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A Study on the Calculation of the Standard Recycling Cost of PVC Profiles and Flooring Waste in Korea

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Abstract: The Voluntary Agreement for Collecting and Recycling Plastic Waste (VA), including polyvinyl chloride (PVC) profiles and flooring materials, will be converted to an Extended Producer Responsibility (EPR) system from 2023. The objective of this study is to calculate the standard recycling cost and the recycling market size for preparing the new system. Among the total recycling companies participating in the VA, a cost analysis was conducted for 11 profile businesses (35% of the total businesses) and seven flooring businesses (58% of the total businesses). As a result, the standard recycling cost was calculated as 0.45 USD/kg for PVC profiles and 0.36 USD/kg for PVC flooring materials. As of 2020, the total market size is 1135 million USD (5.86 million USD for PVC profiles and 5.49 million USD for PVC flooring materials). Our research shows that few countries have nationally managed accurate data regarding PVC profiles and flooring waste. Compared to the European Union (EU), the total amount of recycled PVC products in Korea seems lower, but the recycling rate per capita is higher. This study can provide basic data about the recycling industry for the recycling academia and the manufacturing field.

Keywords: polyvinyl chloride; profile; flooring; recycling cost; Extended Producer Responsibility

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1. Introduction

Construction, automotive, packaging and electronics industries are the main sectors in Europe where polyvinyl chloride (PVC) plastics are used [1]. For example, over 60% of PVC production in Western Europe is used only in the building and construction sector [2].

In Korea, the Voluntary Agreement for Collecting and Recycling of Plastic Waste (hereinafter referred to as 'Voluntary Agreement') has been established by the Ministry of Environment in 2008. Polyvinyl chloride profiles and flooring materials are subject to waste charges. Under the Voluntary Agreement, if the agreed quantity for recycling is fulfilled, the waste charge can be exempt. However, in article 12 of the "Act on the Promotion of Saving and Recycling of Resources" [3], which came into force in July 2021, the period of Voluntary Agreements on the recovery and recycling of products, materials, and containers made of plastic was limited to a maximum of five years. Of 17 items, for which the period of implementation of the Voluntary Agreement exceeded five years, four items including industrial film, agricultural film, household goods (20 types), and replacement water purifier filters, for which a collecting and recycling system has been established, are scheduled to be converted to an Extended Producer Responsibility (EPR) system in 2022. The other 13 items including PVC profiles and flooring materials will be converted to the EPR system in 2023.

Profiles and flooring materials produced with PVC are among the most utilized synthetic resin products, and are subject to EPR conversion. The statistics provided by the

Korea Petrochemical Association showed that 276,475 tons of PVC profiles and 285,447 tons of PVC flooring materials were shipped in 2020. Out of 1,474,000 tons of PVC shipments in Korea, PVC profiles and flooring products accounted for 38.1% of domestic PVC synthetic resin products [4].

According to the amendment of the Enforcement Decree of the "Act on The Promotion of Saving and Recycling of Resources" [5], a profile is defined as "a synthetic resin product used for the production of the ash as a manufacturing object of plastic wire, rod, tube, hose, and plastic window according to the standard industry classification." A flooring material is defined as "a finishing material made of PVC used to cover the inner floor of the building as a manufacturing object of plastic products for wall and floor covering according to the standard industrial classification" [6].

To improve the physical properties of PVC raw materials, plasticizers, stabilizers, and pigments are added to produce products of various qualities and colors [7]. PVC is widely used for both residential and commercial buildings due to its excellent insulation, corrosion resistance, durability, energy efficiency, and airtightness [8]. However, there is a problem with leachate [9–11] in landfills where additives such as phthalate-based plasticizers and stabilizers are used. In addition, hydrogen chloride and dioxin generated during the incineration of PVC materials can cause problems [12], highlighting safety concerns. Many of the problems with thermal recycling are caused by process additives, such as stabilizers and plasticizers commonly used in PVC processing [13]. To minimize environmental damage, incineration and landfilling with PVC profiles and floorings should be reduced and recycling should be promoted more actively to save resources for economic utility and to revitalize Small and Medium Enterprises (SMEs).

The current waste disposal situation in the four Nordic countries is influenced by several factors that impede economies of scale and high PVC collection and recycling rates. PVC waste sources are somewhat geographically dispersed, and quality requirements for recycled PVC are high [5].

PVC waste will continue to be generated until alternative material comes into play. More attention should be paid to developing relevant recycling technologies and fostering relevant industries. This study is focused on calculating the collecting and sorting, recycling cost, and the standard recycling cost by analyzing the system for the recovery and recycling of PVC profiles and flooring waste in Korea. Based on the data collected in this study, the current recycling market size is also estimated.

2. Results and Discussion

2.1. Recycling System for Profiles and Flooring

Profile and flooring waste mainly occurred during building demolition, reconstruction, moving, and interior construction. Both products are valuable. They are voluntarily recovered by individual businesses or demolition businesses. There are two recovery routes: collecting waste materials at the building demolition site and collecting scraps generated at the manufacturing or construction site [14] (Figure 1).

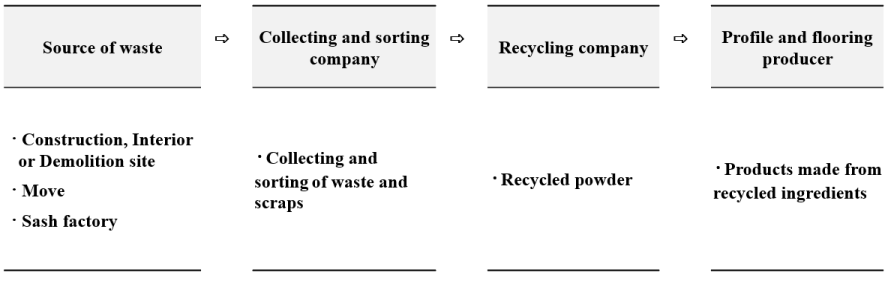

Figure 1. Profile and flooring waste recycling process.

Since the profile has a low content of foreign substances or other materials, it produces high-quality waste that can be recovered and recycled among PVC products [15,16]. Profile waste mostly comes from the manufacturing process or window removal site. A profile collecting and sorting company performs a pre-sorting operation to remove the vinyl, steel reinforcement, rollers, and silicone from profiles purchased from professional private collectors, which are carried out by hand. The degree of completion of the sorting work greatly influences the quality of recycled raw materials [17]. When the recovery and sorting company's work is completed, the recycling company buys it and produces recycled material by processes such as cutting, primary grinding, precision sorting (magnetic and optical sorting), and secondary grinding. Recycled materials (pellets, powders) are then once again used for profile production and other products (moldings, soundproof walls, etc.) [18, 19] (Figure 2).

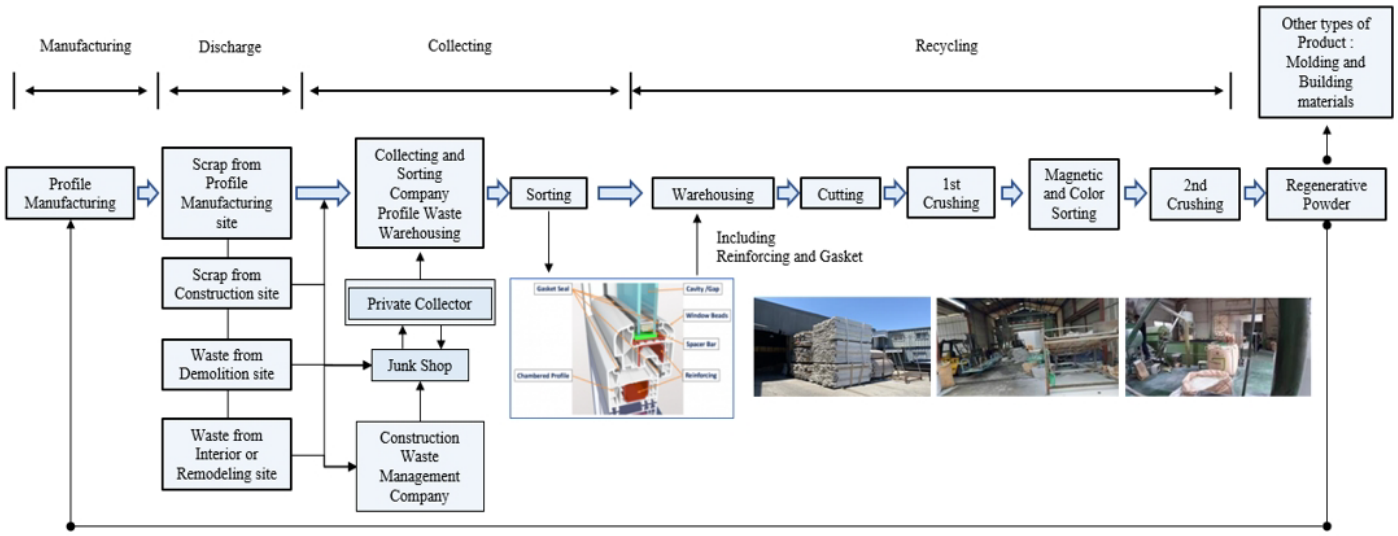

Figure 2. Material flow chart of profile.

Flooring waste is produced during the interior/remodeling process or building demolition process. Collecting and sorting companies collect or take over materials from junk dealers or private collecting companies. They then manually remove the edges of floorboards and foreign substances such as silicone and vinyl. After this process, materials are then brought to a recycling company. The flooring is finished with silicone to fill seams at the construction stage. In the first stage of sorting, it is necessary to remove foreign substances (silicone, tape, etc.) that can reduce the defect rate in the recycling stage [20].

Due to brand image and quality control, large companies rarely use recycled raw materials [21]. However, mid-sized companies use them as raw materials for decorative tiles. In this process, they mix $CaCO_3$ to enhance hardness to suit commercial buildings [22] (Figure 3).

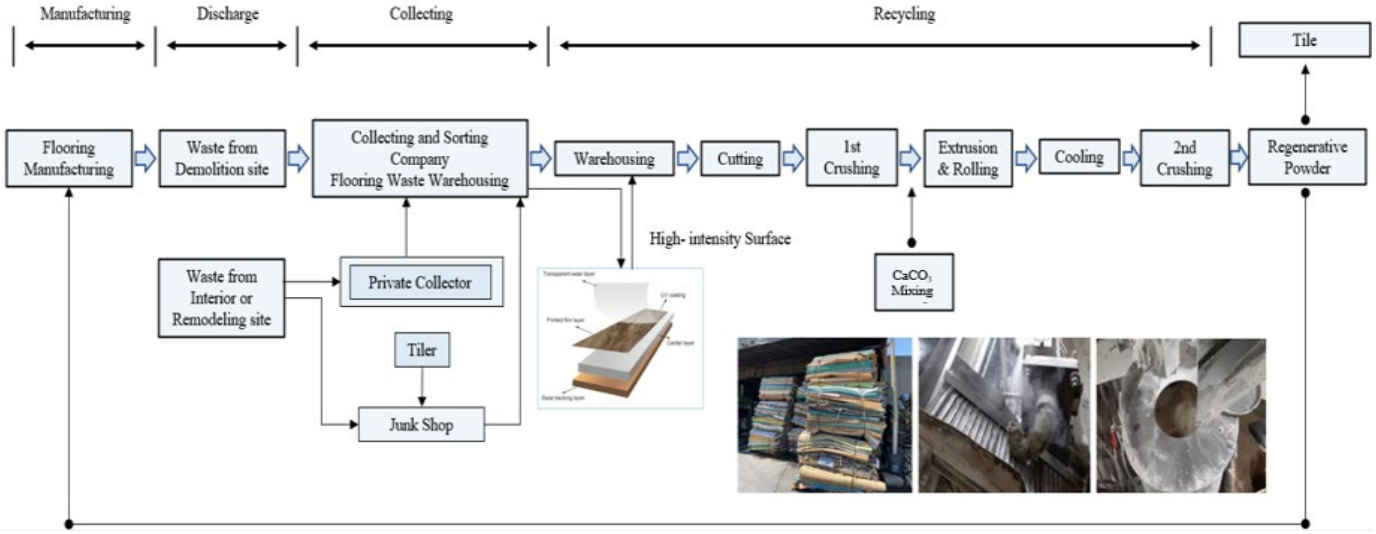

Figure 3. Material flow chart of profile.

2.2. Cost Analysis to Calculate Recycling Standard Cost

Standard recycling cost was calculated based on the above-mentioned recycling process (Figure 3). Based on the survey, costs required in recovery and recycling stages were estimated as follows:

To confirm the cost of the recovery stage of the profile, the acquisition cost and sorting cost of raw materials obtained from target companies were examined. As a result, the raw material purchase cost and the sorting cost seemed to have a ratio of 7:3. The raw material purchase amount was 10,500 tons annually with a total purchase cost of 1,750,000 USD. Twenty and 15 foreign workers were deployed for the first sorting (removal of steel for reinforcement) and the second sorting, respectively. Consequently, referring to the result of the cost analysis, it was calculated as 0.24 USD/kg (Table 1).

Unlike the profile, in the flooring sorting stage, only the primary sorting process was performed to manually remove silicon, etc. The annual purchase cost was 3,517,500 USD with a purchase quantity of 21,105 tons. The cost of the recovery stage was 0.20 USD/kg (Table 1).

Table 1. Net cost of the profile and flooring collecting and sorting (unit: USD/kg).

Category	Amount and Cost		Comment	
	Profile	Flooring		
Purchase volume	10,500 tons	21,105 tons	Additional correction of process loss rate of 5% to total sales volume	
Purchase price	0.17	0.17	Cost of purchasing from junk shops, collecting individuals, and agencies.	
Collecting cost	1,750,000	3,517,500		
The 1st sorting	438,161		20 people (based on overseas workers)	Profile
				Reinforcement; wheel removal
				Flooring
				Silicone, tape, and edge removal
The 2nd sorting	328,621		15 people	Profile

			(based on overseas workers)	Plastic film; other substances removal and cutting
Total sorting cost	766,782	766,782		
Total cost	2,516,782	4,284,282		
The unit cost	0.24	0.20		

The recycling cost was calculated separately for each recycling company. There was a difference in production cost depending on the size of the facility. To compensate for the high recycling cost of small businesses, weights were provided in proportion to the number of materials purchased. Recycling costs were calculated in the basic unit (USD/kg) for 11 profile recycling companies and seven floor material recycling companies. As a result, the recycling cost was calculated as 0.21 USD/kg for profiles and 0.18 USD/kg for flooring materials (Table 2; Figure 4).

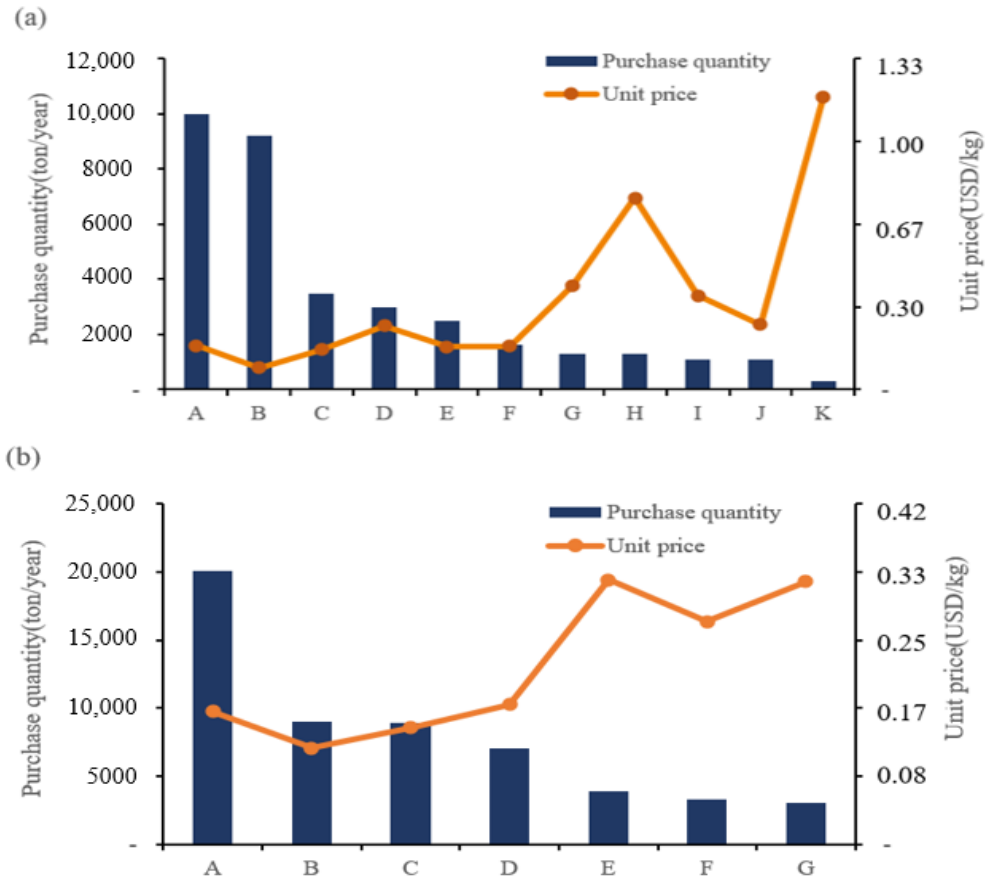

Figure 4. Weighted average unit price of (**a**) profile and (**b**) flooring recycling.

Table 2. Net cost of profile and flooring recycling.

Profile Company	Amount of Raw Materials Purchased (Ton/Year)	Ratio	Unit Cost (USD/kg)	Flooring Company	Amount of Raw Materials Purchased (Ton/Year)	Ratio	Unit Cost (USD/kg)
A	10,000	28.6%	0.18	A	20,100	36.5%	0.16
B	9231	26.4%	0.09	B	9000	16.3%	0.12
C	3500	10.0%	0.16	C	8900	16.1%	0.14

D	3000	8.6%	0.26	D	7000	12.7%	0.17
E	2500	7.2%	0.17	E	3850	7.0%	0.32
F	1636	4.7%	0.18	F	3270	5.9%	0.27
G	1290	3.7%	0.42	G	3000	5.4%	0.32
H	1300	3.7%	0.77		-	-	-
I	1100	3.1%	0.38		-	-	-
J	1100	3.1%	0.26		-	-	-
K	300	0.9%	1.16		-	-	-
The standard cost for recycling profile (USD/kg)			0.21	The standard cost for recycling flooring (USD/kg)			0.18

Although a great deal of electricity was used to melt the flooring, unlike the profile, the flooring recycling cost was lower than the profile recycling cost. The reason for this was that the unit price of flooring was reduced by increasing the plant's facility capacity with the successful establishment of a mass production system.

The standard recycling cost for the profile was 0.45 USD/kg, which was the sum of the recovery cost of 0.24 USD/kg and the recycling cost of 0.21 USD/kg. In the case of flooring materials, the recovery cost was 0.18 USD/kg and the recycling cost was 0.18 USD/kg. Thus, the standard recycling cost was 0.36 USD/kg (Table 3).

Table 3. Results of calculating the recycling standard cost (unit: USD/kg).

Items	Collecting and Sorting Unit Cost (A)	Recycling Unit Cost (B)	Standard Recycling Cost (A + B)
Profile	0.24	0.21	0.45
Flooring	0.18	0.18	0.36

In the case of profile, many accessories need to be removed in the sorting process. Thus, profile recycling requires a relatively large amount of manpower. The cost was approximately 27% higher than that for recycling flooring materials. In the recycling stage, flooring recycling companies increased their production scale and lowered their cost (approximately 12% lower than that for the profile). As a result, the standard recycling cost for profiles was found to be approximately 21% higher than that for flooring materials.

2.3. Results of Total Recovery and Recycling Market Size Estimation

To estimate the size of the recycling market, first, the market was divided into a collecting and sorting market and a recycled raw material market. Raw materials were divided into high, medium, and low levels by quality. The purchase amount of each was obtained. Purchase and sales unit prices were then obtained by applying a weighted average. These values were multiplied by the profile and flooring recycling amount in Korea in 2020. The total recycling market size was estimated by adding these values. For the profile, the weighted average purchase price of recycling companies was 0.40 USD/kg. The selling price of recycled raw materials was 0.71 USD/kg. For flooring materials, the weighted average purchase price of recycling companies was 0.20 USD/kg. The sale price of recycled raw materials was 0.42 USD/kg (Table 4).

Table 4. Purchase price of waste materials and sales price of recycled materials.

Price and Percentage (Unit: USD)		Quality Level			Weighted Average Price
		High	Medium	Low	
Profile	Percentage (%)	60.2	29.7	10.1	-
	Purchase price	0.47	0.33	0.17	0.40
	Sale price	0.85	0.55	0.36	0.71
Flooring	Percentage (%)	46.6	38.3	15.1	-
	Purchase price	0.25	0.20	0.06	0.20
	Sale price	0.54	0.35	0.22	0.42

According to the Korea Vinyl Environment Council, the number of recycled materials was estimated to be 49,179 tons for profiles and 74,570 tons for flooring materials in 2020. If we estimate the total market size by multiplying the standard recycling cost obtained earlier by the above production, the size of the recovery market, the profile was 2.04 million USD, and the flooring was 1.56 million USD.

In the case of the recycled raw material market, the profile was 3.49 million USD, and the floor material was 3.14 million USD. Combining the size of the collecting, sorting, and recycling market, the profile was 5.53 million USD, and the flooring size was 4.70 million USD. Summing up, the total was nearly 10.23 million USD.

Based on the above values, the total market size was estimated using the market share of 94.4% of participating producers and 85.5% of the market share of flooring producers in the Voluntary Agreement.

Considering this, the size of the recovery and the sorting market was 2.16 million USD for profile and 1.83 million USD for flooring. In terms of the size of the recycled raw material market, the profile and flooring were 3.70 million USD. In terms of the overall recycling market size, the profile was estimated at 5.86 million USD, and the flooring material at 5.49 million USD, totaling 11.35 million USD (Table 5).

Table 5. Profile and flooring recycling market size (unit: 1000 USD).

Scope of Market		Collecting Market	Recycled Ingredients Market	Sub-Total	Total
Voluntary Agreement participating market	Profile	20.4	35.0	55.4	102.3
	Flooring	15.6	31.4	47.0	
The entire market	Profile	21.6	37.0	58.6	113.6
	Flooring	18.2	36.7	54.9	

3. Materials and Methods

3.1. Research Procedures and Methods

For this study, first, the cost structure and recycling process of the EPR system stipulated in the "Act on the Promotion of Saving and Recycling of Resources" were analyzed. For the calculation of the standard recycling cost, necessary items were decided, and a questionnaire was prepared to investigate the current recycling status depending on the business entity. Related data were collected by conducting an on-site survey (Figure 5).

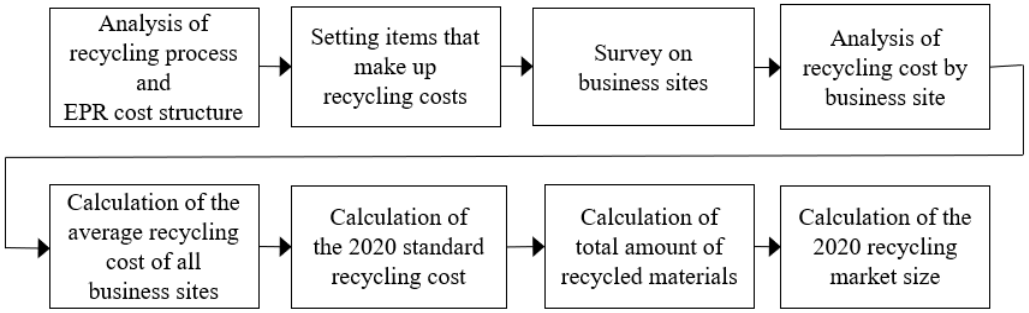

Figure 5. Procedure and contents of the research.

3.2. Analysis of the Cost Structure of the EPR System

The EPR system is based on a method of sharing the economic burden between producers and recycling business operators by recycling contributions, recycling subsidies, and recycling dues. Classifications (1)–(3) and the calculation formulas for each cost are shown in Table 6. The classification of cost in the EPR system is shown in Figure 6.

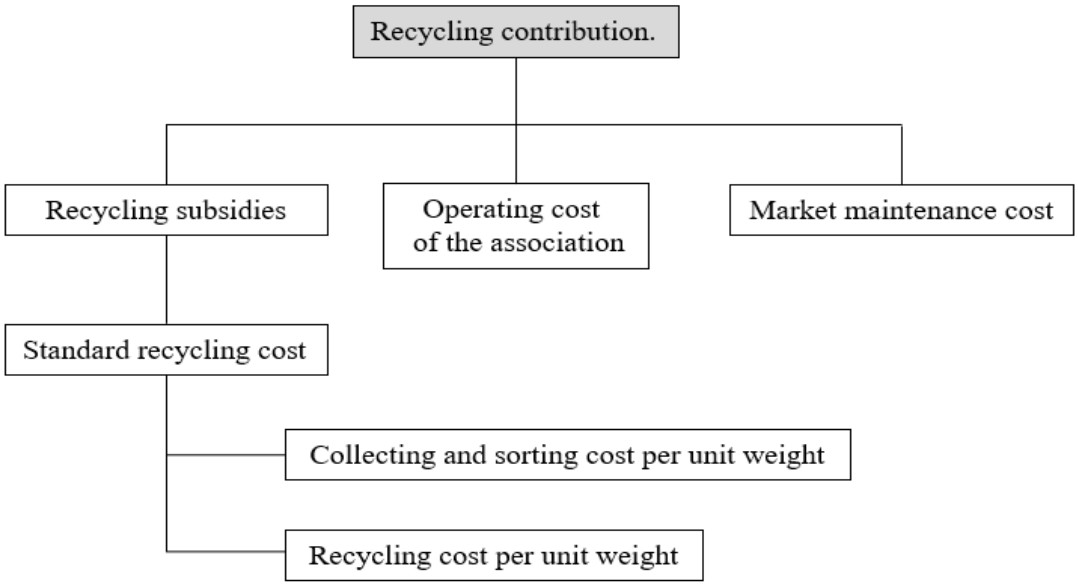

Figure 6. Classification of cost in the EPR system.

Table 6. Classification of the cost to be calculated and the formula used to calculate it.

Classification of Cost	Formula to Calculate the Cost
(1) Standard recycling cost	= Recovery cost (collecting/transport cost + sorting cost) + Recycling cost
(2) Recycling subsidies (costs to support recycling companies by reflecting the cost of purchasing and selling valuables)	= Standard recycling cost − Renewable value (Availability of recycled resources)
(3) Recycling share cost	= Recycling subsidies + EPR system operating cost (association (a mutual aid association) operating cost) + Recycling promotion cost such as education, publicity, and technology development + Market maintenance cost

Recycling contribution includes recycling subsidies, operating costs of an association (a cooperative) that connects several producers with recycling businesses (collecting, sorting, and recycling), R&D costs, public relations costs, and market maintenance costs for coping with an unstable recycling market environment. The recycling subsidy is considered an economic incentive for recycling companies to actively participate in the collecting, sorting, and recycling of the product. It is a key means of securing the mandatory recycling capacity that producers need to achieve. The standard recycling cost is a basic item in the calculation of recycling contributions, recycling dues, and recycling subsidies. To calculate the standard recycling cost, first, the process is classified into the collecting/sorting stage and the recycling stage. Second, the facility cost, and operating cost of each stage are divided by the amount of purchased raw materials and calculated in the basic unit (USD/kg) [23].

As of 2021, 32 businesses (21 profiles and 11 flooring materials) participate in the voluntary agreement by joining the Korea Vinyl Environmental Council, which functions as a mutual aid association. These 32 producers are obligated to recycle. The market share of participating in the voluntary agreement in 2018–2020 was found to be 94.4% for profiles and 85.5% for flooring.

There are about 120 Recycling Business Operators nationwide, of which 43 businesses (31 profile businesses and 12 flooring businesses) participate as members of the Korea Vinyl Environment Council. Among them, a cost analysis was conducted for 11 profile businesses (35% of recycling profile businesses participating in the agreement) and seven flooring businesses (58% of recycling flooring businesses participating in the agreement).

Collecting and sorting businesses were divided into two groups: collecting and sorting. For recycling businesses, business sites were divided by size: large, medium, and small. Each location was selected for an on-site survey (a total of six) (Table 7).

Table 7. Criteria for selecting companies to be analyzed.

		Comments
Analysis Target Companies	Profile	• Out of 31 recycling companies participating in the 2021 Voluntary Agreement, 18 companies responded to the survey. • The companies built more than 15 years ago or producing non-targeted products (e.g., PVC pipe, etc.) were excluded → 11 companies analysis. • Of the 11 companies, 35% subscribed to the Voluntary Agreement.
	Flooring	• Eight companies out of 12 recycling companies participating in the 2021 Voluntary Agreement responded to the survey. • One company built 15 years ago out of eight responding companies was excluded → seven companies' analysis. • Of the seven, 58% of the companies that subscribe to the Voluntary Agreement were analysis.

Cost analysis was carried out based on the "Contract Rules of the Ministry of Strategy and Finance" (Table 1. Manufacturing Cost Invoice) [24]. To calculate manufacturing cost, data on annual throughput, manpower composition, facility investment cost, and operating cost were obtained from each company. Profit was excluded from items to be calculated. Only the net cost was calculated and divided into two stages: (1) a collecting and sorting stage; and (2) a recycling stage. Facility costs and operating costs invested by companies were converted into basic units (USD/kg, KRW 1200 = 1 USD) based on the throughput. They were then compared and analyzed.

In addition, there was a difference in production cost depending on the processing scale of the company. For this reason, weight should be given to the number of raw materials purchased depending on the target companies. This was calculated with the weighted average method as shown in the formula below:

$$Average\ cost\ of\ recycling = \sum_{i=1}^{n} x_i f_i = \frac{x_1 f_1 + x_2 f_2 + \cdots x_n f_n}{f_1 + f_2 + \cdots + f_n}$$

x_i = *unit cost of production*

f_i = *amount of raw material purchased*

A standard method was used to calculate the unit production cost for each company in the collecting and recycling stage [25] (Table 8). Labor costs were divided into three job groups: office workers, machine equipment managers, and production workers (Koreans and foreigners). Accordingly, the standard labor cost was determined and calculated by job group. As for labor costs for Koreans, full-time wages of office workers, machine operation and assembly workers, and simple labor workers were applied from the "Report on Labor Status by Employment Type". The labor cost for foreigners was based on the minimum wage presented by the Ministry of Employment and Minimum Wage Commission, which was 1519 USD/month for application years from 1 January 2021 to 31 December 2021 (Table 9).

Table 8. Items for calculating recycling cost.

Items	Details
Labor costs	• Labor costs were reviewed by dividing it into four job groups (office workers, machinery workers, and production workers (domestic, foreign))
Depreciation costs	• The standard durability year for recycling facilities is 10 years. • Five years were applied for the standard durability of the vehicles (truck, forklift) ※ Ref [26]
Present value of investment costs	• As the investment cost for each business and facility differs depending on the period, the present value of the base year 2020 is used for analysis. ※ Ref [27]
Use of weighted average in the calculation of the standard recycling cost	• It is difficult to compare them equally because the production scale of each target company is different and there are differences in investment costs and operating costs. Weight was assigned to each company based on the target company's total production, and the weighted average was used to obtain the recycling standard costs.

Table 9. Labor cost calculation standard and four major insurance premium rates.

Type of Worker	Personnel Expense (USD/Month)	Comment
Office worker	3488	Office job
Machine Operator	2838	Device operation and assembly
Labor workers (Korean)	1833	Simple labor
Labor workers (foreigner)	1519	The minimum hourly wage standard

Insurance	Rate (%)		
	Total Rate	Employee's Share	Employer's Share
National pension	9	4.5	4.5
health insurance	6.67	3.335	3.335
Long-term care insurance	10.25% of health insurance	50%	50%
Employment insurance	1.85	0.925	0.925
Industrial accident insurance	2	2	

National pension (salary × 9%), health insurance (salary × 6.67%), long-term care insurance (health insurance × 10.25%), employment insurance (salary × 1.85%), and industrial accident insurance (salary × 2%) were included in the calculation, where the cost of employed manpower was obtained (Table 9).

Facility investment cost was analyzed in the form of depreciation costs for recycling facilities and vehicles (trucks, forklifts). The depreciation period was set to be ten years for facilities and five years for vehicles. Operating expenses were separated into electricity cost, fuel cost, repair cost, waste treatment cost, land/building rental fee, and utility bill. Next, 8% ("General Management Ratio" (Contract Rules) was applied for general management expenses [24]. Facility investment costs were different depending on the type of raw material (profile, flooring), the level required by transaction clients, installation facilities, and the arrangement of the process line for process optimization, which made it difficult to standardize the process. Accordingly, the actual investment cost by the facility was converted as of 2020 by applying the producer price index.

4. Conclusions

This study aimed to analyze the standard recycling cost and the size of the recycling market that would be required when setting the recycling contribution and levy within the EPR system. This basic data could also be used for establishing and operating recycling policies. This study had the following conclusions.

First, the cost of collecting and sorting profiles was calculated as 0.24 USD/kg by adding the cost of purchasing profiles from individual collectors and junk dealers with the cost of primary sorting, to remove reinforcing steel from purchased raw materials, and secondary sorting, to remove vinyl and so on. In the case of flooring materials, the cost of collecting and sorting flooring, including the cost of purchasing flooring and decorative tiles by individual collectors and labor costs for the primary sorting process by manual work, was found to be 0.18 USD/kg.

Second, recycling cost was assigned a weight proportional to the amount of throughput for each recycling company. It was evaluated to be 0.21 USD/kg for profiles and 0.18 USD/kg for flooring materials. Accordingly, the standard recycling cost is the sum of the collecting and sorting costs and recycling costs. The recycling cost was 0.45 USD/kg for the profile and 0.36 USD/kg for the flooring.

Third, when calculating the unit cost of purchasing recycled raw materials and selling unit prices of recycled raw materials, a weighted average was utilized based on the quality of raw materials and the throughput of the target company. Accordingly, the purchase unit price of profile recycling companies was 0.40 USD/kg and the selling unit price of recycled raw materials was 0.71 USD/kg. For flooring, the purchase unit price was 0.20 USD/kg and the sale unit price of recycled raw materials was calculated to be 0.42 USD/kg.

Fourth, in terms of total collecting and sorting market size, it was 2.16 million USD for profiles and 1.83 million USD for flooring materials as of 2020. Regarding the market for recycled raw materials, it was 3.70 million USD for profiles and flooring materials. Considering the entire recycling market, it was estimated to be 5.86 million USD for profiles and 5.49 million USD for flooring materials, with a total market of 11.35 million USD.

The global PVC supply has decreased due to difficulties in hiring foreign workers caused by the ongoing COVID-19 situation and the shutdown of petrochemical plants due to the cold wave in the United States in early 2021. Currently, the material shortage of synthetic resin waste is worsening. Recycling costs may increase even further in the future due to the continuous upward trend of international oil prices.

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

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