

Economic Returns from Recycling Practices in Taiwan: An Assessment Framework

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Abstract

This study assesses the economic and environmental impacts of Taiwan's recycling industry, focusing on market values in 2022 and 2023. Recycling forms the backbone of Taiwan's circular economy, generating employment and supporting sustainability. The total market value was NT\$140.9 billion in 2022 and NT\$148.3 billion in 2023. Government investments of NT\$15 billion annually spurred GDP growth, economic output, and over 20,000 green jobs each year. The findings emphasize recycling's role in fostering economic resilience and sustainability, providing a foundation for policy development, stakeholder engagement, and international cooperation.

1. Introduction

Amid the dual crises of global resource scarcity and environmental degradation, resource recycling has become one of the key initiatives to accelerate energy conservation, carbon reduction, and the transition toward a circular economy. The Ministry of Environment of Taiwan has implemented the "4-in-1 Resource Recycling Program," integrating community members, local cleaning teams, recycling processors, and the Resource Recycling Management Fund. This initiative aims to reduce waste, promote resource recovery, and establish efficient recycling channels and market systems, ensuring proper handling and reutilization of recyclable materials.

Overall, resource recycling serves as the foundation of the circular economy and has been a pivotal environmental industry in Taiwan for decades. It not only generates high value-added economic benefits but also significantly contributes to environmental protection. Socially, resource recycling provides employment opportunities, particularly stabilizing grassroots communities, thereby directly supporting the three core pillars of sustainable development: economic, environmental, and social dimensions.

We conducted the "Analysis of Economic and Environmental Benefits of General Waste

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Recycling” project in 2020, which established a methodology for estimating the economic value of general waste recycling and a model for quantifying environmental benefits. Using these tools, we evaluated the economic value, monetized economic impacts, and environmental benefits for 2022–2023. In this paper, we aim to estimate related economic from the recycling markets in Taiwan.

2. Literature Review

Recycling generates substantial economic benefits by creating jobs, reducing costs associated with waste disposal, and providing valuable secondary materials for industries. Studies indicate that recycling supports economic growth through the creation of green jobs and revenue streams across collection, processing, and remanufacturing sectors. For instance, the recycling industry in Taiwan contributes to local economic stability by employing community members and producing high-value-added products from waste (Nguyen et al., 2020). Globally, recycling reduces reliance on virgin materials, mitigating supply chain risks and fostering resource efficiency. Furthermore, recycling programs have been shown to generate three times more revenue per ton compared to landfill disposal, while simultaneously lowering municipal costs through decreased landfill usage (Okonta F. & Mohlalifi, 2020). Additionally, recycling initiatives promote innovation in manufacturing, where materials such as recycled metals and plastics are repurposed into high-demand products, further stimulating economic activity (Ellen MacArthur Foundation, 2019). These economic advantages underscore the critical role of recycling in driving sustainable development and economic resilience worldwide.

From the perspective of job creation (Bureau of Labor Statistics, 2021), the recycling industry supports approximately 1.17 million jobs in the United States, with direct employment in recycling operations averaging \$77,300 in wages and benefits per worker. Economic analyses indicate that recycling generates about three times more revenue per ton than landfill disposal and creates nearly six times as many jobs. For municipalities, recycling can lead to substantial cost savings by reducing landfill usage fees, which can exceed \$80 per ton in some areas. Furthermore, the recycling sector plays a crucial role in the manufacturing supply chain by providing essential materials for new products, thereby decreasing reliance on virgin resources and fostering innovation within the economy. Overall, the integration of recycling into local economies not only enhances sustainability but also promotes financial stability and job growth across various sectors.

3. Scope of Investigation

According to Article 2, Paragraph 2 of the current Waste Disposal Act of Taiwan (hereinafter referred to as the Act), “general waste” is defined as “waste other than industrial waste.” Additionally, Article 5, Paragraph 6 of the Act stipulates, “Items for general waste recycling”

shall be determined by the central competent authority. However, municipal or county (city) competent authorities may add other general waste recycling items based on specific local needs, which must be submitted to the central competent authority for record-keeping.”

In accordance with these provisions, the Ministry of Environment has announced the “General Waste Recycling Items” to be managed by implementing agencies. The current items managed by the Resource Circulation Agency of the Ministry of Environment are as follows:

1. Recyclable waste as defined in Article 18, Paragraph 1 of the Waste Disposal Act (hereinafter referred to as “designated recyclable items” subject to the principle of the Extended Producer Responsibility, EPR).
2. The following items that do not fall under the category of designated recyclable items:
 - Paper.
 - Iron.
 - Aluminum.
 - Glass.
 - Plastics (excluding plastic bags), including PET, PE, PVC, PP, and PS.
 - Compact discs.
 - Mobile phones and their chargers (including dock chargers and travel chargers).
 - Edible oils.

For this project, the first category above is referred to as “designated recyclable EPR items,” while the subsequent categories are collectively referred to as the “additional Non-EPR categories.” This project will assess the resource recycling values for these items for the years 2022 and 2023.

3.1 Assessment of recycling value chain

The term “value” is most intuitively defined as “the production value of an industry.” This is equivalent to the total value of products leaving the production and manufacturing sites of a given industry. The formula for output value is as follows:

$$\text{Output Value} = \text{Production Volume} \times \text{Average Selling Price (ASP)}$$

This formula underscores the two critical factors in value assessment: production volume (measured in quantity or weight) and price. It also aligns with the concept of market transactions. Based on previous commissioned studies by the Resource Circulation Agency, the stages in the resource recycling process that generate market value include the collection, processing, and manufacturing stages. Therefore, the recycling industry encompasses the collection, processing, and regenerated-material-application markets. Thus, as Figure 1, the total value of the recycling industry can be considered the sum of transactions in these three categories of markets.

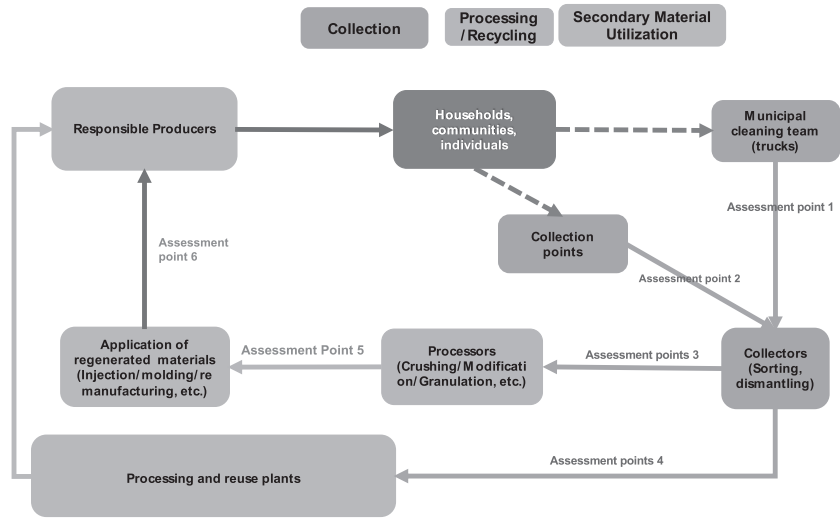


Figure 1 Stages of Recycling Industry in Taiwan

3.2 Collection market

More specifically, the collection market is created by three channels as follows.

- Municipal Environmental Protection Bureaus or district office cleaning teams collect recyclable materials and conduct transactions in the collection market.
- Communities, schools, and institutions collect recyclable materials and conduct transactions in the collection market.
- Recycling stations or operators dismantle and sort the recyclable materials from the first two points and resell them to processing operators in the collection market.

3.3 Processing market

Processing operators use physical or chemical methods to further process recyclable materials. This includes crushing, pelletizing, refining, and extracting, which are then resold to manufacturers using recycled materials.

3.4 Regenerated-material-application market

Manufacturers purchase recycled materials and incorporate them into their production processes to create new products, which are then sold in the remanufacturing market. The products may follow two paths:

1. **Business-to-Business (B2B):** Recycled materials are used to produce intermediate products, such as steel rebars or structural steel, which are supplied to industries such as construction, machinery, and shipbuilding as raw materials. For instance, recycled plastic pellets may be used to manufacture new plastic bottles or caps, which are then supplied to

personal care product manufacturers.

2. **Business-to-Consumer (B2C):** Recycled materials are used to produce end-user products, such as carbon black extracted from used tires being used to manufacture wetsuits, which are sold to consumers. Similarly, recycled glass can be used to create new art pieces or frames for retail.

4. Data Sources and Methods

4.1 Data collection for value calculation factors

Based on prior project experiences in assessing the value of the recycling industry, data sources for production volume and price include secondary data, such as:

- Certification data from the Recycling Fund,
- Resource Recycling Management System (RRMS),
- Household Waste Management System (HWMS),
- Results from price surveys commissioned by the Ministry of Environment,
- Publicly available market information.

These data sources primarily reflect transactions in the recycling, processing, and even some intermediate product markets. For the gaps in secondary data, particularly at the two ends of the recycling value chain, such as the high-value reuse product markets, surveys are employed to ensure comprehensive value assessments.

Specifically:

1. For the “designated recyclable items” subject to EPR regulations under the current project, data on the collection market, processing market, and intermediate product market are readily available, making secondary data a practical and efficient resource for assessment.
2. For the reuse end-market, which represents the apex of the recycling value chain with the highest value, data availability is limited. Since the final disposal and reuse flows of each item are difficult to ascertain and the survey sample is scattered, market investigation and experience accumulation are needed to better capture the data and gradually develop secondary datasets for this segment.

4.2 Methods for evaluating market value

(1) Collection market assessment (by secondary data)

As shown in Figure 2, the assessment methods are designed for different channels in the collection market:

1. **Revenue from municipal cleaning teams** (Assessment point 1 in Figure 1):

Data from the Ministry of Environment’s HWMS on annual sales revenues from recyclable

Assessment points		Assessment Methods		
Collection Market	1. Township, county and city cleaning teams' income (K) from selling recyclables	□	- Household Waste Management System (HWMS) - Data from the annual Survey on Sale of General Waste Recycling Waste in municipalities	
	2. Communities, schools, government agencies and organizations' income from selling recyclables	□	K	$\times$ Resource recovery of schools, communities, and institutions by county and city (HWMS) / Resource Recovery by cleaning Team (HWMS)
	3. Collectors' income (from selling mandatory recycling items)	□	Collected amount (tonn) (RRMS)	$\times$ Unit market price of the collected material (by Audit and Certification Program Survey)
	4. Collectors' income (from selling other recyclables)	□	Collected amount (by compilation of MOE data)	$\times$ Unit market price of the collected material (by government reports, open market data etc.)

Figure 2 Assessment methods for the collection markets

waste are used. Alternatively, data are obtained from municipalities and district offices. This method ensures relatively accurate official statistics.

2. Revenue from schools, communities, and institutions (Assessment point 2):

Data from the HWMS on recycling volumes for schools, communities, and institutions are analyzed alongside cleaning team recycling revenues to estimate the revenues from these sources.

3. Revenue from collection operators (Assessment points 3 and 4):

For designated recyclable items, RRMS data on annual material processing volumes and pricing are aggregated to estimate transaction revenues. This method, based on audited and certified data, provides reliable estimates. For additional categories, official and industry-association data are used to calculate annual transaction revenues.

(2) Processing market assessment (by secondary data) (Assessment point 5)

For designated recyclable (EPR) items, revenue data from the Recycling Fund's reports are aggregated to estimate processing market revenues. Due to the overlap of processing and reuse for certain materials (e.g., paper and metals), additional categories do not undergo separate processing stage assessments.

(3) Regenerated-material-utilization market (by secondary data and surveys) (Assessment point 6)

While secondary data on the reuse market are limited, prior survey data provide a basis for estimates. Two evaluation methods are employed:

1. **Secondary data:** Adjustments to previous survey data based on annual variations in recycled material outputs and inflation rates. While efficient, this method assumes proportional price changes with inflation and cannot capture specific price variations.
2. **Surveys:** Targeted surveys for high-value categories such as recycled paper and metals are conducted. For instance, surveys involving major paper mills and their downstream

partners help estimate the value of recycled paper products.

5. Calculation Results

5.1 Collection market

According to the planning outlined in the previous section, the assessment of collection market value involves three main components:

5.2 Revenue generated by municipal cleaning teams (Assessment point 1)

Based on data from the Ministry of Environment regarding cleaning teams across the nation, there are currently 356 cleaning teams distributed among various counties and cities in Taiwan (Figure 3). Tainan City has the highest number of teams (38), while Chiayi City has the lowest (1). Data on annual recycling revenues from these cleaning teams are compiled by municipal environmental protection bureaus and uploaded to the Household Waste Management System (HWMS) of the Ministry of Environment. This includes details on recycling models (e.g., categorized or uncategorized, regional or non-regional), recycling volumes (in tons), unit prices (in NT\$/kg), and total annual revenues. However, the structure and detail of the uploaded data vary by municipality due to localized practices.

In 2022, New Taipei City reported the highest recycling volume at 112,200 tons (18%), followed by Taoyuan City with 82,400 tons (13%) and Taichung City with 79,500 tons (12%). These three cities accounted for 43% of the total recycling volume of all cleaning teams nationwide. Other significant contributors included Kaohsiung City (59,600 tons, 9%), Taipei City (59,000 tons, 9%), and Tainan City (51,800 tons, 8%). Collectively, the six largest cities contributed approximately

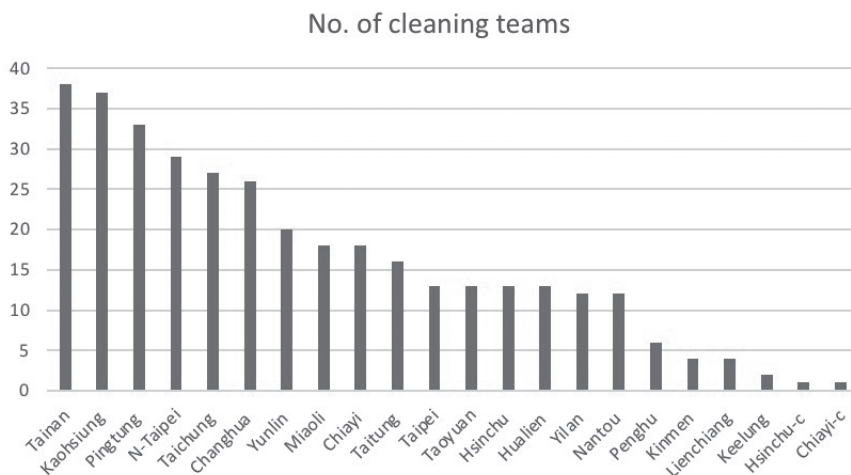


Figure 3 Distribution of cleaning teams across cities and counties (Data Source: Ministry of Environment Resource Circulation Agency, June 24, 2023)

70% of the total recycling volume of cleaning teams nationwide.

In 2023, the trend was similar, with New Taipei City leading at 125,100 tons (18%), followed by Taoyuan City (82,400 tons, 12%) and Taichung City (81,100 tons, 12%). Together, these three cities accounted for 42% of the total recycling volume of cleaning teams. Kaohsiung City (62,800 tons, 9%), Taipei City (58,300 tons, 8%), and Tainan City (52,700 tons, 8%) brought the six largest cities' contribution to approximately 67% of the nationwide recycling volume for 2023.

Table 1 presents the revenue data from recycling sales for 2022 and 2023, as reported by local environmental protection bureaus and uploaded to the HWMS. Total revenues were approximately NT\$749 million in 2022 and NT\$683 million in 2023. Among these, New Taipei City reported the highest revenue, exceeding NT\$200 million in both years, accounting for over 40% of the total revenue. Taichung City followed, with revenue surpassing NT\$100 million in both years, contributing approximately 20%. Revenues from other counties and cities were generally below NT\$50 million.

Table 1 also indicates that recycling revenues in 2023 were generally lower than in 2022

Table 1 Collection volumes and revenues by cleaning teams in cities/counties in Taiwan in 2022 and 2023

Municipality	Collection by cleaning teams in 2022 (kg)	Income from recyclable sales in 2022 (NT\$)	Collection by cleaning teams in 2023 (kg)	Income from recyclable sales in 2023 (NT\$)
Taipei	59,007,100	12,608,052	58,349,790	22,602,014
N-Taipei	112,169,135	309,382,204	125,059,463	263,615,866
Taoyuan	82,419,726	27,911,927	82,398,495	27,897,631
Taichung	79,507,909	134,588,963	81,050,016	111,366,622
Tainan	51,755,397	21,502,338	52,734,453	18,515,089
Kaohsiung	59,581,122	34,144,390	62,794,995	30,651,807
Keelung	15,279,595	4,865,245	16,518,835	6,147,805
Ilan	14,402,344	24,330,404	15,814,836	7,892,596
Hsinchu	12,819,878	23,097,793	14,044,998	14,826,636
Hsinchu-c	28,957,596	3,530,495	31,213,675	1,557,508
Miaoli	17,778,941	17,853,510	19,355,091	19,563,903
Changhua	18,446,421	30,615,732	22,596,898	37,504,325
Nantou	10,434,364	22,365,672	10,639,540	28,084,714
Yunlin	18,312,602	17,392,775	21,578,526	15,311,444
Chiayi	16,369,905	19,095,727	17,071,088	19,776,559
Chiayi-c	9,725,772	1,231,977	10,582,038	151,349
Pingtung	2,520,897	11,047,359	3,686,818	10,692,837
Hualien	11,897,500	26,770,414	12,618,340	29,681,105
Taitung	11,850,305	1,234,098	14,371,562	607,530
Penghu	7,761,099	763,184	9,859,901	10,072,751
Kinmen	12,429,318	4,708,138	12,382,672	12,928,559
Lienjiang	1,268,630	0	1,410,288	0
Total		749,040,397		682,993,550

for most municipalities, despite recycling volumes not declining. This revenue reduction is attributed to lower recycling prices in 2023 compared to 2022. Additionally, in some counties, centralized outsourcing was replaced by individual district-level outsourcing, resulting in price reductions. Conversely, certain counties transitioned from district-level outsourcing to centralized government contracts, which also led to decreased prices.

5.3 Revenue generated by organizations other than cleaning teams (Assessment point 2)

In addition to municipal cleaning teams, the first-line actors in the collection market include communities, schools, institutions, individuals, and independent operators (hereinafter referred to as non-cleaning teams).

Non-cleaning team recycling volumes were approximately nine times that of municipal cleaning teams. The most significant difference was in wastepaper recycling, where cleaning teams collected approximately 137,700 tons, while non-cleaning teams collected 2.705 million tons

Table 2 Collection volumes and revenue by non-cleaning teams in cities/counties

Municipality	Collection in 2022 (tons)	Revenue from recyclable sales in 2022 (NT\$)	Collection in 2023 (tons)	Revenue from recyclable sales in 2023 (NT\$)
Taipei	449,098	95,959,004	589,359	228,290,459
N-Taipei	933,678	2,575,250,561	958,126	2,019,656,963
Taoyuan	689,107	233,369,509	650,361	220,192,507
Taichung	852,367	1,442,863,979	868,279	1,193,057,126
Tainan	539,428	224,112,986	550,775	193,377,338
Kaohsiung	842,456	482,790,844	885,705	432,334,754
Keelung	103,236	42,214,641	103,973	50,656,880
Yilan	91,253	145,303,177	96,363	46,041,638
Hsinchu	151,952	243,699,448	147,583	138,361,183
Hsinchu-c	103,236	30,757,399	129,570	14,042,058
Miaoli	112,692	156,937,648	89,229	124,291,047
Changhua	313,220	331,150,617	320,283	384,831,258
Nantou	99,480	125,144,382	109,778	159,290,583
Yunlin	122,235	115,255,783	130,294	88,285,980
Chiayi	109,721	200,805,272	111,838	207,882,183
Chiayi-c	70,660	11,216,591	78,648	1,207,243
Pingtung	180,657	108,981,996	183,628	90,993,438
Hualien	73,021	200,987,639	75,117	210,692,455
Taitung	42,973	3,239,671	42,367	1,507,767
Penghu	21,465	6,498,252	20,352	55,603,675
Kinmen	4,242	1,607,040	4,275	4,463,462
Lienchiang	1,166	0	863	0
Total		6,778,146,439		5,865,059,998

*Note: "Non-cleaning Teams" refers to entities outside of government sanitation departments, including community organizations, schools, institutions, and individual operators (independent traders).

in 2022, a difference of 20-fold.

In 2023, non-cleaning team recycling volumes remained nine times higher than those of cleaning teams. The most significant disparities were observed in wastepaper, aluminum containers, other metal products, dry batteries, lead-acid batteries, and edible oils, with differences ranging from 19-fold to 49-fold.

Among non-cleaning teams, the largest contributors to recycling volumes were communities (45% of the total) and institutions (44%), followed by registered individual operators (10%). Schools accounted for the smallest share at just 1%.

Due to the lack of actual sales volume and pricing data for non-cleaning teams, the evaluation references the revenue of municipal cleaning teams based on their corresponding recycling volumes. A linear estimation is used to approximate the revenue for non-cleaning teams, calculated as follows:

$$\begin{aligned} & \textit{Estimated revenue for non-cleaning teams} \\ &= \textit{Collection volume of non-cleaning Teams} / \textit{collection volume of cleaning teams} \\ &\times \textit{revenue of cleaning teams} \end{aligned}$$

The evaluation results are shown in Table 2. The estimated recycling revenues for non-cleaning teams are approximately NT\$6.778 billion for 2022 and NT\$5.865 billion for 2023

5.4 Collection revenue for traders

(1) Collection revenue for traders (Designated EPR Recyclables) (Assessment point 3)

For designated recyclable items, the evaluation of recycling revenues for traders relies on the following data sources:

- Quantity: Data from the Resource Recycling Management System (RRMS) on the material processing volume for each item.
- Pricing: Data primarily obtained from on-site price surveys conducted in commissioned audit and certification reports from the Resource Recycling Fund Management Committee (RRMC) over the years.

Table 3 summarizes the estimated revenue from recycling transactions for traders, based on RRMS data. The estimated transaction values are approximately NT\$7.58 billion for 2022 and NT\$8.39 billion for 2023.

(2) Collection revenue for traders (non-designated recyclables) (Assessment point 4)

Using secondary data on quantity and price (e.g., Recycling Fund statistical reports, market price surveys commissioned by the Resource Circulation Agency, industry association data, publicly available market price platforms, and news reports), the estimated transaction values for traders in the collection market for the additional 5+6 items are presented in Table 4.

The estimated values are approximately NT\$35.85 billion for 2022 and NT\$36.83 billion

Table 3 Collection revenue from trading designated recyclable EPR items

Category	Items	Estimated Value in 2022 (NT\$ million)	Estimated Value in 2023 (NT\$ million)
Waste electrical and electronic equipment	LCD TVs, computers, portable computers, printers, air conditioners and heaters, washing machines, refrigerators, electric fans, TVs, keyboards, monitors	3,263.60	3,845.16
Non-plastic waste containers	glass containers, aluminum containers, iron containers, aluminum foil packs, pesticide containers-plastic, paper containers	818.66	840.50
Waste plastic containers	PET, PVC, PP/PE, foamed/unfoamed PS, organic plastic containers, flat containers (PET or PVC), other waste plastic containers	1,183.34	1,247.74
Waste motor vehicles	Car scrap	675.06	666.74
Waste lighting sources	LED lighting, incandescent bulbs, fluorescent bulbs built into the ballast, (non-) straight tube fluorescent lamps, high-intensity lighting, compact lighting, ring tube fluorescent lamps	2.81	2.76
Waste lead-acid batteries	lead-acid batteries, special lead-acid batteries	676.53	861.92
Waste dry-cell batteries	Waste dry-cell batteries	56.22	49.42
Waste tires	tires, waste tires	904.04	875.48
Total		7,580.26	8,390.22

for 2023. Among these, wastepaper accounted for over 20% of the total transaction value, while other metal products represented over 75%, with the combined proportion of these two categories exceeding 95%.

Therefore, for subsequent reuse market surveys, the focus will be on wastepaper and scrap metal, as they are representative of the broader categories.

Table 4 Collection revenue from trading non-designated recyclable items

	Collection by local organizations (tons) in 2022 (A)	Ave. Price range (NT\$/kg) (B)	Estimated sale value in 2022 (NT\$) (C = 1000A × B)	Collection by local organizations (tons) in 2023 (D)	Estimated sale value in 2023 (NT\$) (E = 1000D × B)
Wastepaper	2,843,095	2.75	7,818,511,250	3,044,123	8,371,338,250
Metal products	1,136,838	24	27,284,112,000	1,157,681	27,784,344,000
Plastic products*	160,232	1.25	200,290,000	163,121	203,901,250
Cooking oil	13,503	35	472,605,000	11,343	397,005,000
Glass products	18,530	0.75	13,897,500	15,689	11,766,750
Styrofoam for packaging	11,575	0	0	9,805	
Discs	2,939	12	35,268,000	2,922	35,064,000
Mobile phones and chargers	1,512	15	22,680,000	1,580	23,700,000
Total			35,847,363,750		36,827,119,250

5.5 Processing Market (Assessment point 5)

The processing market primarily involves transactions between processors handling designated recyclable items and regenerated-material-utilization manufacturers. For the non-EPR items, since the manufacturers themselves often act as processors, the processing stage is integrated into the material-utilization process. Consequently, the evaluation of the processing market value focuses on designated recyclable items.

According to the Recycling Fund Important Statistical Reports, the audited revenue from processors handling designated recyclable items reached NT\$16.728 billion in 2022 and NT\$18.623 billion in 2023 (Table 5). Of this, approximately 65% came from sales revenue generated by processors, while the remaining 35% was derived from Recycling Fund subsidies. Among processors, the highest revenue proportions came from waste plastic containers and waste electronics, each accounting for approximately one-quarter of the total revenue.

Table 5 Revenue for processors of Designated Recyclables (2022–2023)

(Unit: NT\$ thousand)

Year	Revenue Source	Waste Plastic Containers	Waste Motor Vehicles	Non-Plastic Waste Containers	Waste Electronics	Waste IT Equipment	Waste Lead Batteries	Waste Tires	Waste Lighting	Waste Dry Batteries	Total
2022	Sales Revenue (A)	1,761,578	3,438,132	676,235	2,266,800	119,929	178,899	2,481,856	4,129	1,021	10,928,578
	Subsidy Revenue (B)	685,278	965,702	1,314,351	1,508,374	498,693	450,232	76,764	85,511	214,475	5,799,380
	Total (A + B)	2,446,856	4,403,833	1,990,586	3,775,174	618,622	629,131	2,558,621	89,640	215,496	16,727,958
2023	Sales Revenue (A)	1,728,582	2,887,930	613,735	2,949,936	158,877	158,154	3,874,714	4,591	7,816	12,384,334
	Subsidy Revenue (B)	816,213	1,026,524	1,311,945	1,670,918	529,959	464,843	88,809	129,880	199,168	6,238,259
	Total (A + B)	2,544,794	3,914,454	1,925,680	4,620,854	688,836	622,997	3,963,522	134,471	206,985	18,622,593

Data Source: Recycling Fund Important Statistical Reports.

5.6 Regenerated-Material-Utilization Market (Assessment point 6)

The assessment of the regenerated-material-utilization market's output value can utilize secondary data evaluation and be supplemented with questionnaire surveys. This project specifically conducted an output value assessment at this stage using questionnaire surveys. Given that Table 4 indicates that the paper and metal waste categories account for more than 95% of market transaction volumes, and as evidenced by the results from previous projects, the utilization market output value for paper and metal waste contributes approximately 46% of the total output value across all stages of the resource recovery industry. Due to the significant

representation of these categories, the project focused primarily on conducting questionnaire surveys for the paper and metal waste categories (Figure 3).

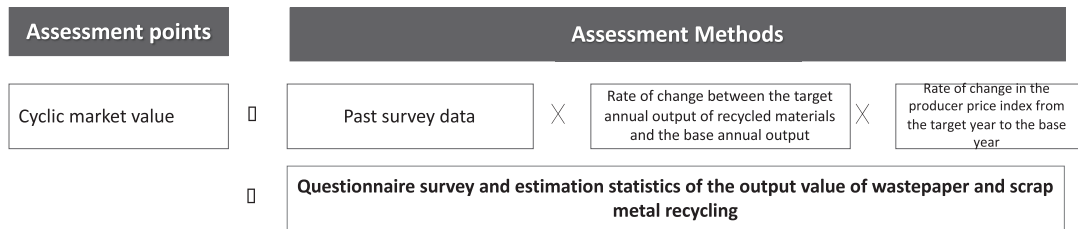


Figure 3 Methods for assessing the regenerated-material-utilization (cyclic) market

Survey target identification, sampling methods, and survey process

This output value assessment targeted specific resource recovery and recycling businesses, employing judgment sampling rather than random sampling. Judgment sampling involves the selection of samples based on the researcher's or field experts' judgment regarding their representativeness. This approach ensures that the selected samples are sufficiently representative of the target population, enabling valid inference. Common applications of judgment sampling include compiling price indices, where items are chosen based on their market significance rather than randomly, which could be time-consuming and inefficient.

This project identified survey targets through various sources, including businesses registered under the Four-in-One Resource Recovery Policy, relevant certified entities, recycling operators traced through the Environmental Protection Agency's Resource Recycling Management Information System, county and city governments' published lists of reuse companies, industrial associations in the paper and metals sectors, and databases of prominent corporations.

Key components of the questionnaire (paper and metal)

The questionnaire encompassed the following:

1. **Basic Company Information:** The questionnaire collected data on company name, contact information, respondent's job title, capital structure, industry type, company age, and scale to facilitate cross-sectional analyses.
2. **Transaction Data in the Market:** For the reuse market, the output value assessment was built upon the following formula:

$$\begin{aligned} & \text{Proportion of regenerated Material Costs (\%)} \times \text{Production Quantity (units)} \\ & \times \text{Average Product Price (NT\$/unit)} \end{aligned}$$

Accordingly, the survey sought to determine the company's role in the resource recovery chain, the production or usage volume of recycled materials, the average sales price, and the proportion of domestic recycled material procurement in the company's total material costs.

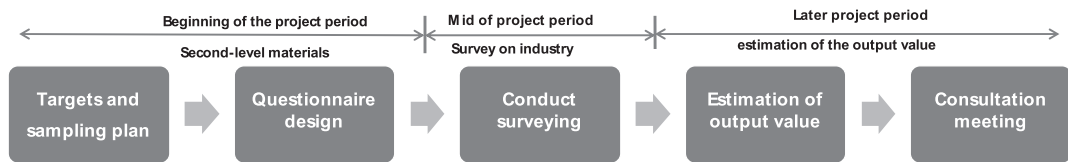


Figure 4 Surveying process for the regenerated-material-utilization (cyclic) market

Questionnaire Distribution and Response Rates

To ensure representativeness in terms of sample size, the project conducted a census survey by distributing questionnaires to all identified reuse operators. For paper and metal waste, 1,200 questionnaires were issued, exceeding the minimum requirement of 1,000 responses stipulated by the project. For paper waste, outreach extended to paper box and product manufacturers in addition to primary recycling operators, resulting in 725 contacted businesses and 176 valid responses. For metal waste, the survey targeted manufacturers of basic metals and metal processing industries, with 475 contacted businesses and 75 valid responses.

The survey employed rigorous screening criteria. Invalid responses were excluded for reasons such as respondents not using recycled materials, relying on recycled materials derived solely from industrial waste, or not being manufacturers. Effective responses were collected from leading domestic paper and steel companies, which are the major contributors to the reuse market’s output value.

Estimated Output Value of Wastepaper Reutilization (Assessment point 6-1)

The survey collected responses from 176 businesses involved in the reutilization of wastepaper, including major domestic paper mills, downstream manufacturers, and recycled sanitary paper producers. The production of recycled products such as corrugated board, industrial paper, and recycled packaging paper formed the basis of the output value estimation. Due to the oligopolistic nature of the domestic paper industry, the output value estimation avoided extrapolations to the entire population to prevent overestimation.

Using collected data on production volume and price or sales revenue, the output value estimation employed either one of the following formulas:

1. Formula 1:

$$\begin{aligned} & \text{Proportion of Domestic Recycled Material (\%)} \times \text{General Waste Contribution (\%)} \\ & \times \text{Production Quantity (units)} \times \text{Average Product Price (NT\$/unit)} \end{aligned}$$

2. Formula 2:

$$\begin{aligned} & \text{Proportion of Domestic Recycled Material (\%)} \times \text{General Waste Contribution (\%)} \\ & \times \text{Annual Sales Revenue (NT\$)} \end{aligned}$$

The total value of recycled paper-related activities for these enterprises in 2022 and 2023 was approximately NT\$51.147 billion and NT\$55.900 billion, respectively. The standard deviations of the collected survey samples were NT\$2.827 billion (2022) and NT\$3.079 billion (2023). Using the interval estimation formula, the 95% confidence intervals for this survey were calculated as NT\$45.607 billion–NT\$56.688 billion (2022) and NT\$49.866 billion–NT\$61.934 billion (2023).

Table 6 Revenue for manufacturers utilizing wastepaper (2022–2023)

Wastepaper	2022	2023
Total output value (NT\$)	51.1 billion	55.9 billion
Standard deviation	2.827 billion	3.079 billion
95%confidence intervals	45.6 to 56.7 billion	49.8 to 61.9 billion
Estimation interval formula	total output value $\pm$ 1.96 * sample standard deviation	

Estimated Output Value of Waste Metal Reutilization (Assessment point 6–2)

For metal waste, responses were collected from 75 companies, including major steel mills and metal processors. The reuse of metal waste involves producing products such as steel, aluminum alloys, and copper alloys. Given that over 80% of recycled metal waste involves ferrous metals and that the domestic steel industry is oligopolistic, the estimation avoided extrapolation to the total population.

The total value of recycled metal-related activities for these enterprises in 2022 and 2023 was approximately NT\$14.778 billion and NT\$12.830 billion, respectively. The standard deviations of the collected survey samples were NT\$0.380 billion (2022) and NT\$0.379 billion (2023). Using the interval estimation formula, the 95% confidence intervals for this survey were calculated as NT\$14.033 billion–NT\$15.523 billion (2022) and NT\$12.088 billion–NT\$13.572 billion (2023).

Table 7 Revenue for manufacturers utilizing regenerated metal (2022–2023)

Scrap metal	2022	2023
Total output value (NT\$)	14.8 billion	12.8 billion
Standard deviation	380 million	379 million
95% confidence intervals	14.0 to 15.3 billion	12.1 to 13.5 billion
Estimation interval formula	total output value $\pm$ 1.96 * sample standard deviation	

6. Conclusions

Taiwan's approach, integrating various stakeholders such as local cleaning teams and recycling processors, aligns with findings from the Ellen MacArthur Foundation (2019), which underscores the economic and environmental gains achievable through collaborative and

systemic recycling strategies.

Break-down of the value chain:

The resource recovery value chain can be divided into three stages: collection, treatment, and reuse. This project evaluated the transaction scale of the recovery market, treatment-reuse market, and other components based on data from the Environmental Protection Administration (EPA). Using secondary data (e.g., the recovery market and treatment market of announced recoverable items) and survey questionnaires (e.g., for wastepaper and scrap metal reuse market players), the findings are as follows:

- The estimated market value of domestic general waste recovery in 2022 (collection stage) was approximately NT\$50.965 billion, with the processing and reutilization stage valued at NT\$90.011 billion, amounting to a total resource recovery market value of NT\$140.966 billion.
- For 2023, the collection stage was valued at approximately NT\$51.765 billion, while the processing-reutilization stage reached NT\$96.602 billion, summing up to a total market value of NT\$148.367 billion.

In addition to the market values, there are also significant macroeconomic impacts from Taiwan's resource recovery policies. In 2022, central and local governments allocated a total of NT\$15.51 billion for general waste management policies. Using input-output (IO) modeling and adjusting for inflation rates, this expenditure was estimated to stimulate NT\$44.127 billion in economic output, generate NT\$23.439 billion in GDP, and support approximately 20,681 green jobs.

For 2023, government expenditures on similar policies totaled NT\$15.18 billion, stimulating an economic output of NT\$44.262 billion, contributing NT\$23.511 billion to GDP, and creating approximately 20,744 green jobs.

Advancing Economic Valuation of the Resource Recovery Industry

From our analysis, continued evaluation of the economic impact of waste recovery will facilitate policy advocacy, social communication, and international exchange. However, future assessments of reutilization market values could prioritize secondary data analysis over survey-based methods to optimize resource efficiency. Furthermore, collaboration with technical innovation sectors, such as textiles or material sciences, could help transform recycling efforts (e.g., moving beyond second-hand use or down-cycling of regenerated materials).

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