Waste Audit of Craft Villages in Urban Vietnam: A Case Study of Trung Van Plastic Recycling Craft Village, Hanoi City

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Abstract.

Plastic waste is one of the world's most pressing human health and environmental concerns. Globally, plastic is the third highest waste source, with the total volume rowing in-line with increases with economic development. Vietnam is a fast growing nation with high rate of urbanization tracking global trends in both generation and consumption of plastic waste. These elements create a number of major challenges for the country's waste management system, especially in urban areas. This study uses waste reduction audit method to assess the emission levels of municipal waste, wastewater and greenhouse gas (GHG) of four types of plastic collection and recycling in plastic craft village Trung Van, Hanoi city. The results show that, solid waste arising from four types ranges from 17-102 kg/1 ton of finished products of each type, in which primary collection and secondary collection generates less than the other two types. For primary and secondary recycling, it also generates wastewater and GHG, of which primary recycling generates 139kg CO2e/1 ton of waste plastic and secondary recycling generates 375 kg of CO2e/1 ton of plastic products. The results of the study are an important basis for proposing solutions to reduce material and energy losses as well as reduce waste generation in recycled plastic production activities in craft villages in Vietnam.

Keywords. Plastic recycling, Waste audit, Craft village, Municipal solid waste, Green house gases, Urban area, Pollution, Hanoi, Vietnam.

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INTRODUCTION

Under the influence of the Renovation process *(Doi moi)*; Vietnam has made remarkable developments in all aspects. The country's economy is maintaining a high growth rate and is built towards industrialization and modernization. Industrial development is the basis for the process of urbanization to be accelerated. According to statistics, as of December 2021, Vietnam has 820 urban areas, with an urbanization rate of 35.2%. In which, there are 2 special urban areas, Hanoi and Ho Chi Minh City [10, 17]. Currently, urban areas in Vietnam have uneven development across regions and large disparities between different regions in terms of geographical characteristics.

Along with the process of urbanization, urban environmental pollution has also increased significantly, causing negative impacts on socio-economic development and community welfare [1, 3].

The National Environmental Report for 2021 published by the Ministry of Natural Resources and Environment (MONRE) shows that most urban areas in Vietnam lack centralized wastewater collection systems and treatment stations; the percentage of green land and parks is very low. In addition, urban Vietnam is also emerging some outstanding environmental problems such as air pollution, water degradation, waste pollution and climate change impacts [18].

In urban areas of Vietnam, craft villages are an important part of socio-economic development, helping to create jobs, increase incomes, and improve living standards for local people. However, they are also important points of environmental pollution today. Among which, scrap recycling craft villages are one of six typical types of production villages. Although it is a type of production that has not been established for a long time and accounts for only 7% of the total number of craft villages, these craft villages have grown rapidly in both scale and type of recycling like metal, paper and plastic [5].

As a type of production in the craft villages, plastic recycling is understood as the activity of using plastic utensils such as plastic cans, plastic bottles... from the waste stream as raw materials for production new plastic products. The basic feature of plastic recycling craft villages in Vietnam is that they often operate on a household scale, focus on groups and have a long tradition. In addition, production technology is manual, input materials are mostly untreated scraps, and most production facilities do not have measures to control pollution, waste treatment and necessary labor protection. Therefore, despite the small number, plastic recycling craft villages have been causing many serious environmental problems [6, 7].

This study is based on the waste audit methodology to quantify solid waste, wastewater and greenhouse gases of each type of production in Trung Van recycling craft village, Hanoi city to determine the norms of material consumption, chemicals and energy, on that basis, propose appropriate mitigation solutions for each type of collection and recycling in Vietnamese craft villages.

METHODOLOGY AND DATA COLLETION

Waste audit method

Waste audit is the systematic and comprehensive review and assessment of the effectiveness of waste management and pollution control of production, business and service establishments. Accordingly, waste audit is seen as a tool to provide information about the environment. The audits are used as the basis for assessing the likelihood of environmental risks posed by the business, its environmental obligations, as well as the level of satisfaction with environmental standards or laws [9, 13].

The study used the waste accounting process proposed by UNIDO (2008) and includes a number of specific steps as shown in Figure 1. Some main contents of a waste audit are presented below:

Categories and weighing

The units surveyed for audit in this study are plastic recycling households in Trung Van craft village, Hanoi. First, input and recycled plastic samples will be collected at each household. Following collection, sampled waste was separated into major material classes andweighed.

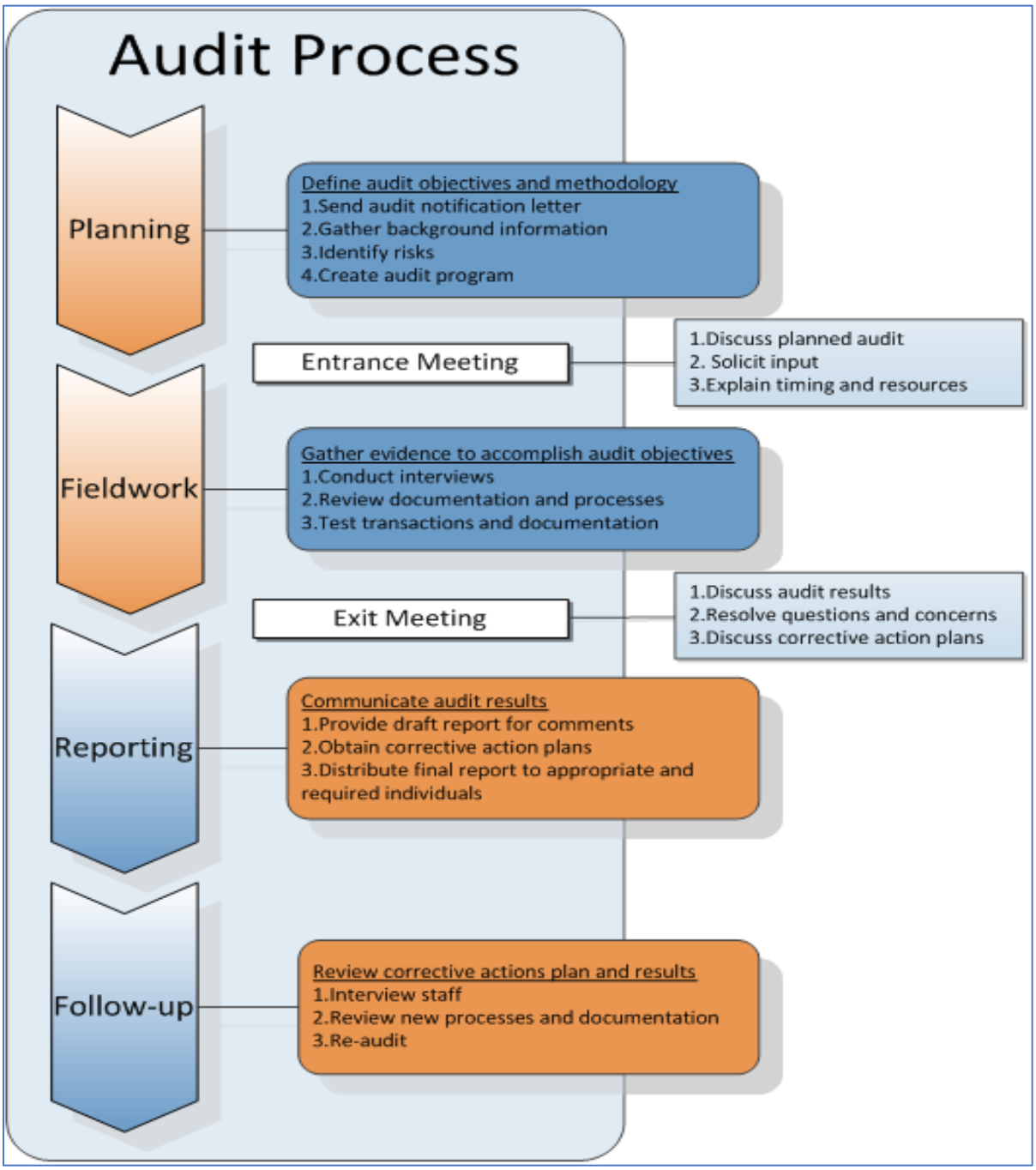

Figure 1. Waste audit process in the study

Source: Audit results (2022)

Dosing by weight and categorizing by category were chosen to allow for an examination of current waste management practices in Vietnam (i.e. recyclables identified in the recycling program) as well as alternatives disposal (i.e. recycled materials). Quantification by weight can also estimate the accuracy of the final design of the waste sent to the landfill by weight. For the purposes of this study, which was designed to assess current waste, wet

weight (on receipt) was considered sufficient to provide waste management guidance and all possible values were count. The nature of sampling prevents long-range movement of moisture due to weather conditions and mixing with other wastes [14, 16].

Two main statistics were used to analyze the collected waste and user data as a whole: (1) coefficient of variation (CVar) and (2) analysis of variance (ANOVA). Data analysis was performed using spreadsheet and Microsoft Excel statistical software. The coefficient of variation is used to examine the impact of the number of users on the type and amount of waste generated and finally to determine the appropriateness of extrapolation of total waste from the data per recycling household for active areas [7, 9].

Data on two variables, daily waste collected and waste recycled per household, are collected for operational areas. The coefficient of variation is used to compare data sets (daily decrease versus per-user reduction) and determine which dataset changes the most. It is expected that, in most cases, determining the amount of waste recycled by each household during each sampling period will reduce the variability of sampled waste. An extrapolation based on each household's would then provide a way to account for the variation over time of the drop.

All data are subject to one-way ANOVA to determine if the recycled waste per family is significantly different from the average level of the area(95% confidence interval). Sample waste is considered to have a normal distribution as Carruth & Klee (1969) showed that when a component makes up more than 30-70% of the waste stream, the waste follows a slightly normal distribution. To test for equal variances, the F-statistic (test for equal variances) was used where appropriate. Bartlett's test is also used to test for equal variances on the data set [22, 23].

If the average value of recycled waste per family from the operational areas differs significantly, an initial sampling plan for the different processes will be supported. These results indicate that familiesrecycle different types/amounts of waste depending on the activity. A per-family average number should be used for comparisons as using daily totals will skew the results.

Finally, for those households with no user-related data (e.g. greenhouses), ANOVA was performed to determine if there were significant differences between waste vehicles generated on different sampling dates or not. Since a different method of extrapolation will be required for these areas, e.g. number of days of operation, it must be determined whether the waste varies according to the day of the week [18, 21].

The final estimate of the total amount of waste and the standard deviation is given by the following formula:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Where $x_i$is the value of waste samples taken from each family. This comparison allows validation of the planning method.

Estimated greenhouse gas emissions from recycling

To calculate greenhouse gas emissions from electricity consumption, the study applies the formula of Bilan Carbon [5]:

Electric ECO2e = Melectricity x Efelectricity x line loss factor

In there:

Electric ECO2e: CO2e load generation when consuming electricity (kg CO2e)

Electricity: The amount of electricity used for production activities of the establishment (kWh)

Efelectricity: CO2e emission coefficient of Vietnam's electricity grid

Efelectricity = 0.9130 (tons of CO2e/MWh)

Line loss factor = 1.08

Data collection

Research and survey activities of households collecting and recycling plastic in Trung Van craft village to collect information related to local socio-economic conditions; information on the current status of plastic collection and recycling; local environmental management activities; information about the recycling process, the amount of input materials, the amount of waste generated from plastic recycling. The study conducted surveys, interviews, and field surveys at plastic recycling facilities to have accurate and complete additional assessments and assessments on environmental issues and environmental risks, as well as the effectiveness of the project of applied technical solutions.

The number of interview survey samples was determined according to the following formula:

In there:

$$n = \frac{N}{1 + N \times \varepsilon^2}$$

n: survey sample size

N: total number of households in the craft village

e: acceptable error level (e = 0.05)

With a population of 328 recycling households in the village, there were 85 households surveyed to collect primary data in the official survey taken place from July to August 2022 at Trung Van recycling craft village, Hanoi.

STUDY RESULTS

Municipal solid waste flow in Hanoi, Vietnam

In Vietnam, as in many other developing countries, municipal solid waste during festivals is either removed by private collection companies and sent directly to landfill or sorted at source for recycling (Figure 2). Recyclable waste is (1) collected by scavengers and waste collectors, or (2) sent by waste generators to private or non-profit recycling centers before being transported to recycling plants through traders. However, landfilling is the preferred form of solid waste disposal in Vietnam: 45% of the material goes to landfill. This high rate is due to the low cost of this form of waste treatment. A major problem with disposing of plastics through waste management is that unlike biodegradable paper and food waste, plastic does not leave the environment permanently. Plastics take hundreds to thousands of years to break down into smaller pieces of plastic, also known as micro plastics (i.e. plastics less than 5 mm in length). As a result, plastic will accumulate on the Earth and reduce the land area while contributing to an almost irreparable pollution of the natural environment.

Due to rapid population growth and impact on consumption patterns, existing landfills are already at full capacity. The identification of sites for additional landfills is complicated by land scarcity and potential environmental impacts. The total amount of waste generated in Vietnam can be significantly reduced by recycling plastic waste and using materials of potential economic value, but little attention has been paid to alternative waste treatment methods [14, 15].

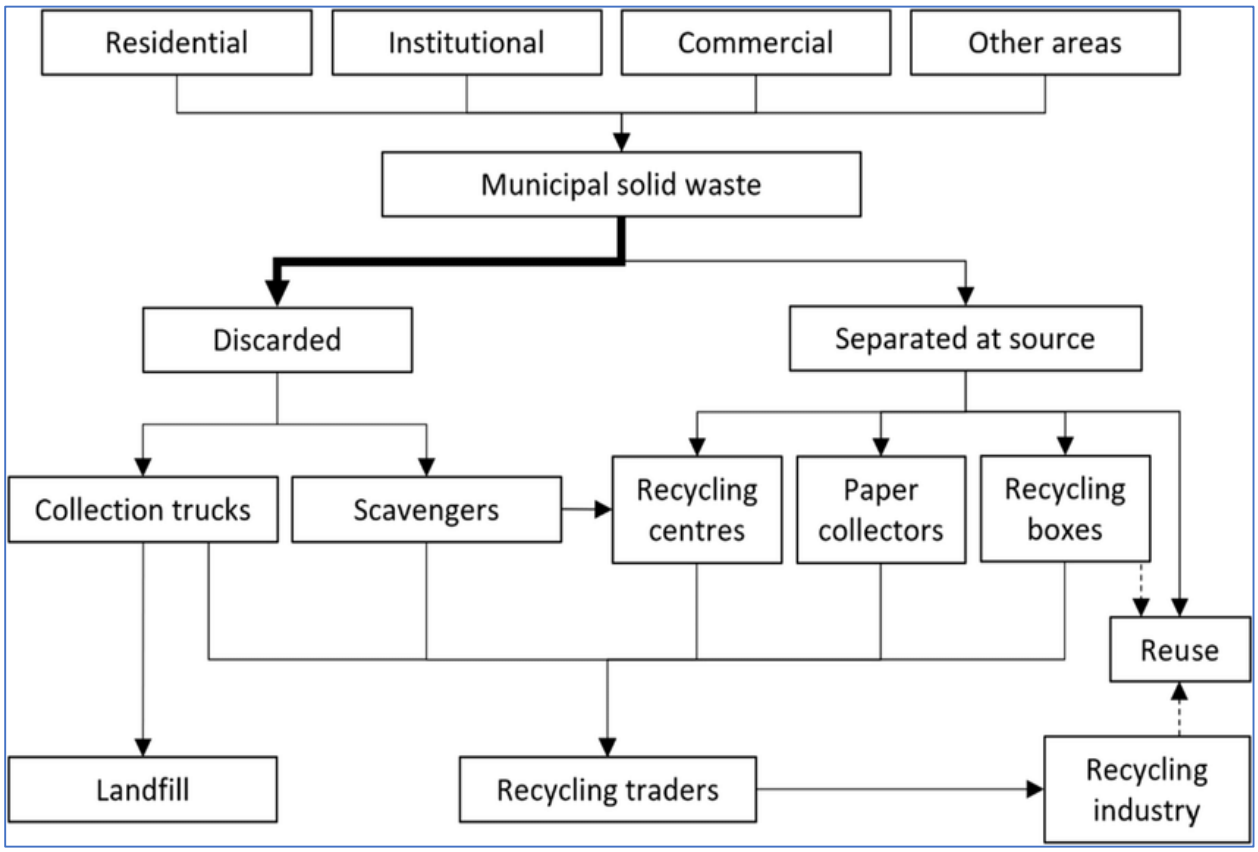

Figure 2. Waste flows in Hanoi city

Source: Audit results (2022)

In Vietnam, most municipal solid waste is disposed of in both sanitary and unsanitary landfills, and there is very little post-consumer plastic recycling in Vietnam. In some jurisdictions, post-consumer plastics are sorted at source and collected by private disposal companies paid for by the city government. However, these amounts are very small compared to the total amount of plastic in the waste. Urban collection initiatives or "*dong nat*" also play a role in collection in Vietnam. Recyclable plastics are also provided directly to industry plastic recyclers, by waste collectors and by consumers through charities and grocery stores, although there are few data on the total quantity and type of plastic [9, 11].

Plastic collection and recycling activities in Trung Van craft village

The survey results show that the average amount of plastic collected and recycled in Trung Van is 140 tons/day. Most of the plastic scraps that are collected and recycled are most commonly used plastics such as HDPE, PET, LDPE, PP, PVC, PS; of which the amount of HDPE used and collected is 40.5 tons, accounting for 28%, followed by PP plastic is 35.5 tons, accounting for 24%, PET plastic is 20.7 tons, accounting for 13.5%, LDPE plastic is 9.5 tons, accounting for 7.7 %, PVC is 5.4 tons, accounting for 3.8%. Other plastics such as PS, PA, ABS makes up a 23% percentage (Figure 3).

The number of households participating in plastic collection and recycling activities in Trung Van is now 328 households and has increased significantly compared to 2015. Plastic collection and recycling activities in this craft village have 4 main types: Primary

collection, secondary collection, primary recycling and secondary recycling, in which plastic recycling primary is performed more than other activities (43.5%). In collection activities, secondary collection accounts for 36.4% while primary collection accounts for 19.5%, very few households have secondary recycling activities.

Plastic collection and recycling activities in Trung Van craft village form a production chain that supplies recycled plastic to the locality and surrounding areas. In there:

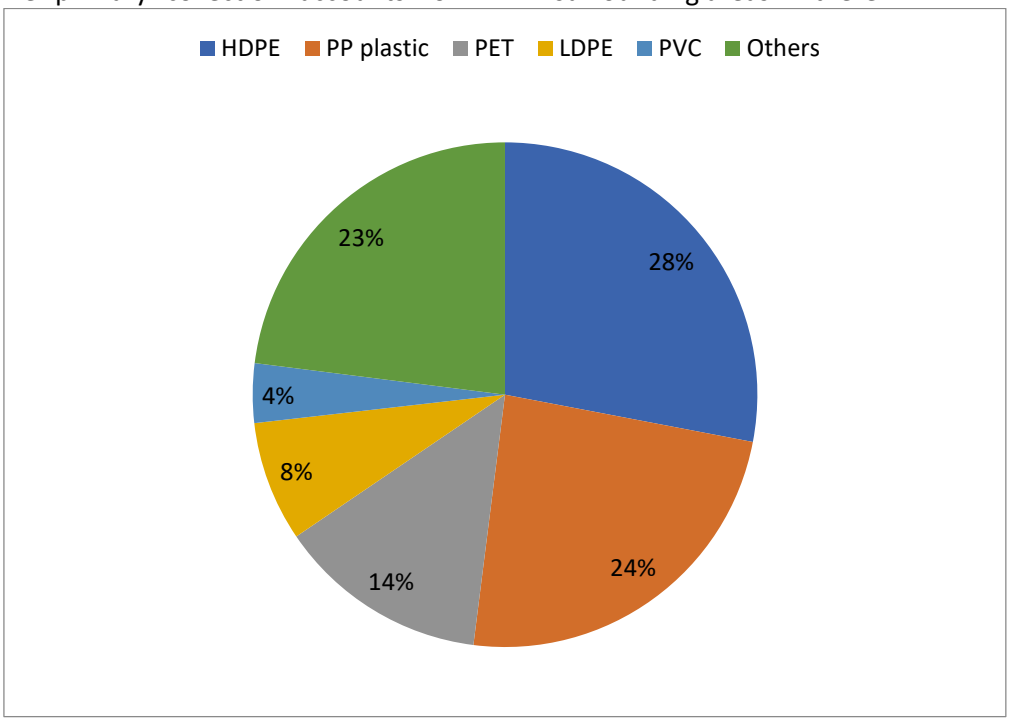

Figure 3. Percentage of plastic components collected

Source: Audit results (2022)

Type 1 (Primary collection): Including establishments that only collect plastic from households, small scrap collectors and resell scrap plastic to other businesses without incurred other activities such as sorting plastic, removing labels on plastic.

Type 2 (Secondary collection): Includes households and establishments that collect scrap at primary collectors in craft villages and other areas in the city. Then sort the plastic scrap and resell the plastic after sorting to other business establishments.

Type 3 (Primary recycling): Includes production households that conduct waste collection activities from secondary collectors in the craft village and from a number of other establishments in the city. After that, pre-processing activities (sorting, cleaning scrap, plastic grinding, drying, granulating) are carried out. The final products created by these producers are plastic particles. These products will be sold to other establishments responsible for processing and forming other products such as plastic bags, chairs, etc.

Type 4 (Secondary recycling): Includes production households that produce recycled plastic products according to the stages. The end products of this type are fully recycled plastic products including: plastic bags, chairs, plastic tables and cups (Figure 4).

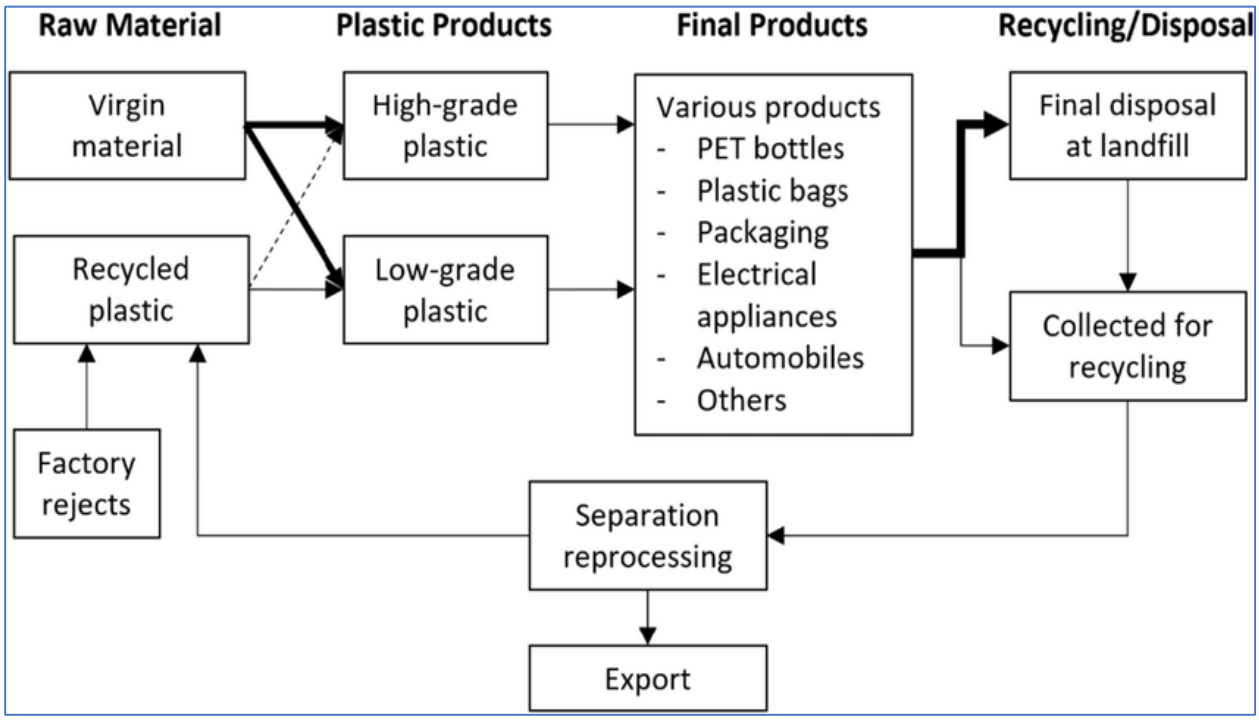

Figure 4. Characteristics of types of plastic collection and recycling in Trung Van

Source: Audit results (2022)

Through surveying in production households in craft villages, the study determined the level of fuel used by each type (Table 1).

Table 1. Norms of fuel used to make one ton of finished products

No	Type of production	Input raw materials	Unit	Usage norms/1 ton of finished product
1	Primary collection	Plastic scrap	ton	1.029
2	Secondary collection	Plastic scrap	ton	1.07
3	Primary recycling	Plastic scrap	ton	1.05
		Electricity	Kwh	145
		Water	m^3	35.2
		Soap	kg	29.1
4	Secondary recycling	Plastic beads	ton	1.5
		Electricity	Kwh	397
		Water	m^3	3.5

Source: Audit results (2022)

The type of primary and secondary collection is because it only collects scrap, so it does not use energy or chemicals. Primary and secondary recycling uses electricity and water in the washing, crushing and recycling of plastics. The electricity consumption norm for secondary recycling is much higher than for primary recycling (almost 3 times). In contrast, water consumption for primary plastic recycling is

many times higher than for secondary plastic recycling (almost 10 times).

Generation of solid waste from plastic collection and recycling activities

The process of collecting and recycling plastic in Trung Van craft village generates solid waste. These solid wastes are mainly impurities mixed with plastic, soil and sand from the process of grinding, washing plastic, classifying plastic and a part of plastic that is scattered during production and transportation. The amount of solid waste generated per unit of finished plastic of each type of craft village production is presented in Table 2.

Table 2. Solid waste emissions per ton of finished plastic

Type	Incurred stage	Amount generated (ton/1 ton of finished plastic)
Primary collection	Transporting scraps	0.019
Secondary collection	Sorting scrap plastic	0.028
Primary recycling	Sorting scrap plastic	0.185
Secondary recycling	Scrap cleaning	0.112

Source: Audit results (2022)

Depending on the operating characteristics of each type, there are clear differences between the generated wastes. For primary and secondary collection, the amount of waste generated is less than for recycling, mainly scattered during transportation and plastic sorting. The main component of solid waste is dirt that adheres to waste plastic products, plastic shells, packaging covers, stickers, etc. For primary and secondary recycling, the amount of solid waste arises mainly from composting activities. Plastic products purchased from localities other than Trung Van village and residues from the cleaning process of scrap and plastic that are scattered during the production process and lost in the blowing, molding or pressing stages of plastic products.

Generation of waste water from plastic recycling

Collection activities do not generate wastewater in the production stages. In plastic recycling, water is used to clean scraps, cool down engines during crushing, granulation and product manufacturing. Wastewater volume of primary and secondary recycling is 38 m3 and 3.9 m3 respectively. The type of primary recycling with wastewater is mainly generated from plastic washing (92.6%), and plastic crushing (5.8%). Secondary recycling has wastewater mainly engine cooling water (3.9 m3/1 ton of plastic products). This amount of water with high temperature is being discharged directly into the environment.

The amount of wastewater used to wash plastic contains harmful ingredients such as cleaning chemicals and many impurities that stick to the plastic. Currently, there is no centralized wastewater treatment system in Trung Van craft village, so production households discharge industrial wastewater together with domestic wastewater, polluting the water environment in canals in the commune. Without timely wastewater treatment measures, the surrounding households will be affected to their health and daily activities.

Indirect greenhouse gas emissions

Plastic recycling production does not directly generate GHG. However, due to the process of using electricity at the plastic grinding, granulation and primary recycling stages, it can be considered as an indirect contribution to GHG generation. Applying the Bilan Carbon formula combined with the fuel norm data in Table 1, the study has calculated the amount of indirect CO2e emissions from the activities of various types of recycling. Activities of primary and secondary collection are manual collection and classification, so these two types do not

generate GHG. Primary recycling generates 139kg CO2e/1 ton of plastic scrap and secondary recycling generates 384 kg CO2e/1 ton of plastic products. The type of secondary recycling emits GHG 2.8 times higher than primary recycling, but it has a small scale of recycling in the craft village Trung Van. For primary recycling, although there is less CO2e emissions from electricity per ton of finished products than secondary recycling, the scale of this type of recycling accounts for the majority in craft villages (38.4 %). Therefore, the total CO2e emission due to primary recycling is higher than secondary recycling on the whole craft village scale.

Besides, plastic recycling activities also generate gases that pollute the environment such as plastic dust, organic tin.... Production households in craft villages currently do not have exhaust gas treatment systems, so the emissions are not treated before being discharged into the atmosphere. The plastic crusher and granulator system in the craft village is old and not regularly maintained and repaired, creating noise and plastic smell when processing. This emission is also one of the main causes of air pollution in the area of Trung Van craft village.

DISCUSSIONS

In all four types of plastic collection and recycling in Trung Van craft village, solid waste is generated that is labels, metal parts, rubber, plastic scrap input at the stage of sorting, cleaning or plastic waste released during grinding and drying. Due to the different characteristics of the types of collection and recycling in Trung Van, solutions need to be suitable for each type.

For primary and secondary collection, solid waste generation rates are 1.9% and 3.2%, respectively. This rate is not high as the waste is mainly non-recyclable scrap plastic after sorting at the purchasing establishments to resell the sorted plastic to recycling business establishments. This amount of solid waste needs to be collected thoroughly in the craft village for treatment according to regulations.

For primary recycling, the solid waste generation rate is 18.8%, which is quite high compared to the national average. The average solid waste generation rate of wet-machined primary plastic recycling in Vietnamese craft villages is about 10%. Waste is often generated by the sorting process of scrap plastic purchased from other localities outside the village and by the cleaning process of scrap plastic, plastic that is scattered during the production stage and lost during the granulation process.

In addition, the input materials of the granulation process have impurities that lead to the blockage of the filter mesh during the plastic extrusion process and the semi-finished plastic must be discarded. o minimize losses, it is necessary to pay attention to solutions such as: Sorting scrap and using less impregnated scrap plastic treatment before entering the production line; Clean the factory to recover the plastic pieces dropped in the production process; The design of the crusher's cap size is suitable to shield the splash of plastic particles into the environment; Use filter cloth bags with small mesh size in the drainage system of plastic washing tanks so that when discharging the water, the waste plastic does not flow with the waste stream into the environment...

Another direction is that it can be recycled separately each type of plastic to ensure uniform resin quality and easy pollution control. While the world's trend is to switch to using eco-friendly biodegradable plastic packaging, many Vietnamese plastic manufacturers have not yet switched to producing these plastic products due to the high cost. Doing these steps well will minimize the use of chemicals in the remaining production process and thus, also minimize the formation of PCDD/PCDF. In good production conditions, one ton of clean plastic scrap input produces about 950 kg of finished plastic particles, so the amount of waste plastic

generated is not much (about 5%) and is put into the crusher for further recycling; so no waste is generated outside.

For secondary recycling, the rate of waste generation is 9.5%. This ratio is at an average level, mainly plastic scraps from the shaping and cutting stages of products and recycled plastic waste (damaged products). Broken semi-finished plastic (from primary recycling) or recycled plastic waste (from secondary recycling) can be resold to scrap plastic recycling production facilities that do not require plastic purity such as: manufacture shoes, belts...

Collection activities do not generate wastewater, while recycling activities (especially primary recycling) generate a large amount of wastewater. This amount of wastewater is mainly generated from plastic washing activities (containing a large amount of detergents and small suspended plastic particles) and cooling of machinery and equipment. However, the production households often do not reuse the water from these activities, but often wash the scrap plastic by pumping - washing continuously, thus generating a lot of wastewater. The 3R principle should always be followed, so it is advisable to carry out a batch plastic wash where water is pumped intermittently in batches and reuse the rinse water from the previous wash for the next wash until no rinsing is done. If more water can be added, new water will be changed and this method can save water in the washing process. For water that is leaking due to a damaged water valve, it is necessary to repair or replace the damaged valve. Production households need to build manholes to collect washing water before discharging into the environment.

For the amount of wastewater to be treated, the distributed wastewater treatment model (in clusters/household) is more suitable for craft villages than the centralized wastewater treatment option because the area of trade villages is usually larger than that of the concentrated wastewater treatment size. The production households should separate the wastewater stream to treat the polluting waste stream before entering the common sewer of the craft village.

For primary recycling, the machinery system is simple and does not consume much electricity compared to secondary recycling. If the above-mentioned solutions to reduce material loss are well implemented, it is possible to reduce the amount of raw materials going into the production stages by 8-10%, which means that the power consumption will also decrease at the rate of 9-10% respectively. In addition, to save energy, production households can install bright corrugated iron panels to take advantage of natural light instead of electricity for lighting, regularly check and maintain the levels.

CONCLUSION AND RECOMMENDATIONS

Waste audit is a form of inspection, review of waste management activities and management system of environmental records/licenses of enterprises. Waste audits include compliance audits and management system audits, aimed at assessing the environmental management of enterprises in reality and under provisions of law.

The study quantified the emissions of four types of collection and recycling in Trung Van. The results have shown that the primary and secondary collection types generate less solid waste than the other two types, but these two types can cause unsightly beauty due to garbage storage and outdoor plastic waste. The two types of primary and secondary recycling produce more emissions in all three types of waste: solid waste, wastewater and greenhouse gases. The study also pointed out cleaner production solutions to reduce emissions and match the current production conditions of Trung Van craft village. The solutions offered include controlling the production process, rationalizing the use of input materials, improving equipment, and recycling reuse. These solutions help to improve the

environment at plastic recycling facilities, in addition to saving costs by making the most of raw materials and reducing waste to the environment.

Over the recent time, Vietnam has actively implemented many solutions to strengthen waste audit for businesses and production facilities to meet practical requirements, in line with international trends and practices. According to the Law on Environmental Protection 2014 of Vietnam, waste auditing is an important management tool to help businesses be aware of the environmental problems that are happening, on that basis, propose measures to prevent and improve the environment effectively. In the National Action Plan for the implementation of the 2030 Agenda for Sustainable Development, waste auditing is an important and breakthrough content in the State Audit Development Strategy to 2030. Some specific solutions to enhance the effectiveness of waste audits in general and in craft villages in Vietnam include:

Firstly, the State Audit should focus on proposing and developing legal documents specifying the waste audit function of the State Audit; formulating and developing waste audit guidelines and methods in the direction of compliance with the system of international auditing standards; increasing awareness and awareness of agencies, units and society on waste audit; develop the organization of the waste audit apparatus under the State Audit; implementing and strengthening waste audits.

Secondly, the Departments of Natural Resources and Environment (DONREs) need to focus on inspecting and guiding enterprises that are eligible to be granted a license to discharge wastewater, and build a standard wastewater treatment system. At the same time, it is necessary to maintain the operation of the working group on the implementation of the wastewater discharge permit plan; inspect, urge and guide enterprises to make licensing dossiers. The Department promulgates Regulations on granting permits to discharge wastewater into water sources for organizations and individuals in the city, divided into stages; Regulations on publicizing the list of dossiers for carrying out discharge licensing procedures. For businesses that have problems with land procedures, location of installation of wastewater treatment systems, etc., the Department needs to have solutions to support timely removal. In addition, the Department of Natural Resources and Environment strengthens inspection and review, requires businesses to strictly comply with the legal regulations on wastewater discharge, if detecting illegal discharge of wastewater, discharge of untreated wastewater, etc. Environmental regulations will strictly handle, even require closure, temporary suspension and suspension of production of enterprises. The Department will publicly post a list of businesses that discharge wastewater into the environment without a discharge permit on the mass media for local authorities and people to participate in monitoring the discharge of enterprises. .

In the long term, provinces and cities urgently build an automatic monitoring system for water sources in the area to promptly monitor and warn about water environment developments, detect and strictly handle illegal acts of discharge untreated wastewater into the environment.

In addition, it is critical to improve the technical factors in environmental audit activities through the issuance of procedures and documents guiding the audit of environmental protection work in industrial clusters based on the existing waste audit guidelines. Along with that, the management agencies need to build and complete the database and meet the physical conditions for auditors to carry out environmental audits in industrial zones and economic zones. The database includes information such as: system of legal documents on environmental protection; management

apparatus, organizational structure, internal control system, functions and tasks of relevant state management agencies; the reporting system of state management agencies on environmental management, inspection, examination and supervision; the management and use of public financial resources and public assets for annual environmental protection activities; information, data and data on audit activities and contents of the State audit.

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CONTRIBUTION

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