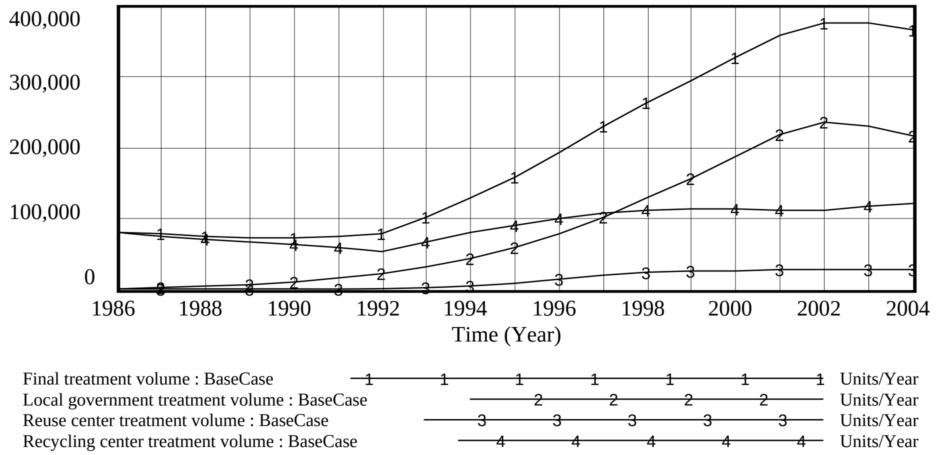
[Figure 11] WEEEReuseCenterCollection

Local government collection (1995-2002) is shown in [Figure 12] The total volume collected by the local government is separated between legal discharge with due levy and illegal dumping without any payment. As referred in the above, this research has configured illegal dumping data based on the existing documents and expert group's judgment. In general, even though the local government collection has been in stable condition, recently, a diminishing trend has been observed, probably owing to the increased producer collection.



[Figure 12] WEEE Local Government Collection

This study has built a series of base scenarios to enhance the models' relevance. Among them, a base scenario dealing with the final treatment volume through either incineration or landfill is presented in [Figure 13]. Annual treatment volume reveals an overshoot-collapsing pattern, culminating in 2002. It may have originated from the fact that a producer had to maximize its recycled volume after the government legally institutionalized the producer recycling duty in 2003.



[Figure 13] Final Treatment Volume Pattern

5. Policy Experiment

1) Policy Experiment Scenarios

This research develops three different types of policy alternative scenarios, as summarized in Table 5. At present, all of the producer collection volume is confined to material or thermal recycle, regardless of equipment quality. Therefore, Alternative 1 assumes that the reuse center supported by the local government would handle 20 percent of producer collection volume. In contrast, Alternative 2 presupposes that all the WEEE volume collected by the local government and reuse center is put into material or thermal recycle processes, departing from the existing customs hinged on a partial collection. The last Alternative 3 tests waste movement if these two alternatives are concurrently adopted. The analytical time span covers from 2005 to 2025.

[Table 5] Summary of Policy Experiment Scenarios

Categories	Contents
Alternative 1	Reuse center supported by the local government would handle 20 percent of producer collection volume
Alternative 2-1	All WEEE volume collected by the local government is put into material or thermal recycle processes
Alternative 2-2	All WEEE volume collected by the reuse center is put into material or thermal recycle processes
Alternative 2-3	Combining Alternative 2-1and Alternative 2-2
Alternative 3	Concurrently adopting Alternative 1 and Alternative 2-3

2) Policy Implications

As summarized in Table 6, if Alternative 1 is adopted, the new purchase rate would be significantly reduced over time: 211,986 units in 2006 to 364,032 units in 2025. It may come from the fact that 20 percent of producer collection volume would be handled by the reuse center supported by the local government in the model. However, Alternative 2 gives only minimal impact on the brand-new product. In fact, even if Alternative 2-3 is adopted, under which all the WEEE volume collected by the local government and reuse center is put into material or thermal recycle processes, its impact on a new phase for electric and electronic equipment is 47,104 units in 2006 and 37,376 units in 2025, respectively. Its amount is about 10 to 20 percent of Alternative 1's. The same movement is observed in Alternative 3, in which Alternative 1 and Alternative 2 are concurrently combined. In deciding Alternative 3's value, Alternative 1 is relatively stronger than Alternative 2.

The results partially explain why producers have not actively joined the reuse movement of electric and electronic equipment. As the producer collection volume is negatively interrelated to the new purchase rate, a producer would resist any waste policy bound for equipment reuse. Even though a producer well acknowledges the fact that reuse-oriented policy would lead to resource cyclical society in the long run, it would definitely hesitate to accept the reuse campaign which might significantly dampen a consumer's purchasing power. Furthermore, as the Extended Producer Responsibility (EPR) stipulates the fact that a producer has to spend its own money to collect the used equipment for the material and thermal recycle, it seems unlikely to expect that a producer would welcome the reuse program.

[Table 6] Impact on Brand-New Equipment Purchase

Categories	2006	2010	2015	2020	2025
Base Run	7,923,200	8,423,424	8,991,744	9,545,728	10,168,320
Alternative 1	211,968	238,080	281,088	323,072	364,032
Alternative 2-1	18,944	2,048	512	1,024	0
Alternative 2-2	28,672	29,184	32,256	34,816	36,864
Alternative 2-3	47,104	30,720	32,768	35,328	37,376
Alternative 3	258,048	268,800	313,856	358,912	403,456

Note: Numbers in Base Run represent the expected brand-new equipment volume (unit). Other numbers imply the expected saving volume (unit) derived from the individual policy alternative.

In contrast, simulation works on the final treatment suggest that Alternative 2 is comparatively superior to Alternative 1. As spotlighted in Table 7, the reduced final treatment volume based on Alternative 2-1 would be 154,216 units in 2006 whereas that of Alternative 1 is 17,374 units in the same year. As in the case of the new purchase rate, Alternative 3, or the combined effort, presents the highest reduced number.

[Table 7] Impact on the Final Treatment

Categories	2006	2010	2015	2020	2025
Base Run	321,502	237,859	220,897	235,122	254,176
Alternative 1	17,374	15,926	18,113	20,568	22,368
Alternative 2-1	154,216	66,686	36,072	32,336	35,883
Alternative 2-2	28,187	28,939	32,340	36,316	40,333
Alternative 2-3	182,507	95,889	68,609	68,867	76,516
Alternative 3	200,523	113,584	87,787	90,322	99,938

Note: Numbers in Base Run represent the expected final treatment volume (unit). Other numbers imply the expected saving volume (unit) derived from the individual policy alternative

If Alternative 2-3 is not available, it would be better to differentiate a time schedule between Alternative 1 and Alternative 2. In the first half, it may be more effective for the local government to take initiatives, adopting Alternative 2-1. In the second half, nonetheless, we should keep in mind that the reuse center supported by the local government should take care of major roles for the WEEE treatment, reflecting Alternative 2-2.

Ⅳ. Discussion

As a derivative approach to social dynamic systems models, this study demonstrates how to build resourcecyclical society based on the dynamic cycles. Using the waste of electric and electronic equipment (WEEE), it presents a practical means to upgrade urban sustainability. Major discussion topics are as follows.

First of all, owing to the Extended Producer Responsibility (EPR) adopted in 2003, the equipment producers in Korea are now additionally burdened with the WEEE recycling duty. Judging from the simulation experiments, the EPR system would significantly contribute to the reduction of the final treatment volume in the first half of the research period. The final treatment volume, which recorded the highest in 2003, is supposed to be continuously diminished up to 2013. However, the trend would be reversed after that point. It implies that the EPR system alone may be at best insufficient or at worst useless in the second half.

Furthermore, as a producer has to recollect the predetermined recycled units whose volume is usually provided by the Korean Ministry of Environment, its top priority is given to howto retrieve all the old equipment. For the replacement demand, the producer does not hesitate to take back the old one free of charge. In order to hit the target number for the recycled units, a producer may well recognize that it may be a cheaper and more convenient way than buying junk items on the black market.

Then, what happens if a producer adopts the reuse-oriented strategy? The simulation results, among others, present two different signals. If the reuse center supported by the local government reuses part of the producer-recycled volume, it would definitely reduce both the required quantity of raw materials and the final treatment volumes altogether. However, this strategy may be confronted with unprecedented objection from the business arena, as producer group as a whole is extremely sensitive to the market trends. In the 20-percent scenario, the reduced consumption volume of a brand-new product would be around 0.2 to 0.4 million units per year. Therefore, without appropriate incentive provisions, it would be difficult for the producers to voluntarily join the reuse-centered movement.

This research also confirms that the final treatment volume would be significantly reduced with minimal impact on the brand-new product consumption, if the local government transforms all the incinerating and landfill volume into thermal and material recycle. The reuse center's experiment also repeats the similar trends, with a relatively weaker impact on the final treatment volume. To enjoy the synergy effect, both the local government and the reuse center together should take immediate actions to discourage the existing customs hinged on incinerationlandfill treatment. Furthermore, they should prepare concrete plans to implement a recycle-oriented strategy.

Particularly, the reuse volume handled by the local government has been decreased over time. But the reuse center has shown the opposite trends whose phenomena seem more preferable for the resource cyclical society. This research also confirms that the reuse center is the most sensitive organization in treating the electric and electronic equipment. The role and function of the reuse center should be strengthened to enhance the level of resource cyclical society.

【References and Notes】

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Article 13 and Article 44 of Waste Management Act and Article 21 of Resource Saving and Recycling Promotion Act in Korea.

Founded in 1976 and organized by more than 1,000 companies, Korea Electronics Association (KEA) is an industrial group which symbolizes the Korean electronics industry.

Stenstoem, M., and T. Ritchey (2004), Scenarios and Strategies for Extended Producer Responsibility: Using Morphological Analysis to Evaluate EPR System Strategies in Sweden, Swedish Defense Research Agency (FOI).

Still, both sides reveal different opinions how to calculate the required waste volume per year. Furthermore, it needs institutional rearrangement as the local government's role and responsibility is not properly defined.

The air conditioner is the only exception. It is understandable as the air conditioner supply ratio

per household is extremely low, that is less than 1 percent in 2005, compared with other durables.

Also, a second-handed or even useless air conditioner can be traded in the local market.

There should be several reasons why all the electric and electronic waste collected by the producer has been directed to the material recycling processes, excluding reuse options. First of all, it is the most urgent task for the producer to satisfy the predetermined recycling volume. If not, it has to endure heavy non-compliance fees. In addition, it seems that the company may wish to minimize the second-handed items in the market as company strategies to retain or promote products' brand value.

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The model assumes that in the best scenario, around 70 percent of used electric and electronic products and components are exported or in the worst scenario, treated as useless waste. It means that neither of them is further considered in the model experiment.

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