Technical Guidelines for the

PREVENTION OF PLASTIC AND RESIN PELLET LEAKAGE FROM FORMAL AND INFORMAL RECYCLING FACILITIES

VIENTIANE, LAO PEOPLE'S DEMOCRATIC REPUBLIC

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Regional Resource Centre for Asia and the Pacific

Regional Knowledge Centre for Marine Plastic Debris

ERIA
Economic Research Institute for ASEAN and East Asia

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Vientiane, Lao People's Democratic Republic

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Disclaimer

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Abbreviations and acronyms

ASEAN	Association of Southeast Asian Nations
EIA	environmental impact assessment
ESMMP	Environmental and Social Management and Monitoring Plan
HDPE	high-density polyethylene
IEE	initial environmental examination
Lao PDR	Lao People's Democratic Republic
LDPE	low-density polyethylene
MOIC	Ministry of Industry and Commerce
MONRE	Ministry of Natural Resources and Environment
NPAP	National Plastics Action Plan for the Lao PDR
PET	polyethylene terephthalate
PP	polypropylene
PVC	polyvinyl chloride
SEZ	special economic zone
VCOMS	Vientiane City Office for Management and Services

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Introduction

Background and context

Plastic and resin pellet pollution of marine environments is a global conundrum. Members of ASEAN (the Association of Southeast Asian Nations) are actively committed to addressing marine plastic pollution challenges and their associated impacts. Plastic recycling is a major way of recovering and reintegrating valuable post-consumer plastics into the value chain. In Vientiane, Lao People's Democratic Republic (Lao PDR), formal and informal plastic recyclers play key roles in driving post-consumer plastic recycling rates. Several recycling factories have been established in Lao PDR within the last 5-10 years. Few licensed plastic recycling factories import plastic waste to meet their recycling capacity. However, they face challenges as the imported plastics do not always meet the mandated cleanliness and recyclability quality standards. This poses a problem, as it hinders their ability to effectively recycle plastic waste. Reliance on domestically sourced recyclable plastics for recycling does not ensure profitability for the big-capacity factories due to challenges of contamination, quality, and inadequacy to meet demand. Notwithstanding, the Ministry of Industry and Commerce (MOIC) and the Ministry of Environment and Natural Resources (MoNRE) have acknowledged the need to work toward increasing the domestic recycling rate.

Global and regional policy initiatives to manage and prevent marine plastic pollution are quickly advancing. On 2 March 2022, the United Nations Environment Assembly in Nairobi, with representatives from 175 nations including the United States and France (partners in collaboration), endorsed a historic resolution to end plastic pollution and forge an international legally binding agreement by the end of 2024 (UNEP, 2022). The Intergovernmental Negotiating Committee (INC) on Plastic Pollution is in the process of developing an international, legally binding instrument for plastic pollution, including in marine environments. Microplastics in the environment, especially in marine ecosystems, pose substantial risks to both ecological systems and human health. Evidence from various studies has shown that plastic pollution can alter habitats and the natural productivity of ecosystems, reducing their ability to adapt to climate change and directly affecting livelihoods, food production, health, and social well-being (GESAMP, 2015; Campanale et al 2020; UNEP, 2021).

The ASEAN community, through the Bangkok Declaration and the ASEAN Framework of Action on Marine Debris, has agreed to step up multi-party coordination and cooperation across the region to address the challenge of marine debris (ASEC 2020a; ASEC 2020b). There was a consensus to explore and promote partnerships between the public and private sectors through various mechanisms, including increasing capacity and the exchange of best practices among ASEAN members. The ASEAN Regional Action Plan for Combating Marine Debris in ASEAN Member States (2021–2025) proposes an integrated approach to address marine plastic pollution in the region. The National Plastics Action Plan for Lao PDR 2022–2030 (NPAP) is one of the latest plastic waste management policy strategies being developed by the country to tackle plastic pollution. Section 1 of the policy (goals 1 and 2) focuses on implementing actions that will lead to a more effective plastic waste management system, a stronger recycling infrastructure, and better recycling techniques in order to create a highly efficient and environmentally friendly recycling system. Section 3 of the policy focuses on how to develop guidance and regulations for plastic recycling plants to manage plastic pollution from factories.

The rising awareness of the leakage of plastic fragments, plastic flakes and pellets into the environment from recycling activities is making the challenges of pollution from recycling facilities a growing concern (Brown et al., 2023). Plastic pollution stemming from plastic recycling can arise from multiple sources. These include the loss of plastic in various forms (macro- and microplastics) during handling, transportation, and recycling processes, as well as from the management of waste and effluents in recycling activities (Brown et al., 2023; Kallenbach et al.,2022). In addition, several steps in the mechanical recycling process – including baling, warehousing, and storage, de-baling, washing, polymer sorting, shredding, grinding, drying, extrusion, pelletizing, and transporting – can cause plastics (macro), and plastic pellets to leak into the environment. These processes involve handling large quantities of plastic materials and reducing this material to a granular size, which increases the likelihood of leakages. In addition, untreated wash wastewater that is improperly managed by plastic recycling factories and discharged into the environment represents a significant source of micro- and macroplastics. Without proper measures and safeguards, the recycling process can become a high-risk source of plastics and other pollutants that leak into bodies of water, soil and groundwater systems. Stakeholders and actors in the recycling industry must be concerned about plastic losses from recycling production processes not only because of their potential impact on organisms and ecosystems but also because such losses have implications for output yield and production costs.

A case for context-appropriate technical guidelines for the prevention of plastic pollution

Fast-growing ASEAN cities have been identified as significant contributors to marine plastic debris, with uncollected and mismanaged plastic waste from land-based sources being major leakage hotspots (Lebreton et al., 2019; Le Tran et al., 2023). However, existing assessments have primarily focused on plastic pollution from post-consumption handling of plastics, neglecting the contribution of plastic recycling processes. Limited access to data from informal and formal recycling facilities, coupled with concerns about regulatory actions, hinders information sharing. Balancing profitability and environmental responsibility poses a challenge for post-consumer plastic recycling businesses, leading to a focus on high-value plastics and inadequate technology adoption (Damanhuri 2010). Inefficient production methods contribute to environmental pollution, as evidenced by the closure of some recycling facilities in Vientiane due to environmental and safety concerns.

The consultation workshops held with plastic recyclers in Vientiane uncovered notable gaps in awareness, knowledge, capacity, and access to recycling information and markets. These gaps have led to various challenges within the post-consumer plastic recycling industry, including market inefficiencies, quality control issues, price volatility, barriers to entry for recycling businesses, and environmental concerns. Addressing these gaps is essential for improving the sustainability and effectiveness of plastic recycling efforts in Vientiane. Moreover, interventions aimed at preventing plastic leakage from recycling must focus on enhancing awareness, knowledge, and capacity among recyclers and regulators to implement effective management practices and address the impact of marine plastics on the environment. Additionally, bolstering the regulatory and supervisory capacities of relevant national and city authorities is vital to assist post-consumer plastic waste recyclers in Vientiane and beyond in addressing plastic leakage from recycling facilities and minimizing environmental damage. Context-specific guidelines play a crucial role in guiding plastic recyclers, policymakers, and regulators to prevent losses and leakages from plastic recycling activities, thus fostering environmental sustainability. This technical guideline provides practical guidance for both formal and informal post-consumer plastic waste recyclers in Vientiane to prevent plastic pollution and leakage.

The guidelines aim to fill knowledge gaps and promote contextually appropriate best practices. They will also encourage industry actors to implement measures to prevent and contain plastic and pellet leakages. Based on the findings of a preliminary assessment of the post-consumer plastic recycling value chain, which analyzed primary sources of plastic loss and leakage, including technology applications, resource availability, access, and regulatory and policy gaps, these guidelines are designed to address key challenges in plastic pollution prevention. .

Outline of the technical guideline

The technical guideline comprises five sections: introduction, plastic recycling processes and operations in Vientiane, prevention of plastics and pellet leakage from recycling facilities, waste management in recycling facilities, and conclusions.

Section 1 provides an introduction and contextual background to the technical guidelines.

The challenges of plastics (micro-and macroplastics) and pellet pollution from recycling that led to developing technical guidelines on plastic pollution prevention were highlighted. The scope, goal, and approach adopted in the development, and limitations of the guideline are presented in this section.

Section 2 presents an overview of the plastic recycling industry in Vientiane, processes and operations of recycling facilities, the policy environment, and the basic considerations for plastic recycling facilities in preventing recycling related plastic pollution.

Section 3 outlines operational practices and guidelines for preventing plastic leakage from junkshops. hese measures are tailored to different stages of the recycling value chain

Section 4 presents operational practices, processing options and guidelines for preventing plastics and pellet leakages from recycling factories.

Section 5 presents strategies and approaches for waste management within recycling facilities, covering solid waste, hazardous waste, wastewater, and air pollution.

Section 1

Enabling environment for plastic recycling

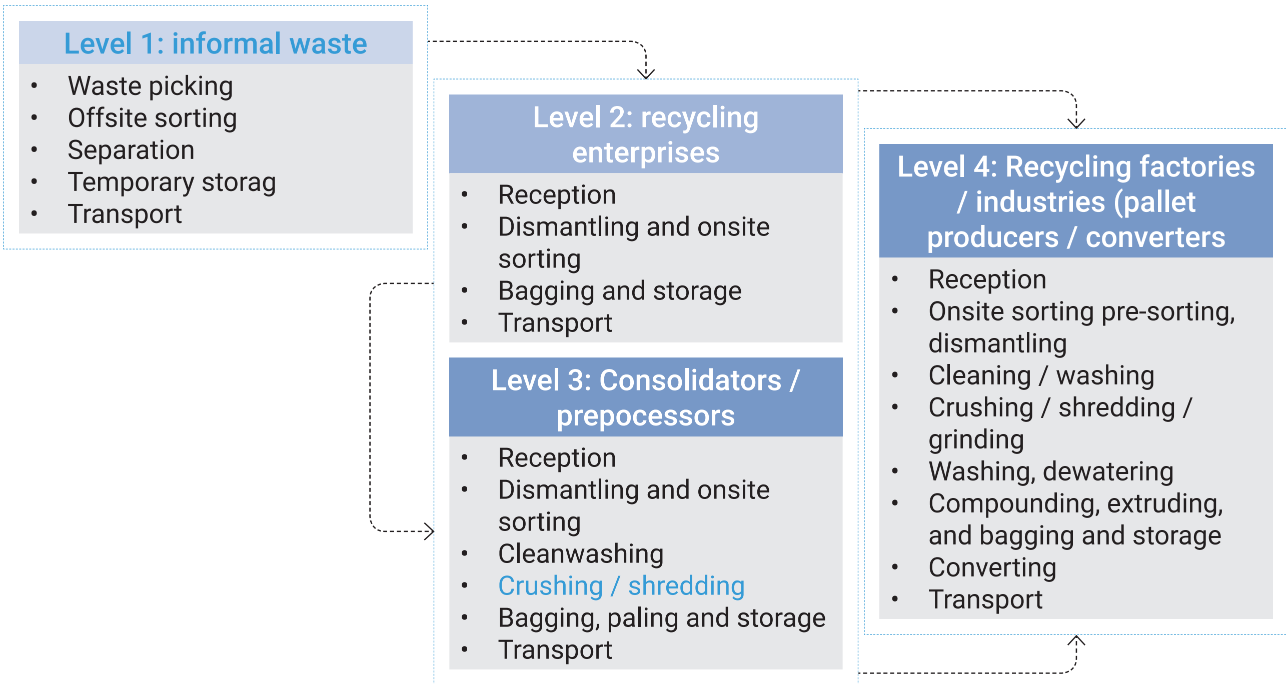
1.1 Plastic recycling landscape of Vientiane

In Lao PDR, plastic waste primarily comes from the consumption of imported plastic products from neighbouring countries like China, Thailand, and Vietnam, as well as from Japan and Europe. Secondary materials to produce plastic products are also imported into the Lao PDR for the local plastic production industry. Following China's ban on plastic waste import, post-consumer plastic waste recycling in Lao PDR has increased in response to the sharp increase in the number of post-consumer recycling facilities in the country. Plastic waste imports countrywide also increased sharply from about 7,800 tons to 10,000 between 2018 and 2019 (World Bank, 2022). Recycled post-consumer plastics are exported to Thailand and China for recycling. The post-consumer plastic recycling ecosystem of Vientiane operates within four levels: informal waste collectors, recycling enterprises, consolidation centres, and recycling factories or facilities (Figure 1).

Level one actors, who work upstream of the plastic recycling value chain, comprise informal waste pickers who retrieve recyclable plastics directly from post-consumer waste and sell it to collection centres or junkyards. They work on the streets of Vientiane and at the KM32 landfill. Included in this category are waste collectors and waste truck drivers, who retrieve valuable plastic materials during waste collection and disposal.

Level two actors include the collection centres and junkshops buy from a network of first-level actors. They typically store their recyclable plastic materials in their facilities and carry out basic or primary sorting, storage, and transportation of recyclable plastics. Some operate as registered, tax-paying family or individual enterprises, while others operate informally without registration. Junkshops and recycling facilities trade sorted polymer streams of recyclable plastic to consolidation centres, who operate at a much larger scale.

Figure 1. The recycling value chain actors and process operations in Vientiane



Consolidation centres, working at the third level of the recycling value chain, have coordinated relationships with level two actors and also operate as businesses. They have greater price-setting leverage and trade larger volumes of plastic with recycling factories and facilities in domestic or regional markets. The recycling factories and facilities are level four actors. They include recycled who buy recyclable plastics from the consolidation centres and import plastic scraps from international markets. Recycling factories and facilities have higher levels of investment and more sophisticated machinery to process recyclable plastics into secondary raw materials in the form of flakes and pellets.

1.2 Enhancing pollution-free plastic recycling in Vientiane

Stakeholder workshops identified four key factors supporting Vientiane's plastic recycling: policies, institutions, technology access, and resources (Figure 2). Policy and regulations play a crucial role in shaping the plastic recycling landscape and mitigating plastic pollution from recycling factories. Stringent regulations regarding waste management, recycling standards, and environmental protection can incentivize proper recycling practices and discourage pollution. Conversely, inconsistent regulations may lead to inadequate waste management and increased pollution. Institutional arrangements, including the organizational structures and partnerships among government agencies, industry players, and civil society, can influence the effectiveness of plastic recycling efforts. Collaborative frameworks and clear responsibilities among stakeholders can streamline recycling processes and enhance pollution prevention measures.

Access to resources, such as funding, information, training, infrastructure, and expertise, significantly impacts the efficiency and scale of plastic recycling initiatives. Sufficient resources enable the adoption of advanced recycling technologies, access to markets, expertise, and services to improve effectiveness and efficiency in the recycling process. Availability of investments can enhance the establishment of proper recyclable plastic waste collection and processing facilities, and the implementation of educational and outreach programs to raise awareness about cleaner recycling practices. Further, access to appropriate recycling technologies, machines and equipment at affordable costs can enhance efficiency in plastic recycling

Figure 2. The enabling framework for supporting the plastic recycling industry of Vientiane

Policy and regulation

Basic policy and regulations on plastic recycling factories
Tax regimes and incentives for recyclers
Prevalence of informality in recycling enterprises
EIA and strict regulatory requirements

Institutional arrangements

Institutional technical and financial capacity
Capacity for effective regulation, monitoring, supervision, and compliance enforcement
Functional overlaps of supervisory and regulatory institutions

Technology

Rudimentary intermediate technology for recycling
Material and process efficiency, cleaner production
Quality of recycling feed stock, poor recycling equality
Access to knowledge and information on processing and treatment technologies

Resources

Information asymmetry and access to market
High cost of production / input cost
Incentives and support, access t finance
Recycling market fragilities, shocks
Access to training and capacity building

and pollution prevention. Innovations in recycling technologies, such as sorting, cleaning, filtering, wastewater treatment and processing methods, can improve the quality and quantity of recycled materials while minimizing pollution risks.

1.3 Policies, regulations, and institutional frameworks

Laws and regulations have been put in place at national and city level to support and encourage cleaner and more ecologically friendly recycling activities in Vientiane. The plastic recycling sector is regulated within relevant national- and city-level policy policies and regulations that prioritize environmental protection through various pollution control measures.

The Environmental Protection Law 2012 serves as an overarching law that defines the principles, regulations and measures related to environmental management, monitoring, protection, control, preservation, rehabilitation and quality, as well as how to mitigate the impacts and pollution created by anthropogenic loads or nature.

The Processing Manufacturing Law 2013 prohibits the ecologically harmful discharge of wastewater, solid waste, noise and air pollutants for processing manufacturing companies. Similarly, the Industrial Waste Discharge Regulation (No. 180/MOIC, 1994) was issued to prevent threats from industrial waste disposal that can be detrimental to human health, and impact water and air quality.

The Environment Impact Assessment Decree (2018) provides regulations and measures on managing and monitoring the implementation of environmental impact assessment activities to make sure that such activities are transparent, aim to protect the environment and help to remedy negative environmental impacts. It states that plastic recycling plants need to have solid waste management treatment systems and the design of these systems must be submitted to MOIC for approval before construction can go ahead.

A more recent regulation with direct implications for the recycling industry is the Plastic Recycling Factory Decree (No. 682/MOIC, 2020), which governs the operation of plastic waste processing plants. The decree aims to ensure that the managerial and operational conditions within recycling factories (including the technical standards) are in accordance with the relevant laws and regulations. It also stipulates standards, conditions for setting up a plastic waste processing plant and conditions for the importing of waste, among others. Recycling factories are required to conduct an environmental impact assessment (EIA) or initial environmental examination (IEE), with an Environmental and Social Management and Monitoring Plan (ESMMP), in order to receive a certificate and business license. Notably, article 5 of the decree notes that imported plastic waste for recycling should be clean and at least 80 per cent of the imported amount should be recyclable.

The various relevant policies mentioned above have prescribed the roles and responsibilities of key agencies and departments with regards to the operation of recycling facilities in Vientiane. The division of powers, resources and responsibilities in the waste management area replicates itself from central to local levels.

VCOMS plays a key role in overseeing municipal solid waste management and creating and improving legislation under the law on waste management in Vientiane. Various other aspects of the plastic recycling industry in the city fall under the purview of multiple government agencies, ministries, and departments, who have mandates to regulate, monitor, supervise and enforce compliance in line with relevant legal and policy provisions. While there are benefits to this multi-agency collaboration, there are also challenges in terms of the distribution of tasks and unclear roles when it comes to enforcing regulatory compliance among diverse administrative entities from central to local level. The government of Lao PDR is therefore looking to enhance institutional capacity to effectively discharge institutional mandates.

1.4 Technology and access to resources

Plastic recycling, particularly mechanical recycling, is a capital-intensive venture. The integration of appropriate technologies, access to resources and access to financial support can play a crucial role in shaping the capacity and profitability of recycling enterprises, particularly informal ones. In order to empower informal plastic recyclers, it is crucial to provide adequate infrastructure, develop supportive policies and encourage community engagement. This involves ensuring access to investments, loans, tax incentives, skilled labour, training, capacity building activities and information.

Initiatives focused on training and improving market access can particularly boost informal plastic enterprises, promoting a more inclusive and sustainable approach to plastic waste management. Many such enterprises in Vientiane operate in resource-restricted environments and rely on manual labour and rudimentary equipment. Those with limited access to financial resources, infrastructure and modern technologies struggle to achieve economies of scale, hindering their cost-effectiveness and scalability. Facilitating access to the necessary resources is an essential part of helping plastic recycling enterprises to enhance their environmental performance.

Integrating suitable technologies has the potential to boost the efficiency of the recycling value chain in Vientiane and have a significant impact on informal recycling practices in the region. While advanced machinery may be financially inaccessible for many informal recyclers, the adoption of simple and cost-effective technologies can still enhance productivity. Technology plays a crucial role in facilitating market access, enabling informal recyclers to connect with buyers, stay informed about market trends and meet quality requirements. Digital platforms streamline transactions and provide valuable information, contributing to a more sustainable and economically viable recycling ecosystem. Balancing technological integration with improved resource access can lead to more resilient and effective informal recycling practices, benefiting both the environment and the livelihoods of those involved.

1.5 Opportunities and outlook

The National Green Growth Strategy 2030 (GoL, 2018) prioritizes policy and investment actions in renewable natural resources, pollution and waste management, environmental fiscal instruments, and nature-based tourism for economic growth, environmental protection, and green job creation. It highlights the need for investment in waste infrastructure and system improvement, emphasizing the importance of efficient waste management in large cities. The strategy also promotes waste reuse as an investment opportunity for job creation and income generation. Despite these goals, clear targets are lacking and gaps persist in analytical support, advisory services and government capacity. A robust advisory framework is therefore crucial for maintaining momentum on this ambitious reform agenda.

More specifically, the regulatory and policy landscape of plastic waste management and recycling countrywide is evolving in response to global and regional efforts to reduce marine plastic pollution. Progress has been made in the past couple of years in terms of regulations and the promotion of environmental protection with respect to the operations of recycling factories. However, there is a need for more specifically tailored policies and regulations, subordinate laws and policies, and implementation guidelines for existing regulations for the recycling sector. This is essential to align with the regional and global drive to address plastic pollution.

Various opportunities exist in Lao PDR to expand the county’s basic policies so that they align with the evolving global and regional policy landscape on pollution prevention and management. For example, policies and regulations related to improving plastic packaging recovery, extended producer responsibility implementation, recycling content and quality, and recycling waste electrical and electronic equipment plastics. In Vientiane, there is already a policy drive to improve plastic waste management and the circular economy, which has implications for increasing product stewardship and the recycling of plastic packaging.

ASEAN members, including Lao PDR, may choose to focus on policy positions that favour a reduction in plastic waste imports in order to encourage a greater level of post-consumer plastic recovery and recycling within their own borders. The realization and adoption of a legally binding, international instrument from the Intergovernmental Negotiating Committee, which addresses the full life cycle of plastic (including its production, design, and disposal), promises to deliver a significant shift in the policy landscape for ASEAN members such as Lao PDR.

1.6 Plastic recycling quality and knowledge gaps

A lack of knowledge and information within Vientiane's informal recycling ecosystem contributes to the sourcing of subpar plastics. The types of plastic polymers that are collected and traded are primarily influenced by the preference of the informal waste pickers. Waste pickers, scavengers, collectors and consolidators are at a distinct disadvantage due to the limited information they have about acceptable polymers and purity standards for recovered plastics. There are also knowledge gaps regarding the conditions of recovered post-consumer recyclable plastics and the preferred polymer types sought by recycling enterprises further down the chain. All of which contributes to low levels of efficiency and high levels of material rejection.

The technical and complex nature of information dissemination pathways relating to the preferred recyclable plastic polymers, colours and purity levels further exacerbates the issue. Improving access to accurate trade information throughout the value chain can improve the quality of the plastics being recovered from post-consumer waste streams. Access to trade information on in-demand plastics also significantly influences the market leverage of plastic recycling brokers, impacting pricing and profitability.

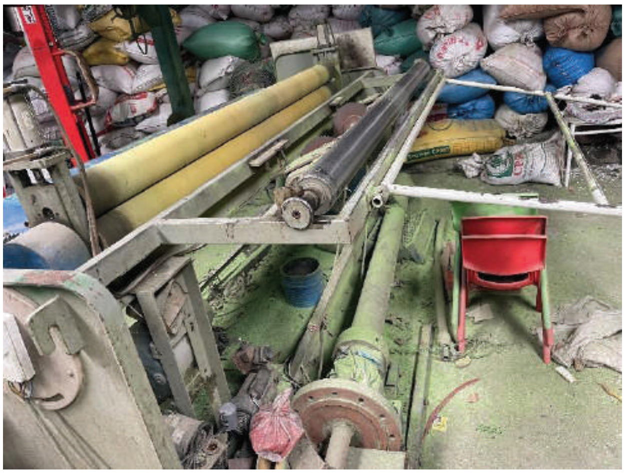
Section 2

Overview of plastic recycling facilities: Processes and operations

2.1 Environmental pollution concerns of plastic recycling processes

The establishment and operation of a plastic recycling facility are primarily influenced by regulatory measures, environmental and financial considerations, and market conditions for recyclables. These factors are closely interconnected, forming a complex relationship where changes in one aspect can have a ripple effect, impacting other factors systemically. Environmental considerations hold significant importance, just like other factors, especially because the production processes of recycling facilities can have notable implications for the environment. Plastic recycling operations can result in either adverse or beneficial effects on the environment.

It is crucial to conduct a thorough assessment to discern the impact of different facility operations and to address environmental concerns. This entails establishing and actively pursuing well-defined environmental performance objectives that align with relevant regulatory frameworks for environmental protection and pollution control. Table 1 outlines the pollution framework considered during the development of the technical guidelines.



Environmental considerations primarily revolve around the impact of recycling activities and production processes on the environment. Such considerations are vital when it comes to preventing the environmental pollution that can result from plastic recycling (e.g. the release of microplastics, nanoparticles and toxic fumes into the air, water and soil). Mechanical plastic recycling must be conducted in a manner that preserves air quality and prevents the release of pollutants, safeguarding both the environment and human health.

Regulatory and policy provisions govern the establishment and operation of recycling facilities

Table 1. Pollution framework

Aspect	Environmental performance objective
Air	Maintain air quality, recovery and minimized airborne microplastic emissions into air either as toxic fumes or particulate/ so environmental values and human health are protected.
Environmental siting	Premises/factories are sited in locations which minimize their potential to cause adverse impacts to environmental values, water resources, human health, and social surroundings.
Land & soil	Prevention of microplastic leakage to soil, (either through direct disposal or wastewater discharge) that may adversely impacts soil, groundwater, and to the environmental values of terrestrial ecosystems and beneficial uses of soil.
Litter and debris	Maintain environmental values and human health by preventing the discharge of litter and debris beyond the premises boundary
Water & wastewater	Prevent adverse impacts to the environmental values and beneficial uses of marine, groundwater, and surface waters.

to mitigate adverse environmental effects, ensure social acceptance, and comply with industrial and trade policies. Relevant regulatory requirements such as EIAs, IEEs and ESMMPs provide the framework for environmental pollution prevention. Compliance with these regulatory requirements must be met as a priority. Creating a favourable domestic policy and regulatory environment can facilitate the operation of plastic recycling facilities. For instance, effective regulations that promote access to high-quality recyclable materials sourced from proper domestic collection, or regulated imports of high-quality plastic scraps, can benefit recyclers. Policy incentives such as special economic zones with tax benefits for the plastic recycling industry can foster private sector innovation and the growth of plastic recycling facilities.

Financial considerations relate to the economic viability of the recycling facility in terms of capital investment and operational costs. Various factors influence the cost structure, including the facility's location (including land acquisition), the type of facility and operational processes, the scale of operations, market conditions and the level of mechanization and automation. Other cost factors such as selecting a site, sourcing permits, design and construction, and setting up processing operations are also critical financial considerations.

2.2 Considerations for setting up a plastic recycling facility

Plastic recycling facilities in Vientiane must adhere to applicable regulations and policies at both the national and city levels. The regulatory provisions offer clear guidelines regarding the permissible locations and designated zones for establishing recycling factories including the relevant environmental requirements (e.g. business registration, permits and siting). Others include measures for ensuring ecological and environmental integrity through pollution control, technical standards and operational conditions specific to plastic recycling factories. In addition, recycling facilities are required to comply with regulations when importing plastic waste for recycling. Figure 4 shows some of the key points that must be taken into account when establishing a plastic recycling facility.

2.2.1 Site selection and regulatory considerations

Acquiring land is a crucial part of establishing a recycling facility, particularly when considering the facility's social and environmental aspects. While facilities in Vientiane are usually situated in areas that have good access to recyclable material sources, other factors influence site selection. The foremost of these is the need to comply with the city's procedures, regulations, and permits relating to the location of waste recycling facilities.

Figure 3. Key considerations for establishment of plastic recycling faciities

Others include availability, cost, and land size. Balancing these factors with accessibility is vital for setting up such facilities.

Urban and peri-urban environments

In Lao PDR, recycling facilities may be situated inside or outside of special economic zones (SEZs) or industrial zones. They are generally encouraged to be within SEZs, which include:

- Saysettha Development Zone
- Long-Thanh Vientiane SEZ
- That Luang Lake SEZ
- Dongphosy SEZ
- Vientiane Capital Industrial and Trade Area (under MOIC)

The Special Economic Zone Promotion and Management Office of the Ministry of Planning and Investment supervises business operations in SEZs, while provincial SEZ management authorities in each province where a zone is located are responsible for approving and facilitating business operations there.[1]

Permits and regulatory compliance

Some of the foremost national- and city-level regulations that facilities must comply with include:

- Law on the Government of the Lao People's Democratic Republic (No. 02/NA)
- Environmental Protection Law (No. 29/NA)
- Environmental Impact Assessment Decree (No. 21/GOL)

Plastic waste recycling facilities such as small and large junkshops are required to obtain a business license from the commercial sector, as stipulated in article 13 of the Law on Enterprises (No. 11/SPO), dated 9 November 2005. Proposed new facilities (especially those that require land) should undergo environmental and social assessments prior to launch. They should also be duly registered by following the appropriate procedures and complying with the regulations from the relevant management organizations.

The location of a facility must not violate the provisions of the Processing Manufacturing Law 2013, the Industrial Waste Discharge Regulation (No. 180/MOIC, 1994), the Plastic Recycling Factory Decree (No. 682/MOIC, 2020), and other relevant policy guidelines and standards.

Other key rules and regulations include:

- Plastic waste for recycling should be clean and at least 80 per cent of the imported amount should be recyclable.
- Recycling shops, facilities, factories and plants need to be situated far away from the community and residential dwellings.[2]
- Small-scale recycling shops in residential areas, without heavy machinery, should fence the areas that they use for work and material storage.
- The storage of waste outside of designated areas is prohibited.
- All plastic recycling factories must have a solid waste management treatment system.
- The design of waste treatment systems must be submitted to MOIC for approval before construction can begin.
- Wastewater from plastic recycling facilities must be treated in line with MOIC-specified standards before being discharged into the environment.

Proximity to bodies of water

The following rules govern the proximity of plastic recycling facilities to water sources:

- Plastic recycling facilities in residential communities must be properly enclosed.

1 Special Economic Zone (SEZ) | Investment Promotion Department (investlaos.gov.la)

2 This is often not the case in practice, with many junkshops and plastic recycling facilities located within communities and urban environments.

- They must not be situated near canals, streams, rivers or other bodies of water.
- Plastic recycling facilities must be situated at least 100 to 250 metres from a watercourse.
- Plastic recycling facilities must not be established in areas with low groundwater tables and recharge points.

Proximity to agricultural land

The following rules govern the proximity of plastic recycling facilities to agricultural land and ecologically sensitive areas such as wetlands, marshlands, and flood-prone areas:

- Plastic recycling facilities should not be established on agricultural lands.
- They should not be established in culturally sensitive areas.
- Efforts should be made to avoid establishing them in wetlands, marshlands, and flood-prone areas; where this is unavoidable, the land should be prepared in an environmentally conscious manner.
- Robust ESMMPs[3] should be developed, with comprehensive impact mitigation and containment strategies, prioritizing avoidance

Box 1. Environmental Impact Assessment Guidelines

The EIA Process requires completion of a Screening and Scoping Report and TOR for EIA activities prior to preparation of the EIA Report.

For the project screening, the project developer shall submit an investment application to MONRE (Decree 112/PM, Article 6). The project developer shall utilize the list of projects subject to EIA, in addition to considering the significance of the potential impacts of the project. MONRE will make a decision based on the information provided by the project developer as to whether the proposed project will have to undertake an IEE or an EIA.

During the project scoping, the project developer will prepare a Scoping Report and detailed terms of reference for preparation of the EIA as required in Decree 112/PM (Article 11). Section 3 of the EIA Guidelines provides guidance on how to prepare the Scoping Report and the TOR. MONRE will revise, comment on and approve the Scoping Report and TOR before the project developer begins preparing the EIA.

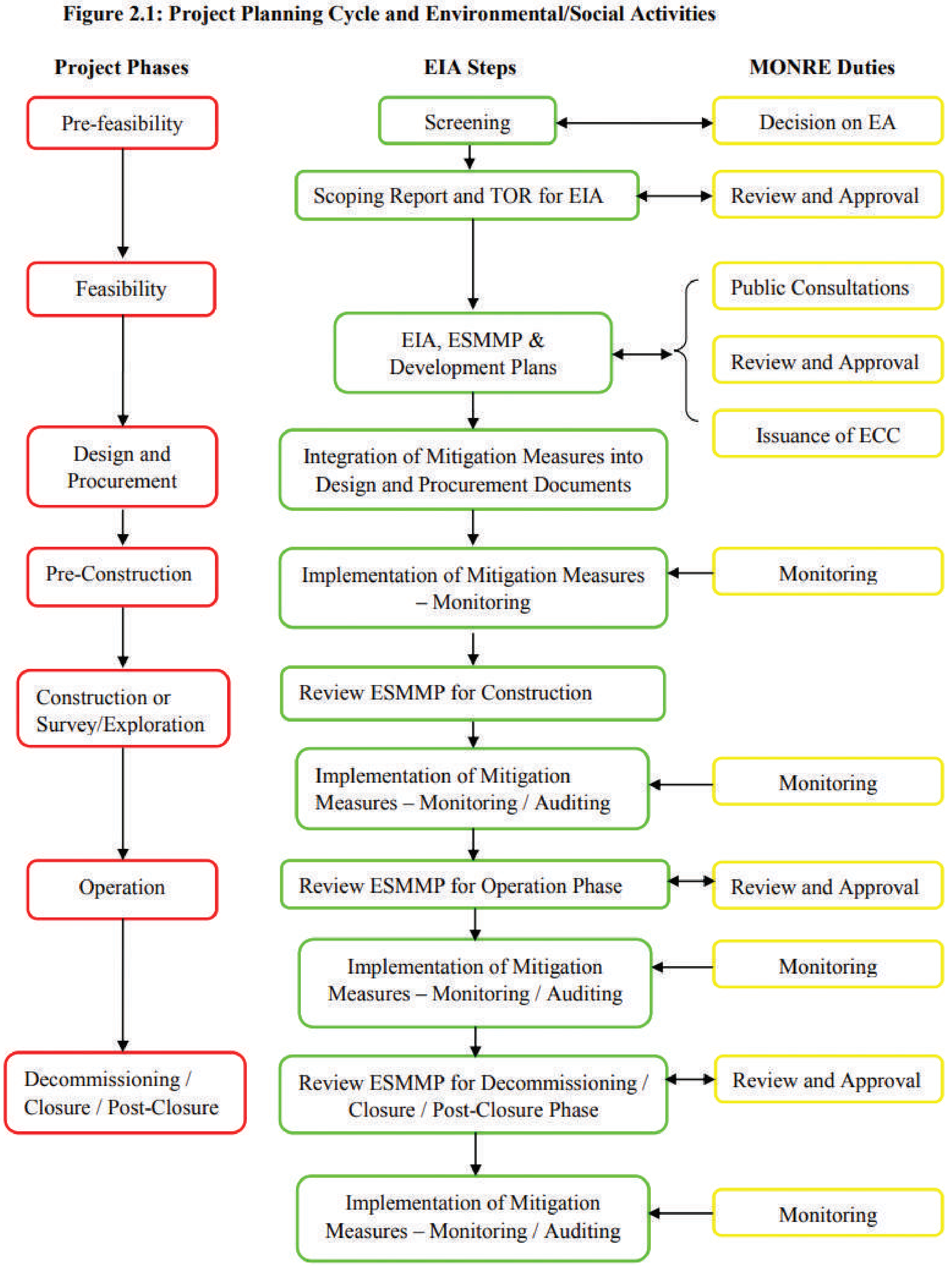
Preparation of the EIA Report, ESMMP and development plans will require consultations with the local authorities and affected people. The Public Involvement Guidelines describe this consultation process. Figure 2.2 indicates the most important steps to undertake during preparation of the EIA, especially with regard to public consultation. MONRE will conduct an administrative and technical review of the EIA Report, ESMMP and development plans. The project developer will be required to revise the EIA Report, ESMMP and development plans to comply with the consolidated comments provided by MONRE and those of the Panel of Experts.

Once MONRE is satisfied with the EIA Report, the ESMMP and the development plans, the Environmental Compliance Certificate will be issued, including specific conditions if required.

Source: MoNRE, 2012

3 ESMMPs: Environmental and social management and mitigation plans

Figure 4. Project planning stages and environmental safeguarding activities[4]



due to potential challenges in implementing and enforcing environmental standards over time.

4 EIA Guidelines (monre.myqnapcloud.com)

Facility or structural considerations

The following rules govern the structure and design of plastic recycling facilities:

- Plastic recycling facilities should have ample storage space for recyclable plastics, designed with appropriate geometry, insulation, and ventilation.
- Facilities should include basic enclosures to prevent harmful substances from leaking into the environment, while meeting industry safety standards.
- Buildings should be conducive for work, feature adequate ventilation, and protect against damp, heat build-up, humidity, and corrosion.
- Structures should minimize dust and noise levels within recycling facilities and consider the integration of specific systems.
- Facilities should include purpose-built structures that can accommodate equipment and technology in compliance with regulations.
- Buildings should have large, clear areas and high ceilings in order to provide maximum space for recycling operations, forklift trucks, storage sites and plastic pollution or material loss containment mechanisms.

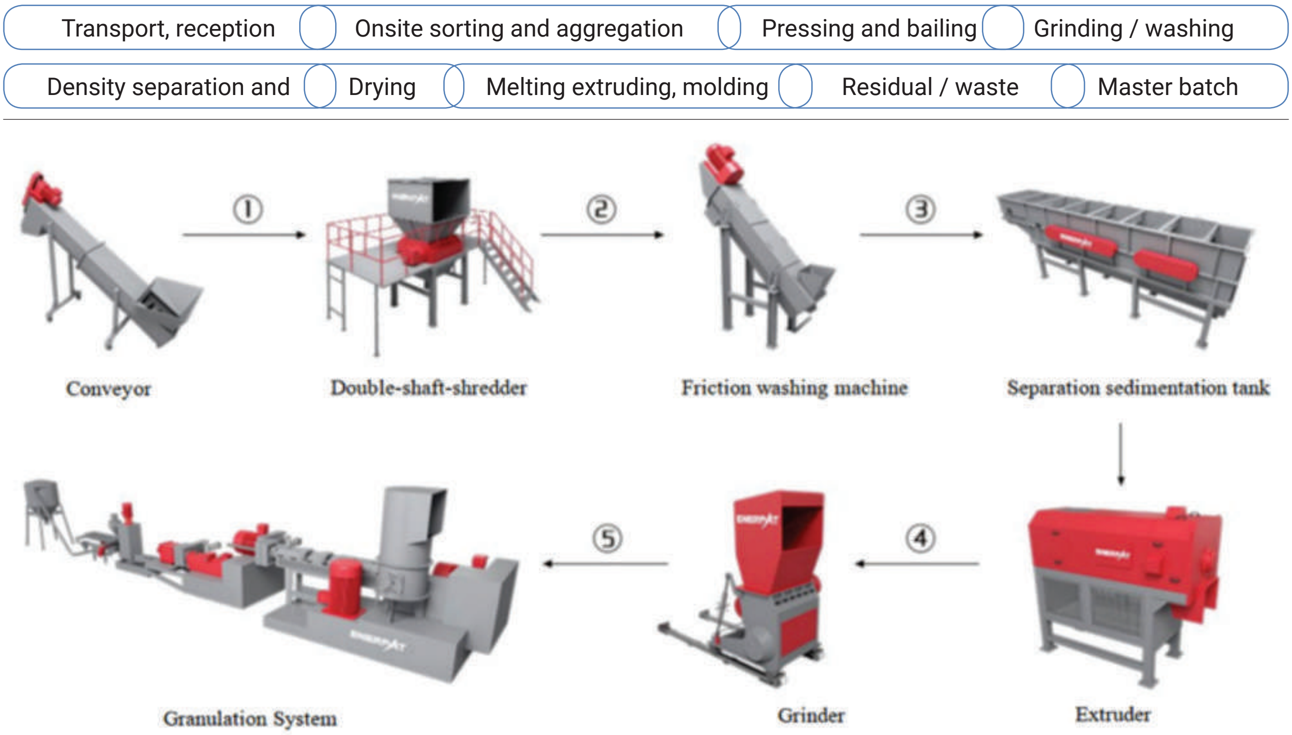
Environmental and social management and mitigation plans (ESMMP)

Based on the scope activities and by the determination of the relevant regulatory agencies, plastic recycling facilities may be required to develop and submit Environmental Impact Assessments (EIAs), Environmental and Social Management and Monitoring Plans (ESMMPs). This ensures the implementation of necessary environmental protection measures from the potential pollution from recycling activities. Additionally, recycling factories must conduct two forms of EIAs: preliminary and comprehensive EIAs. The preliminary EIA aims to identify potential non-severe environmental impacts and propose mitigation measures, including those related to climate change. This assessment is submitted to the provincial office of natural resources and environment for review. The comprehensive EIA evaluates all potential social and environmental impacts, including those related to climate change, and is submitted to the Ministry of Natural Resources and Environment for review (MoNRE, 2019). The steps for developing and obtaining approval for environmental and social safeguard plans are shown in Figure 5.

2.1.2 Plastic recycling machinery, and equipment related losses

Plastic recycling machinery and equipment decisions can have significant impact on the processing efficiency, profitability and ultimately environmental pollution risks posed by the mechanical recycling factories. Unfortunately, mitigating environmental pollution risks ranks low among the priorities for recycling factories when selecting machinery and equipment. Plastic recycling factories utilize a range of technologies and equipment customized to their specific needs. While a variety of technology and machinery options exist, recycling shops with simpler operations face different considerations than recycling factories relying on advanced machinery. Medium and large-scale facilities typically prioritize investment in technology and machinery to optimize recycling processes, expand capacity, enhance product quality, and drive profitability. The selection of recycling machinery and equipment is commonly influenced by key factors such as technology suitability, adaptability, cost, ease of use, and maintenance.

Efficient plastic recycling machinery minimizes losses during processing, whereas rudimentary equipment can significantly reduce efficiency, as observed in some recycling factories in Vientiane. Despite this, rudimentary and old plastic recycling machines are commonly used in many recycling facilities throughout Vientiane. The utilization of improvised, outdated, and rudimentary machines and equipment in recycling factories, although potentially cost-effective, exacerbates plastic losses and leakage during the recycling process, leading to environmental risk. For example, outdated sorting equipment and washing units may not be able to effectively separate different types of plastics, and clean shredded plastic effectively leading to contamination and increased waste. Other observed



common causes of plastic losses during processing include increased downtime-related issues. Frequent machinery breakdowns, brief stops, material shortages, misfeeds, and component jams, along with improper repair and maintenance, contribute to processing speed alterations and downtimes, leading to significant plastic material losses. Additionally, outdated machinery often requires more frequent maintenance and repairs, further decreasing overall productivity and contributing to material losses. Another common challenge includes improper or poor configuration and alignment processing line that encourages frequent manual interventions and interruptions leading to increased intended material release or loss of fugitive plastics, including scraps, micro plastics, threads and strands, and powder into the environment.

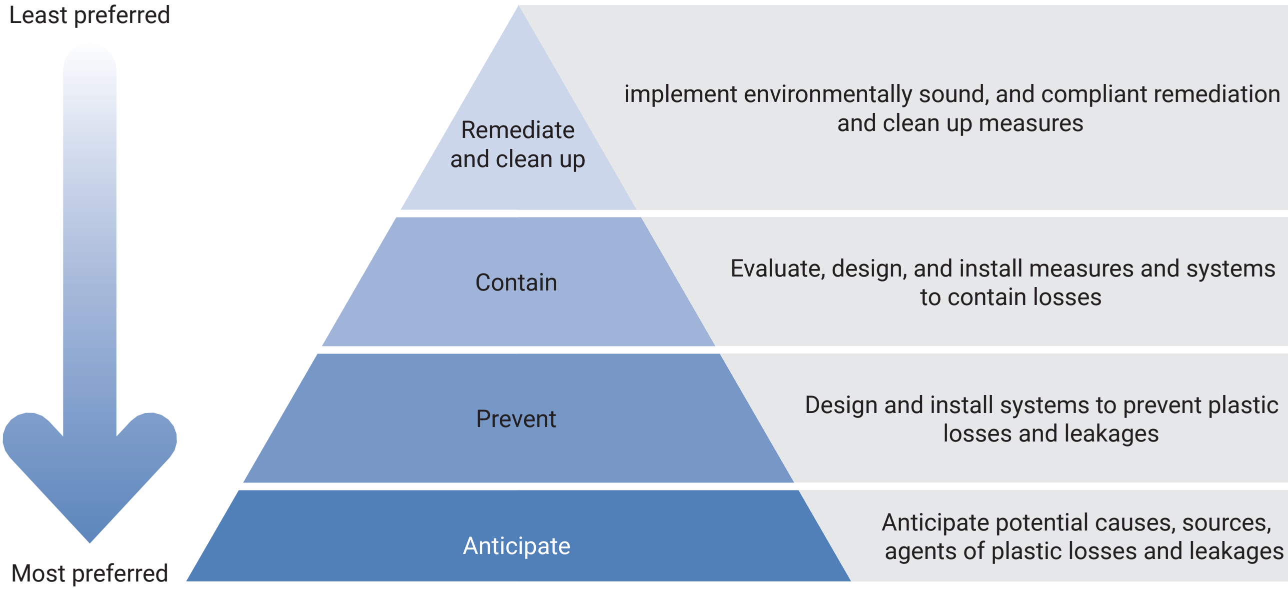
To prevent and minimise plastic and resin pellet losses during preprocessing and processing operations, it's essential to optimize machine and equipment configurations in the process flow. This includes ensuring an appropriately optimized selection and setup of machines and processing equipment. Selecting appropriate, efficient, and modern recycling machines and equipment is crucial for minimizing losses and promoting sustainable plastic recycling. Regularly improving and optimizing machinery configurations is essential for reducing material losses across different recycling processes.

2.1.3 Pollution prevention, containment systems and clean up

Plastic and resin pellet leakages and losses during mechanical recycling processes can result from intentional or unintentional causes. While most losses are avoidable, in some cases, preventing them may be challenging. However, the crucial step is to establish measures to contain or prevent such plastics from leaking into the environment. These preventive measures involve anticipating potential causes, taking decisive steps to prevent leaks and prioritizing loss prevention in post-consumer plastic handling. This includes modifying handling and transportation practices, choosing machinery with loss-limiting mechanisms, adjusting processing line configurations, ensuring regular maintenance, and adding parts to limit losses. Installing prevention measures not only reduces material and product losses, but also improves product quality.

If preventive measures prove difficult or ineffective, the next step is implementing containment measures. These measures involve systems and structures that are designed to trap and retain lost

Figure 5. Hierarchy of loss and leakage prevention measures[4]



plastics and resin pellets from pre-processing or processing lines. Containment systems enable the collection, proper disposal or return of lost materials into the value chain. They can be area-specific (designed for a defined working area) or facility-wide (covering the entire factory and its operations). Area-specific systems are usually primary, with facility-wide systems serving as backups. Containment actions may involve installing mesh or screens in storm drains, or using baffles, skirts, skimmers, or vacuum systems to retain plastics. Common practices in Vientiane include installing berms around processing units.[5]

As a last resort to prevent plastic leakage from recycling facilities, effective cleanup and remediation measures should be implemented. These measures involve collecting, removing, and thoroughly cleaning up plastic and resin pellet losses, spillages and leakages. Remediation must adhere to accepted protocols and comply with relevant national- and city-level regulations. Adequate training on procedural requirements and environmentally sound cleanup and disposal (in compliance with regulations), is essential for workers within the facility, transporters, and offsite workers.

Figure 6 provides an overview of the various actions that can be taken to prevent pollution, plastic loss and leakages within plastic recycling facilities.

Handling and containing smaller plastic particles, such as microplastics, filaments, and powders, presents a greater challenge compared to larger bulk and macro plastics. Effective housekeeping practices play a crucial role in minimizing plastic and pellet losses, thereby reducing the need for heavy remediation measures. While some losses may be unavoidable due to technological constraints, it's essential to assess the loss and leakage situation comprehensively. Proper evaluation and prioritization of measures should follow, with the most effective and feasible options applied based on their sampled effectiveness.

2.2 Pre-processing handling and related plastic losses

Environmentally friendly plastic recycling should not only prioritize efficient polymer recycling but also limit the production of harmful waste throughout the entire value chain. This includes both the preprocessing, processing, and post-processing handling of recyclable materials. Pre-processing handling encompasses collection, primary sorting, transport, and storage, and is primarily focused on removing impurities and contaminants, and sorting

5 Adapted from Operation Clean Sweep Manual

of plastics into deferent polymer types. The objective of pre-processing is to segregate high value recyclable materials from impurities and categorize them into uniform polymer types, thereby enhancing the quality of recyclable plastic materials. The quality and composition of mixed plastic streams can vary significantly between collection systems, leading to differences in materials at the same sorting facility on different days. These variations depend on the collection methods and sorting approaches that have been used. Plastic losses in pre-processing can occur due to various factors related to the handling practices of informal waste workers and junkshops. These factors may include inadequate sorting techniques, lack of proper equipment for material separation, inefficient storage methods leading to material degradation, and insufficient knowledge about the value and proper handling of different types of plastics. Additionally, the informal nature of these operations often means that there are limited resources available for investment in technologies or infrastructure to minimize losses. As a result, significant amounts of plastic may be lost or degraded during the pre-processing stage, contributing to overall material losses in the recycling process.

2.2.1 Transportation, reception, sorting and storage related losses

Potential losses and leakage due to offsite primary sorting

In the absence proper material recovery and sorting centres, plastic losses, and leakage during offsite sorting of recyclable plastics results from various factors. The absence of a dedicated sorting infrastructure may contribute to inefficiencies in the sorting process. Without specialized equipment and facilities, sorting is often conducted manually, increasing the likelihood of sorting errors and misclassification of recyclable plastics. Post consumer recyclable plastics may become contaminated with non-recyclable materials or foreign substances during handling and transportation. Some of these contaminants may render the plastics unsuitable for recycling and lead to their rejection and disposal as residual wastes. Without stringent quality control measures in place, low-quality or contaminated plastics may be accepted during sorting, only to be rejected at later processing stages, leading to unnecessary losses.

Off-site primary sorting of recyclable plastics is carried out to enhance the quality of plastic prior to feeding into the mechanical recycling process. Primary sorting starts from the moment plastic materials are recovered from waste streams and continues until mechanical recycling commences. However, sorting rates, quality and efficiency may differ at each stage of the recycling value chain. Improving the quality of plastic material recovery by actors at the lowest level of the value chain (waste pickers, scavengers, itinerant buyers, etc.) can significantly reduce the amount of rejected plastic materials. Despite primary sorting efforts, rejected residual plastics may include non-recyclable polymers, low-value polymers, contaminated materials, and composite packaging.

To overcome these challenges, it’s essential to set up specialized sorting facilities, enforce quality control through practices like source segregation, and enhance transportation and handling methods. These initiatives ensure the availability of clean and properly sorted materials for recycling programs. By collecting and sorting materials by type, we can establish a reliable supply chain for recycling.

Transportation related losses and leakage

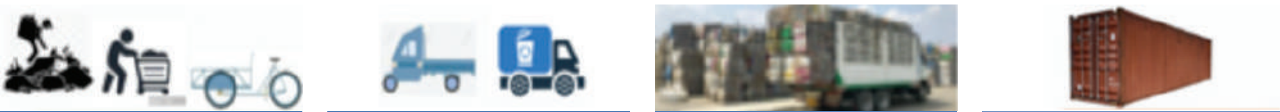
Plastic recyclables are transported in various ways at different points of the recycling value chain (Figure 7). Improper handling or transportation practices can cause breakage or spillage of sorted plastics, resulting in additional losses and leakage of recyclable materials. Informal waste pickers usually collect small amounts of recyclable plastic materials and either carry the materials themselves, by hand or transport them using bicycles or motorized carts. Junkshops often employ motorised tricycles, mini-trucks, and trucks for transportation, while aggregated and consolidated volumes are transported by larger logistics containers. Without proper care and handling, plastic losses and leakage to the environment can occur during transportation. As observed during the scoping exercise in Vientiane, plastic losses to the environment during transportation occur due to various factors such as spillage, leakage, improper handling, and inadequate packaging. For example, if plastic materials, in transit are not securely packed or transported in open containers, they may be susceptible to spillage or scattering along the transportation route. Additionally, rough handling during loading and unloading processes can result in damage or breakage of plastic items, leading to losses. Furthermore, if transportation vehicles are not properly maintained or equipped to handle plastic materials, there is a risk of leakage or spillage during transit. Therefore, ensuring proper packaging, handling, and maintenance practices during transportation can help minimize plastic losses.

Pre-processed and processed plastic materials can be stored at different stages in the recycling value chain. Ineffective storage and transportation processes, poor conditions and handling, and the improper management of materials can cause plastic scraps and pellets to leak into the environment. To prevent this, plastic recyclers including informal waste pickers, collection centres, junkshops and consolidation centres must put in place appropriate and specific measures to reduce plastic losses and leakage from storage. The duration of recyclable plastic storage may vary from short-term to long-term, depending on the specific purposes.

In Vientiane, informal waste pickers may choose to temporarily store their daily collections to build up larger stock or sell them directly to junkshops. The decision whether to store or sell daily largely depends on their access to temporary storage spaces and the volume of recyclable plastic materials traded. Junkshops and collection centres store their collected recyclable plastics primarily to accumulate stock, and pre-sort materials into various polymers and grades. They often choose to amass substantial quantities of recyclable plastic, mostly sorted by polymer types. This strategy not only allows them to potentially maximize their profit but allows them to offset transportation costs by selling larger volumes of plastic.

A common practice among junkshops and collection centres is to temporarily open their storage containers under the sun. This helps to remove organic and food waste contaminants, as well as odours, from freshly received plastic materials. Such impurities may pose technical, economic or market barriers for effective recycling. The conditions

Figure 6. Recyclable plastic transport mechanisms along the value chain[5,6]



Level 1: IWWS

Heap piling and direct sales
- super sack scraps
- tricycle carts
- push trolleys (push / bicycle / motorized)

Level 2: Recycling enterprise and MRFs

Stockpiling and minimal anticipatory inventory management
Transport
- motorized carts
- minitrucks
- tricycles

Level 3: Consolidators and preprocessors

- speculative inventory management
- stockiling
- bales and super scrap sacks

- Mid-, heavy-duty trucks
- Open / with rails
- Cargo containers

Level 4: Recycling and converters

- speculative inventory management
- stockpiling / long term
- pellet sacks

Shipping cargo container
- shipping drums
- heavy duty trucks
- resin bulk sacks / super scrap sacs
- shipping companies

6 Garbage collector Icon - Download in Glyph Style (iconscout.com)

7 Minimalistic Flat Cartoon Commute Commuter Tricycle Transport El PNG Image Free Download AI images free download_1369 × 1024 px - Lovepik

for storage may also vary based on the intended purpose and facility requirements. However, it is crucial to prioritize measures that prevent and contain any plastic leakage during the storage process.

Regulatory considerations

The following are some regulatory considerations that should be taken into account when transporting, storing and sorting recyclable plastics:

- Post-consumer recyclable plastic collection, transportation and storage must adhere to environmental protection laws, including the Environmental Protection Law 2012 and other pertinent by-laws.
- Carts and trucks that are used for recyclable waste collection and transportation must align with the regulations and standards set by the Department of Public Works and Transport in Vientiane.
- The collection and transportation of recyclable plastics in Vientiane must fully comply with the relevant provisions of the Decision on Municipal Solid Waste Management in Vientiane (sections 2 and 3).
- Recyclable plastic transportation must comply with all applicable regulatory provisions and technical standard of the Plastic Recycling Factory Decree (No. 682/MOIC, 2020).

Section 3

Operational practices and guidelines for junkshops and consolidation centres

3.1 Preventing plastic leakages from junkshops, consolidation centres

3.1.1 Transportation

The following sorting and transportation processes can help to minimize losses when processing recycled plastics:

- Collected post-consumer plastics must be securely bagged and transported securely to prevent losses.
- Recyclable plastic scraps and lightweight packaging should be transported in open carts and mini trucks.
- Small and lightweight plastic scraps and packaging should be bagged in woven polypropylene (PP) sacks without perforations during transportation and storage.
- The use of low-density polyethylene (LDPE) bags for transporting recyclable materials under extreme manual handling conditions should be discouraged.
- Vehicles transporting recyclable plastic materials, including carts (pushed, motorized or tricycles), mini-trucks and large trucks, must ensure the materials are properly contained in order to prevent spillages.
- Where practical, appropriate polyvinyl chloride (PVC) transport tarpaulins, canvases or suitable cover nets should be used to secure plastic materials during transportation to recycling facilities.

3.1.2 Material reception and staging areas

Reception and staging areas, commonly found in most junkshops in Vientiane, serve as typical offloading and, in some cases, dismantling areas, where plastic fragments are frequently discovered. These areas are designated spaces within a recycling facility where materials are temporarily stored or sorted before being processed further. Staging areas help streamline operations by organizing materials for efficient processing. The following are some best practices when establishing areas that receive recycled plastic materials:

- Allow adequate space within the recycling facility to incorporate logical, efficient, process material flow with maximum safety and efficiency.
- Provide sufficient segregation between the various delivered recyclable plastics material types and sources to avoid or minimise cross contamination.
- Designate plain working areas, free from obstructions, for activities such as dismantling, weighing, and pre-sorting plastics.
- Where necessary, swiftly move received plastic materials off the tipping floor to sorting or processing area in a timely manner.
- Whenever possible, pave or cover these designated areas with tarpaulins to prevent plastic fragments from escaping into the soil. In cases where such designated areas are not feasible, ensure that plastic scraps are carefully contained and regularly collected.
- Keep areas designated for receiving, weighing, and pre-sorting plastic materials at a considerable distance from drains, canals, rivers, watercourses, or flood-prone areas.

3.1.3 Dismantling bulk multi-component plastic materials

Operational conditions, investment capital, equipment use, and capacity vary among junkshops and consolidation centres. However, it is crucial to ensure prevention, containment, or remediation measures when it comes to plastic scraps loss during the dismantling process. The systematic dismantling of multi-component, multilayered packaging, and various electronic items (including large and small household appliances), at junkshops should be conducted in a way that avoids creating plastic scraps that could escape into the environment.

For fragile and brittle items, or those it would be difficult to dismantle without forceful breaking, practical steps should be taken to contain, collect and safely integrate the broken plastic fragments – otherwise, these fragments may escape into the environment, contributing to plastic pollution levels. Dismantling areas must incorporate adequate containment measures to prevent such occurrences. The dismantling of small and certain large household appliances may be performed on sufficiently flat and wide tables, allowing for the separation and safe disposal of waste electrical and electronic equipment components in compliance with national regulations and guidelines. Proper measures are useful to prevent, minimise potential risks of plastic leakage from dismantling activities.

Measures to prevent and control plastic loss and leakage during bulk material dismantling

- Set up a dedicated working area within the recycling facility for dismantling bulk, hard electronic and electrical equipment that contains valuable plastics.
- Designate dismantling areas as clear workspaces, free from obstructions and vegetation. Unpaved areas can trap small plastic scraps, so regular collection is essential. In paved areas, use tarpaulins to prevent plastic scraps from escaping.
- Avoid setting up dismantling areas near storm drains.
- Utilize appropriate tools for dismantling and minimize uncontrolled crushing, hammering or shattering of plastics, if possible.

3.1.4 Compaction, baling, and transporting

Compacting and baling recyclable plastics maximizes storage space and reduces transportation costs in Vientiane. Land acquisition is a significant capital expenditure for recycling facilities, and transportation costs are a substantial budgetary concern for recycling businesses. Medium and large junkshops, as well as material recovery facilities, use compaction and baling due to the large quantities of recyclable plastics processed in Vientiane.

Vertical hydraulic compaction and baling machines, albeit some old and not optimally functioning, are the types that are commonly used. These machines compress various plastics, such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), big bags, rigid plastic and plastic film into consolidated, free-standing cubes. The resulting bales predominantly consist of mixed plastic polymers, often PET bottles with HDPE and PP caps in assorted colours. Consequently, recycling plants receiving these bales conduct secondary sorting to separate mono-polymer and colour streams. The highly dense bales, typically attached to woven HDPE or PP sacks, are strapped for safe stacking, loading, transportation and separation. Bales can be stored either internally or externally based on available space.

Recycling plants receiving these bales need to conduct further sorting before the recycling process can begin. When conducted properly, compaction and baling operations pose comparatively low risks of plastic loss. However, neglecting proper housekeeping practices can turn these operations into potential points where plastic can be released into the immediate environment. The operational mechanisms involve volume reduction through crushing and compression, generating plastic scraps that may escape into drains, soil, and nearby vegetation, especially in unpaved working areas.

Preventing and containing plastic loss during compaction and baling

- Carry out sorting within the factory premises to prevent contamination from dirt, oil and dust.
- If the storage area is contaminated, use pallets when stacking bales to limit excessive contamination.
- Implement measures to contain, collect and properly dispose of rejected, low-value polymers and other impurities.
- Ensure brooms, dust pans and containers are placed nearby and are accessible to workers.

3.1.5 On site pre-sorting in junkshops and consolidation centers

In Vientiane, the offsite sorting practices employed by junkshops, landfills (such as KM32) and consolidation centres are driven more by business- and profit-related motives than environmental consciousness. Unlike more advanced countries that utilize sophisticated sorting technologies, entities in Vientiane predominantly rely on manual and occasionally semi-mechanized (though not widely adopted) methods, or a combination of both for sorting. Smaller junkshops with lower capacities and investment capital typically use basic and outdated equipment for dismantling and initial sorting. The semi-mechanized sorting process entails manually identifying and handpicking recyclable plastic waste as it moves along a conveyor belt. Manual sorting, which is the most common method, involves predominantly female workers who sit and sort through piles of recyclable plastics in designated areas within the facility. While manual sorting is challenging and time-consuming, recyclers report that it is effective and meets their needs. During the sorting process, quality control measures are carried out. However, where low throughputs are handled, the application of mechanical sorting can be cost prohibitive for some facilities.

Space limitations and speculative inventory decisions may impact the quantity and categorization of plastics during sorting. Nevertheless, sorting plastics into distinct quality streams, polymer types and colours add value and is carried out to meet the specifications of recycling plants and other buyers, both within and outside Vientiane. Sorted plastics may have an enhanced sales value and potentially increase the l profit margin derived from trading recycled plastics. Residual waste is typically generated at various stages of the primary sorting process. The sorting quality and streams depend on the business orientation of each recycling facility, client demands, preferred plastics and processing capacity. Recyclable plastic packaging (including small and large household items) obtained directly from waste pickers often contains impurities, multiple material layers and polymer types, which require sorting and processing to achieve impurity-free, monostream, recyclable plastics. Rejected parts may consist of specific plastic films, rejected or non-recyclable polymer streams and coloured packaging, among other items. Some hazardous substances might be separated for proper waste disposal. Recycling centres receive plastic packaging of different qualities, grades, and designs, some of which may have a low number of recyclable polymers. Common contaminants include organic impurities, oil and colour-stained plastic packages, which are cleaned or separated during the recycling process.

While sorting is generally considered a low-risk source of plastic loss, inadequate handling of plastic during the dismantling process and improper disposal of low-value, contaminated, coloured and non-recyclable plastic pieces can result in plastic fragments entering the environment. It is essential to take basic steps to ensure that materials are handled correctly and rejected polymer streams and impurities are disposal of in an environmentally friendly way. This helps to minimize the potential environmental impact of residual or low-value plastic and non-recyclable plastic fragments..

Considerations for preventing and containing plastic losses and leakage during sorting

- Ensure plastic is sorted away from bodies of water.
- Sort plastic in designated, vegetation-free areas.
- Anticipate and mitigate the risk of plastic loss and leakages due to rain, floods and wind.
- Use tarpaulins to capture residual plastics the result from dismantling.
- Collect and dispose of rejected, non-recyclable plastic polymers in an environmentally sound manner.
- Adjust for appropriate feeding speed of plastic materials on the conveyor belt and control the burden depth of material across the sorting belt.
- Safely dismantle electronic equipment, disposing of hazardous components responsibly.
- Wear appropriate safety gear during sorting to prevent injuries.

3.2 Shredding, washing, and drying

3.2.1 Pre-processing in junkshops, consolidation centres

Some junkshops and consolidation centres in Vientiane enhance the value of collected recyclable plastics by providing pre-processing services. They gather plastics from local dealers and junkshops, conduct primary sorting by polymer type and colour, and produce plastic flakes from PET bottles and shreds from rigid plastic packaging for export to international markets, notably Vietnam and Thailand. The plastic flakes and shreds are sold as high-value secondary raw materials that can be used to produce plastic resin pellets. The flakes are required to meet market quality conditions by having a low proportion of contaminants and foreign polymers. PET flakes are used in fibres to produce various types of clothing such as t-shirts and jackets. They are also used in the manufacturing of automobile seat covers, sofa and chair covers, and carpets. Apart from PET bottles, some recycling centres also produce flakes from polyolefins that are found in products such as baby chairs, cups, trays and boxes, toys, sandboxes, canisters, bowls, and laundry tubs. Pre-processing recycled flakes and shredded plastics requires extra investment in processing equipment. Recycled PET flakes may be produced in a selection of colours (mainly light blue, dark blue, green and clear) but light blue to clear PET flakes is predominant in Vientiane. Various size ranges may be produced, based on market requirements, however plastic flakes that are at least 10 mm in size after pre-processing is preferred. The ability of junkshops and consolidation centres to offer pre-processing depends on their access to capital investment, their access to the market and demand requirements. The majority of them will sell to local recycling plants based in Vientiane instead, as they lack the funds to purchase additional processing units for washing, decontamination and high-quality sorting, in addition to shredding machines.

3.2.2 Shredding processes

Shredders characteristically reduce the sizes of PET bottles by shredding or cutting them into small, uniform sizes. Shredders and grinders come in various designs and mechanisms to shred and mill plastics. In the manually-fed, single axis, conventional knife shredders, shredding is achieved by using a fast-cutting flange milling rotor that is often equipped with knives to cut to the desired sizes. Wet or dry shredding options are available, with each application selected based on the needs and preference of the customer. Wet shredding integrates resistance washing into the shredding process. while dry shredding does not. The double axis grinders typically deployed in shredding have double hexagonal tooth flange milling rotors that typically operate in a low rotation, high torque mode, which allows maximum power to crush or grate volumetric pieces of plastic into the desired reduced sizes. In Vientiane, most plastic recyclers rely on industrial grinders with open rotor designs, which can be fed either manually or mechanically. These open rotor designs provide sufficient space around the rotor for agitation and cooling during the shredding process. However, it's important to note that open rotor designs are best suited for processing lighter

plastic materials, as opposed to closed rotor grinder designs.

3.2.3 Washing and drying

Washing is primarily done to achieve thoroughly clean plastic flakes. Based on the type and purity of the received plastics, the washing process can be done in a few or multiple steps. A pre-washing prior to flaking or shredding, used by some recycling facilities, is carried out to remove impurities. Surfactants or an alkaline solution are often used in this stage. A subsequent rinsing process may be employed as a next step to remove residual chemicals and impurities in a tank with a low-speed agitator. The third washing step is the post-shredding washing of flakes. This is done via a process called floatation washing, which removes impurities and further separates the polymer streams. Further sorting or separation by polymer type is achieved during this process. The floatation washing process uses the difference in specific gravities to separate the desired PET flakes from other PP or PE materials included in the shredding. By using water as the flotation medium, polymers with densities below 1 g/cm³ (e.g. cleaned PP and PE) will float and be separated from the heavier polymers (e.g. PET, PS and PVC) of 1.38–1.43 g/cm³ density, which will sink. Hot water is mostly used in this process to remove impurities and separate the polymers through flotation. Wet shredding technologies combine shredding and friction washing in an integrated manner. This approach has the advantages of reducing flake losses from the crushing chamber and enabling blade cooling and reduced blade abrasion.

The techniques most practiced in Vientiane involve having a separate size reduction grinder unit coupled with large open density floatation units (steel, water-filled tubs) that have water inlets and drain valves. The density floatation units are fed with the flakes through closed auger units that convey materials into the large floatation washing tank units. The washed plastic flakes are then dried to remove the water and some sand particles, either mechanically (via expensive machines) or by spreading them out on tarpaulins in the open. Junkshops and consolidation centres in Vientiane mainly employ the latter approach as it helps to cut down on the pre-processing costs during flake production.

3.2.3 Plastic losses and leakages during shredding, washing and drying

Various handling processes during the shredding and washing stages can cause plastic material to escape into the environment. Integrated shredding and washing units, or coupled washing and shredding units, may help to reduce the risk of this occurring. However, these units may not be suitable for some production configurations.

More specifically, plastic material losses can occur while loading the grinders, during the griding process and when the shredded plastic and flakes are discharged. Flakes, small chips of plastic and powders often escape into the immediate environment during agitation, cutting and shredding. Older grinders and shredders, and those with an open design, are particularly known to release fragments of plastic that often appears as fine, dust-like emissions and are carried into the atmosphere. These airborne particles settle on the surrounding equipment and surfaces and create an inhalation risk for workers. The issue is particularly prevalent in small, enclosed facilities with axial aspirators or axial ventilator fans installed on the roof, but without dust capture and filtering mechanisms. Investment in sophisticated dust capture and filtering devices appears to be a secondary priority and an added expensive for recycling facilities.

Floatation washing processes also contribute to plastic losses during process. Shredding and washing are not fully mechanized processes in junkshops or consolidation centres in Vientiane and rudimentary methods that involve manually collecting floating plastic scraps with plastic sieves are common practice. These methods can cause washing water that is contaminated by microplastics to spill onto the floor and around the body of the machines (Brown et al., 2023).

A range of measures can be put in place to prevent, contain, and remediate plastic losses from shredding, washing and drying. These measures are quite diverse, and their effectiveness may be based on the ability of a facility to tailor the specific intervention to their own operation, configuration, and handling practices. However, overarching principles and guidance on proper housekeeping and handling procedures can be broadly applied.

It is recommended that facility owners and shredding machine operators start by anticipating where and when plastic material could be released during the shredding process and in what form. Preventive and alternative steps should then be taken to minimize this risk.

Preventing and containing plastic loss during shredding, washing, and drying

- Ensure that wastewater from pre-cleaning, washing, and rinsing is not released into drains or water bodies.
- Filter wastewater with appropriately sized nets and filters to remove plastics, channelling permeates into properly designed wastewater treatment units in compliance with national standards.
- Optimize the washing process by regulating water flow using valves to limit the supply to the grinding and washing units in integrated systems.
- Pave the pre-washing working area to facilitate cleanup and prevent microplastics, pellets and flakes from spreading.
- Consider designing pavement floors with slopes and berms to act as containment barriers in paved working areas.
- Calculate and optimize water quantity and plastic input into washing units to prevent spillage and clogging.
- Operate the conveying system properly to avoid clogging and anticipate potential plastic losses during blockage clearing by placing catch pans or tarpaulins under the working area.

3.1.6 Bagging and storage

Plastic, mostly PET, flakes produced in medium- and large-scale recycling facilities are typically bagged in woven PP sacks and stored prior to being transported to buyers. Under poor handling conditions, these flakes can be released into the immediate environment within bagging and storage areas.

Unlike advanced formal recycling enterprises that use highly automated systems for bagging and warehousing, most consolidation and pre-processing centres in Vientiane manually fill the sacks. Plastic can easily spill during this process or escape through punctures in the bags caused by various factors during storage. Attempts must therefore be made to minimize the risk of spillage during filling and bagging, and cleanup measures must be instituted to ensure the prompt removal and safe disposal of flakes should spills occur.

Based on the specifics of their storage conditions, enterprise owners and workers must anticipate potential agents that could cause plastic flakes to leak while in storage. Factors such as punctures from nearby materials, the inadvertent tearing of storage sacks by workers, rodents, etc. must be controlled and eliminated where possible.

Preventing and containing plastic loss during bagging and storage

- Implement immediate cleanup measures for collecting and disposing of spilled flakes, with tools like brooms, dustpans and collection buckets readily available.
- Regularly clean up flakes and powder spilled during the bagging process, and consider using bagging equipment designed to prevent losses.
- Choose puncture-resistant bags, like woven PP bags, for bagging plastic flakes, and line larger containers with puncture-resistant material.
- Properly collect and dispose of spilled, contaminated or undesirable flakes.
- Securely stitch up and seal flake sacks once the desired weight is attained.
- Consider environmental exposure factors when selecting storage sites, protecting flakes from wind, sun, water, flood and potential vandalism.
- Designate clear, accessible storage areas with paved and clean floors.
- If using unpaved floors, ensure dryness and cleanliness, and protection from vegetation, rodents and waterways.

Section 4

Operational practices and guidelines for preventing plastics and pellet leakage from mechanical recycling factories

4.1 Preventing plastic leakages from plastics in recycling factories.

Due to the scale of production, and the type and quality of materials they deal with, plastic recycling factories in Vientiane adopt a mix of manual, fully mechanical, and semi-mechanized processing operations to weigh, clean, shred, dry and pelletize plastics (Figure 8).

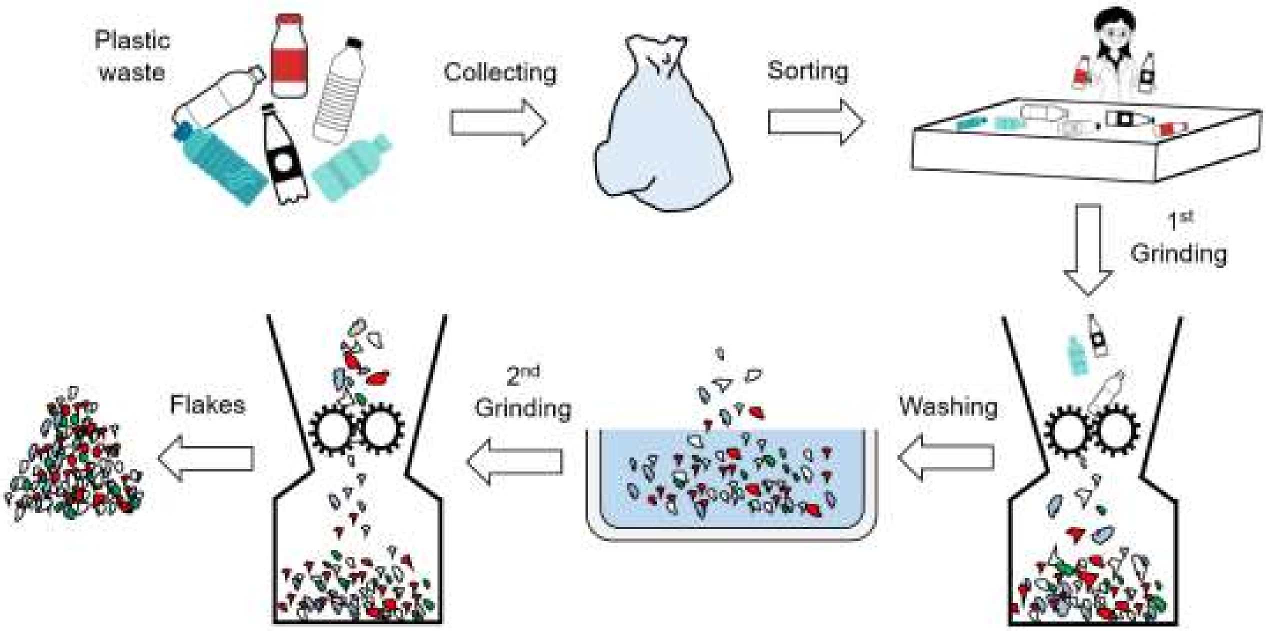
Generally, these factories receive both domestic and imported plastic scraps as their raw materials. They typically produce recycled resin pellets for the international market, although some sell to the domestic market too. Extensive sorting and cleaning are therefore required to ensure pellets meet market quality grades.

Based on their relationships with multiple junkshops, collection centres, consolidation centres and pre-processing centres, factories receive source plastics of varying degrees of purity, colours and polymer mixes. These require various levels of pre-processing, prior to being turned into pellets. Therefore, recycling factories will establish the same pre-processing operations that can be found in consolidation and pre-processing centres, with the addition of some other processes such as de-baling, mechanical drying, melting, extruding, pelletizing and bagging. The following guidelines are designed to help recycling factories in Vientiane prevent, reduce, contain and clean up any plastic and resin pellets leakages and losses that can occur during these processes.

4.1.1 Reception and de-baling

Recycling factories and plants receive post-consumer recyclable plastic from both domestic dealers and international markets in different forms, packaging and quality conditions. Plastic waste bales, especially those made up of PET bottles from

Figure 7. Mechanical recycling process of post-consumer plastics (Delvar et al., 2019)



Preventing and containing plastic loss during reception and de-baling

- Ensure that the received plastics, whether in bales, PP sacks or bulk hard plastic form, are stored within clear and clean factory premises, in compliance with relevant regulations.
- Position weighing bridges strategically within the recycling premises to connect reception areas, offloading areas, storage areas and the recycling operations enclosure.
- Keep plastic material reception and storage areas clean, free of vegetation, dry and in compliance with regulations.
- Design reception areas to contain plastic materials and prevent losses, with paved areas being the preferred choice for receiving plastics into the facility.
- Use pallets (wooden or plastic) to elevate plastic waste bales in stacks above the ground, so that they can be lifted easily by forklifts and to minimize the risk of abrasion and mishandling.
- Collect and properly manage PP baling twine, ropes or wires during de-baling.
- Train forklift operators in damage prevention and proper cleanup procedures.
- Keep plastic bags and other loose film wraps away from operational areas, as they can wrap around forklift wheels and cause mechanical problems over time.

the international market, may be bought at different purity and quality levels, as either post-commercial or post-consumer.

Received plastics bales are de-baled and pre-processed on site to separate the plastic into various quality, colour and polymer streams. In some advanced, highly mechanized factories, compacted bulk bales are fed into bulk handling de-baler systems with singulation capabilities. In Vientiane however, de-baling is usually done manually, and the bales are moved with light-duty forklift trucks. A commonly observed practice is the temporary pre-storage of plastic waste bales outside (within the premises of the factory) for a few days to remove odours and other potential contaminants.

Minimal plastic waste is released during the reception and de-baling process. Where losses can occur is through rough handling and forklift movements, which can cause small fragments to break off from the bales, and the poor handling of rejected, low value or unrecyclable materials. However, it is still important to anticipate problems and install measures to prevent potential losses.

4.1.2 Primary sorting and label scrapping (manual and semi-mechanized)

Received recyclable plastics at recycling factories undergo pre-sorting, primary sorting and secondary sorting processes to ensure polymeric purity for resin pellets. Pre-sorting rapidly separates recyclable plastics following material reception and de-baling, while primary sorting intensifies the process, enhancing the quality of the plastic being fed into the mechanical processing lines. Thorough sorting is crucial as recyclers are required to meet certain quality specifications with their resin pellets, and contaminants can degrade the physical and chemical properties of recyclable plastics during processing, diminishing their quality and value.

Primary sorting follows in-facility pre-sorting, which is primarily aimed at separating plastic polymers into different quality grades and categories. The degree of impurities or multi-component plastics in received materials influences this step. The polymeric purity of pellets is compromised if the plastics are not sorted properly. For instance, PET bottles with PP or HDPE caps may require sorting and separation during primary sorting.

Workers, mostly women, manually sort the plastics based on colour and polymers, removing contaminants. This process requires a high level of skill in order to spot, isolate and remove particle contaminants. While conveyor belts can enhance productivity, Vientiane recycling factories typically rely on manual labour for primary sorting. Some use semi-mechanized sorting on conveyor belts for

Preventing and containing plastic loss during sorting

- Maintain clean and clutter-free working areas for primary sorting, keeping them clear of extraneous materials, tools and equipment.
- Ensure that the sorting location is free from drains, vegetation, puddles, watercourses and slopes.
- Take preventive measures against potential causes of plastic loss, such as flooding and wind, by installing suitable countermeasures during the sorting process.
- Establish and enforce housekeeping procedures and protocols to ensure the diligent adherence to prevention and containment measures.
- Ensure that workers understand and follow protocols for the handling and disposal of rejects, complying with relevant national regulations including the Processing Manufacturing Law 2013, Environmental Protection Law 2012, Plastic Recycling Factory Decree (No. 682/MOIC, 2020) and Industrial Waste Discharge Regulation (No. 180/MOIC, 1994).
- Keep brooms and rubbish collectors readily available, along with holding containers and sacks for rejects.
- For semi-mechanized systems with conveyor belts, regularly service the conveyor systems to minimize downtime.
- Use belts with the right specifications, providing a sufficient incline and friction to retain materials while minimizing abrasion.
- Anticipate and prevent the overloading of conveyor belts or sorting tables to avoid spillovers and unintended losses.

high-value polymer streams, but the process remains predominantly manual.

Apart from rejects and particle contaminants, plastic seals, caps and films often litter primary sorting areas. The proper handling of these rejects and hard-to-recyclable plastic materials is crucial to prevent losses and environmental leakage. Maintaining clean sorting areas and implementing area-specific containment measures is essential, whether using concrete or non-paved working areas.

4.2 Shredding, grinding, washing and drying

4.2.1 Shredding and grinding

Shredding is the first step in the size reduction process, where pre-sorted plastic materials are cut into smaller pieces for further processing into secondary raw materials. It helps the mechanical plastic recycling process by reducing a wide range of plastic materials to reusable scraps that can be easily cleaned, separated into different polymers streams, dried and melted to produce resin pellets. At the shredding stage, plastic materials still contain various types of contaminants including sand particles, chemicals, and organic matter. The level of contamination will vary depending on the source of the recyclable packaging and degree of pre-processing cleaning. The end products of shredding pieces of plastics or flakes, which are further processed in order to be turned into resin pellets, or uniform flakes that are typically between 20 mm and 200 mm in size. The size requirements often vary based on market specifications and quality requirements.

The shredding process in recycling factories is similar to the one described in section 3.1.5 for junkshops, consolidation centres and pre-processing facilities. The mechanisms and pathways for plastic material loss are also the same and so the same measures can be taken to prevent this from occurring. Grinding further reduces the particle size of the shredded plastics (flakes and scraps), prior to melting and extrusion, and can be done as wet or dry. Wet grinding reduces potential plastic losses through dust generation. Grinding is particularly suitable for HDPE polymer processing, where a hopper feeding system is used.

Some considerations for choosing shredders and crushers for recycling factories

Plastic polymer type

- What type of plastic (PP, PE, PVC, etc.) will be processed and in what form (film, sheet, parts, bags, lining, etc.)?
- Do you require a highly specialized shredder, or do you need a versatile crusher or shredder that can handle various materials?

Size reduction requirements

- What are the dimensions of the material to be crushed and loaded into the crusher or shredder? This will influence the crusher (shredder) type and size:
  - Knife crushers are suitable for materials up to 15 mm thick.
  - Shredders are universal and can handle materials of any thickness.

Shredding mechanism

- How will the material be unloaded from under the crusher (shredder) – through pneumatic transport, via a conveyor or by being poured into the receiving hopper (box) under the crusher or shredder?
- What fraction of crushed material should be at the outlet after shredding? This determines the filter mesh size on the crusher (shredder), affecting performance. Smaller mesh diameters reduce shredder or crusher capacity.
- Evaluate different shredding mechanisms (e.g., single shaft, double shaft, granulators) based on their suitability for the type of plastics and the desired output.

- **Throughput capacity**
- What is the deigned shredding capacity, size is expected? This will affect the size and cost of the plastic crusher (shredder).
- How will the material be loaded into the crusher (shredder) – manually or by conveyor?
- For medium and large crushers (plastic shredders), manual loading can be challenging, and a conveyor allows for easier handling. Additionally, a conveyor facilitates the installation of a metal detector, protecting the knives and rotor from metal pieces. Assess the shredder's throughput capacity to ensure it can process materials at the required rate without causing bottlenecks in the recycling process.

Durability and maintenance

- Look for a shredder that is durable and requires minimal maintenance to maximize uptime and minimize operating costs over the long term.

Energy efficiency

» Consider the energy efficiency of the shredder to minimize operating costs and environmental impact.

Safety features

» Ensure the shredder has appropriate safety features to protect operators and comply with safety regulations.

Integration with existing equipment

» If integrating the shredder into an existing recycling system, ensure compatibility with other equipment and processes.

Budget

» Evaluate the initial cost of the shredder as well as long-term operating costs to determine the best value for your budget.

Preventing and containing plastic loss during grinding and shredding

» Implement containment measures in the working area to recapture plastics released during shredding, including paved floors and berms.
» If containment measures are impractical or costly, prioritize routine housekeeping measures for effective containment.
» Keep the working area clean, clear and sufficiently spacious, ensuring it remains dry without water puddles.
» For wet shredding processes, promptly fix leakages and use catch pans to collect accidental leaks.
» Use nets, mesh or tarpaulins in working areas to collect plastic materials released during the shredding process.
» Install a safety curtain on the inlet hopper of the shredder to prevent PET flakes from splashing out during operation.
» Configure feed hoppers for the effective delivery of recyclables into the shredding chamber.
» Ensure machines are regularly maintained and rusty or faulty parts are replaced to reduce downtime and minimize the risk of plastic losses.
» Use collection trays under discharge and loading valves, and connection points.
» Securely place the joints and connecting parts of grinders to avoid allowances that can serve as leakage points for microplastics and powders.
» Optimize the shredding process by reducing water flow (for wet shredding) and install control valves to limit the water supplied to the chopper and washing tank.
» Ensure cutting discs, knives and blades for shredding on the shafts are in good condition and sharp to avoid plastic fractures, minimizing the excessive generation of plastic dust.
» Place containers and sacks near discharge outlets to collect and capture plastic scraps that overshoot.

Preventing and containing dust and odours produced by shredding

- Use appropriately sized dust collection equipment in operations that generate plastic dust.
- Maintain dust collection equipment according to manufacturer guidelines.
- Select recommended filters suitable for the type and quantity of dust produced.
- Regularly clean or replace filters and collection equipment.
- Raise awareness about cleanup procedures for plastic dust spills.
- Implement housekeeping practices to minimize dust accumulation.
- Store captured plastic dust in leak-resistant containers.
- Educate employees on the proper handling of plastic dust.
- Promote methods to handle and process plastic to minimize dust creation.
- Adhere to national EIA regulations for containment.
- Consider installing a baghouse filter to reduce and control air pollution, if economically feasible.

4.2.2 Washing and density-based flotation separation

Plastic flakes washing

In the processing line, plastics typically pass through three or four washing stages (pre-washing, float washing, special washing, and rinsing) to eliminate contaminants. These contaminants, which include acid-producing substances, water, coloured impurities, acetaldehyde, labels and films, and inert particles, can compromise the quality of final processed plastic products. Pre-washing is carried out before the shredding and grinding steps. In Vientiane, it is crucial for locally sourced post-consumer plastic packaging to be pre-processed or cleaned. An effective pre-cleaning process can eliminate over 90 per cent of impurities (Nithitanakul et al., 2023). Hot water and chemicals are introduced into the washing drum or tank to facilitate the cleaning process of plastic materials. Vientiane utilizes both continuous and batch-type pre-washers, adapting the inlet feed designs to specific applications. Continuous batch pre-washers use a continuous material feeding and water circulation system, extending the service life of chemical water and reducing additive costs Batch washing allows plastic packaging to soak in chemical water for an adequate duration, which is suitable for recycling oil bottles.

Pre-washed plastics are subsequently shredded, friction washed and shredded further into smaller plastic flakes. Friction washing is done by a high-speed revolving rotor, as a special washing process with hot water and surfactant or alkaline solution (optional). Based on the desired quality of the flakes and pellets (e.g. food grade standards), subsequent washing stages may be required. Large amounts of water are consumed during the washing process, particularly for old washing units. Recent innovations have reduced the water consumption of washing units to about 2 m^3–3 m^3 of water per ton of material. Also, innovative technologies for the removal of organics and surface contaminants from flakes include dry cleaning, which cleans surfaces through friction without using water (Hopewell et al., 2009).

Density based flotation separation

Clean water is used to rinse the flakes in a tank with a low-speed agitator. Next, in the floatation separation washing line, smaller sized plastic flakes are separated based on their densities. Plastic flakes feeding into the flotation separation drum still have some degree of contaminants and more than one polymer type. The process uses the differences in the density of the materials to separate the various polymers (e.g. PET flakes may be separated from lighter plastics such as PE or PP flakes). However, the separation process can be quite difficult for polymers that have a similar density (e.g. PET is 1.3 g/cm3 and PVC is 1.5 g/cm3). A mechanical drying process is then employed to dry the plastic flakes (mostly PET flakes), whereas polyolefins are dried by a thermal dryer.

Occurrence of micro plastics in wash waters

Washing operations along the processing line are perhaps the main source of plastic leaks within recycling factories. The washing process generates copious amounts of wastewater that contains marked quantities of plastic particles (of varying sizes), and chemical and other particulate contaminants that pose ecological risks to the environment. Studies estimate that microplastic emission quantities in wastewater from recycling facilities and factories ranges from about 0.014 t/year to 5.8 t/year (Suzuki et al., 2022). However, these figures may vary for recycling facilities in Vientiane. Mechanical shearing and abrasion during the various washing processes can cause fine shreds, strands, fragments and microplastics to be deposited in sludge or water column as particulate suspensions. Washing drums, wash tanks and conveying systems can experience leaks or spillovers onto the floor. The washing process for flexible LDPE plastic bags is commonly characterized by the generation of micronized strands and filaments in the water column, in sludge, and around agitators or rotating baffles in the washing drum, and these are very difficult to reclaim. Finally, wash or cooling waters at the compounding and pellet-making stage may also contain microplastics and residual pellets that have broken off during the extrusion process.

4.2.3 Measures for preventing microplastic leakage in waste wash water

The handling of post-washing wastewater is also responsible for a major release of particulate plastics. Proper primary treatment measures must be implemented to pre-treat the wash waster effluent to reduce the level of plastic particulates. Some modern washing tanks are fitted with inner screen tubes that function as a de-watering device and filter for contaminants. The sludge components must also be properly treated prior to disposal in compliance with the relevant national and city regulations. Appropriate location-specific measures may be implemented to prevent, reduce and clean up plastic leakages during the pre-washing, flake washing and float washing processes. Among the surveyed recycling factories in Vientiane, the main way that they attempt to prevent plastic leakage during the washing process is by using rudimentary equipment such as plastic sieve bowls, nets and meshes to selectively remove some of the plastic particles from the wash waters. The use of pre-installed or integrated filtration systems is largely absent from their processing lines. Water leakages onto the floor are allowed to dry or are washed into wastewater channels with largely minimal filtration or plastic removal pre-treatments.

Preventing and reducing plastic losses throughout the various washing stages can significantly reduce the overall level of leakages within a recycling facility. This will involve the adoption of practical approaches suitable for each facility based on the setup of their processing line. While it may be impossible to entirely prevent all forms of plastic loss in some cases, systematic housekeeping measures and the enhancement of processing lines can help to reduce the level. Existing berms and containment boundaries must be kept clean and free of sand and sludge, as it is relatively difficult to clean up and recover plastic particulates stuck in dirt-filled rooms. Additionally, area-specific containment boundaries must be sufficiently designed to trap and contain plastic that has escaped from the processing line. While many facilities may be reluctant to invest in new technologies to help reduce their plastic leakages, it is reasonable to install effective housekeeping measures, operational protocols and routines to minimize these losses both in specific working areas and across the whole facility.

Flake de-watering and drying

Plastic flake de-watering and drying are critical aspects of the plastic recycling process, particularly when it comes to reducing the moisture content of

Preventing and containing plastic loss during washing

- Identify and evaluate the potential causes of plastic loss during the washing process (both mechanical and operational) and develop appropriate mitigation measures.
- Identify, design and install appropriate containment systems to trap and collect plastic flakes and pellets (area-specific and facility-wide containment systems may be installed).
- Optimize washing processes by correctly estimating the appropriate feed and water quantities to minimize the risk of spillage, clogging, entanglement and system overloads.
- Prevent leakages by ensuring influent and effluent pipes connected to wash tanks, and rotating drum friction washers, are unbroken, leak-free and fit for purpose.
- Promptly replace worn out machine valves and seals to prevent leakages.
- Optimize the chopping and washing process of raw materials by installing valves to limit the flow of water supplied to the chopper and washing tank.
- Use surface skimmers or vacuum systems to prevent loose pellets, flakes and powder for accumulating on the ground or floor.
- Ensure concrete water chambers at the base of conveyor systems can contain wash waters without spillages.
- Install an anti-spill mechanism for the washing tank to help limit the loss of water and materials, and to increase washing efficiency.
- Design effective conveyor units to reduce the risk that water will spill or flexible plastic films will become entangled around moving parts.
- Use high pressure washers to clean floors and recover stuck plastic particulates and filaments.
- Consider fitting drains, vacuums with screens or meshes on intake hoses to collect pellets without disturbing gravel.
- Install a sludge removal screw at the bottom of the wash tank (where possible) and ensure sludge treatment is carried out in line with regulations.
- Consider the use of hydrocyclones and centrifugation mechanisms within sink floatation systems, where applicable, to improve the effectiveness of the density separation process.
- Install a rotating net in the wash tank to collect small pieces of material that are not collected and transported by the vane.
- Increase the rinse time after washing by loading the resin through the waterspout.
- Installing more stainless steel nets along the washing tank to pick up small pieces of plastic before they are discharged into the water stream.
- Use biological detergents instead of dishwashing liquid to reduce the impact on the surface water environment.
- Add additional filtration to the compounding and pelletization wash tanks to remove smaller particles.
- Install filtration units in rotating drum wash tanks, where possible, based on the particle profile (designed to filter smaller particles) and that of the separation system.
- Use appropriately sized filtration systems in compounding and pelletization wash tanks to remove smaller particles.
- Employ reverse washing options with the flaps, where possible.
- Reuse wash water to cool plastic flakes to increase washing efficiency.
- Use natural surfactants to increase washing efficiency.
- Ensure berms and containment ditches are installed around working areas to trap spilled wastewater.
- Install baffles, skirts and booms in containment ditches or ponds.
- Place appropriately sized screens in all storm drains to match plastic particle profiles.

- Clean the storm drains regularly to prevent drain clogging and overflow, and particularly after it rains.
- Consider installing two-stage screens on storm drains to minimize clogging problems.
- Consider using water spraying systems and flushing of PET flakes with recycled wash water during friction washing to avoid clogging.
- Consider using demountable alloy steel paddles and screens instead of fixed ones for easy daily maintenance and repairs, as well as high abrasion resistance.
- Where applicable and practical, use a screw de-watering machine to remove the water.

flakes and films. Water from the washing process must be sufficiently removed from plastic flakes prior to the melting, compounding and extrusion, and pelleting processes.

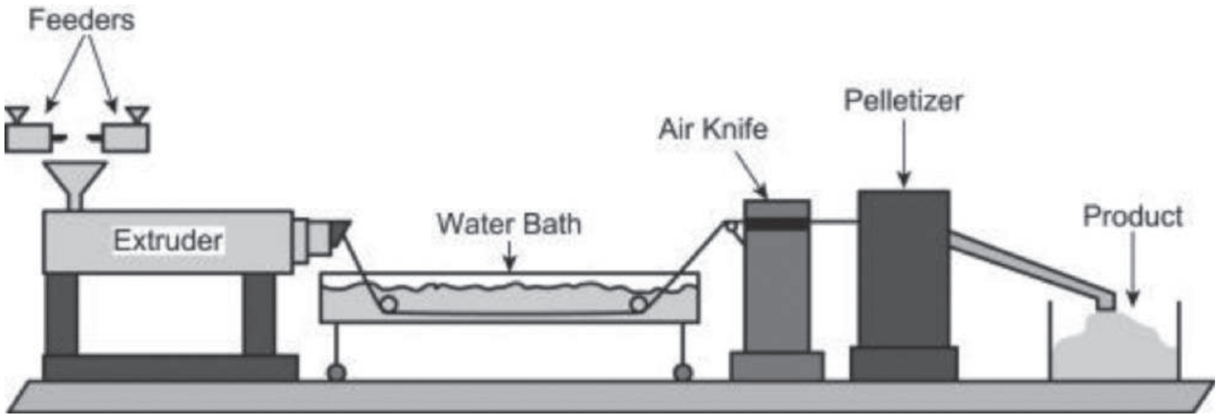
Both de-watering and drying methods have implications for cost and quality of output. Mechanical drying processes, in addition to extrusion and pelletizing, demand a high level of energy and consume significant amounts of electrical power, which has cost implications for the overall pellet production process. The use of mechanical de-watering machines is common and helps to reduce the moisture content of flakes significantly. In fact, various industrial-size screw de-watering machines are available for use to remove excess water from washed flakes. Similarly, the drying process may be achieved by using mechanical dryers or open-air drying. High-pressure blower system may be employed to blow shredded plastic flakes through a pipeline system with a hot air flow to ensure flakes to sufficiently dry before entering the extrusion and pelletizing process line.

At this stage, the sources of potential plastic loss or leakages include the handling of wastewater

Preventing and containing plastic loss during drying

- Design and install appropriate containment channels and drains with screens that match the profiles of particulate plastics.
- Install an effective wastewater filtering system to filter out microplastics.
- Ensure filter cakes and sludge are handled, treated and disposed of in compliance with relevant national regulations including the Industrial Waste Discharge Regulation (No. 180/MOIC, 1994), Processing Manufacturing Law 2013 and Plastic Recycling Factory Decree (No. 682/MOIC, 2020).
- Use a screw de-watering machine to remove material moisture.
- Install a mechanical drying system, where practical, to remove water from the plastic.
- Install a high-pressure blower system with a hot air stream, where practical, to mechanically dry flakes and reduce moisture significantly.
- Dry out plastic flakes for longer before feeding them into the extrusion and pelletizing process line
- If possible, avoid open air flake drying.
- Where unavoidable, carry out open air drying in enclosed, clear, accessible spaces within the factory premises, with measures installed to collect spilled flakes.
- Avoid open air drying by the roadside, near drains or waterways, or in areas with vegetation.
- Anticipate floods, strong winds, and human or animal dispersal agents that may cause flakes to escape into the environment during open air drying.
- Put measures in place to contain any potential flake losses during open air drying, and ensure any spillages are promptly cleaned up and effectively collected.
- Use cordless vacuum suction cleaners fitted with meshes or nets that match the profiles of plastic.

Figure 8. Compounding, extrusion and pelletizing process line[7]



from the de-watering process and open flake drying practices. Particulate plastics, particularly micro- and nanoplastics, are retained in wastewater during the mechanical de-watering process. Measures and systems must therefore be installed to properly handle, filter, treat and dispose of these. Some recyclers opt to dry flakes in the open air to reduce costs. While open air drying may be economically attractive, the downsides of this approach lie in the long drying time and the risk of pellet contamination with dust and foreign materials. Even more concerning is the risk that plastic flakes could escape into the environment during handling and drying. This is a very common occurrence in some recycling shops in Vientiane and one that leaves their drying areas, often open spaces and near vegetation, littered with flakes. Preventive, containment and cleanup measures must be put in place to prevent, reduce and remediate plastic flake losses during drying.

4.3 Secondary sorting or colour sorting

Secondary sorting, which involves separating coloured polymers like blue, yellow and natural flakes, may precede the melting and pelletizing stages. This additional sorting process, based on the physical properties of plastic scraps, aims to enhance the quality of the final pellets.

Advanced sorting technologies such as electrostatic sorting and near-infrared spectrum sorting are employed to achieve a more effective colour separation. The complexity and cost of technologies used in shredding, washing and drying, and primary and secondary sorting make them more suitable for larger enterprises that can benefit from economies of scale. In Vientiane, smaller recycling businesses often rely on manual primary sorting due to space limitations and limited capital investments, which restrict equipment usage in pre-processing operations.

4.4 Compounding and pelletizing

The plastic pelletizing process converts the sorted plastic flakes into pelletized plastics that can be used as clean raw materials for manufacturing processes (Figure 8).

It involves melting and compounding clean flakes into a new plastic material by using either a single or twin-screw extruder to produce hot, continuous, cylindrical filaments or strands of plastic. The strands pass through a water bath to remove the heat and solidify them, before being cut into pellets in the pelletizer. The screw compounding process may involve adding a colourant in the form of liquid, powder or concentrate to the molten polymer to alter the colour of the plastic, or combining multiple plastics with fillers, colourants, reinforcements, flame retardants and stabilizers to create a completely different formulation that possesses distinct properties and is suitable for specific end-use

8 source: Drobny, J. G. 2014

purposes. Several factors contribute to the quality of pellets, such as the type and quality of the plastic flakes, the type of pelletizing machine employed, and the heating and cooling system utilized. The quality of pellets can also be influenced by the transmission system and the extrusion process.

Primarily, three types of pelletizers are used in recycling factories: the strand pelletizer, the underwater pelletiser and the water ring pelletizer. However, only the strand pelletizer and underwater pelletizer are commonly used in Vientiane. The strand pelletizer cuts molten plastic strands into pellets, while the underwater pelletizer submerges the plastic melt into water to cool and solidify the pellets. The water ring pelletizer cools and solidifies the plastic melt in a ring of water before cutting it into pellets. The choice of pellets is influenced by the quality requirements and the type of flakes being recycled. Some recyclers may employ a second extrusion stage equipped with grit filter discs to remove impurities such as sand and dust from the plastic. The extruder's filter discs are recycled by subjecting them to a burning process that eliminates impurities present in the plastic. Insulation sleeves are wound around extruders to reduce heat loss and energy consumption when melting the plastic flakes. Despite this, the ambient temperature of the working environment around the extruder is often elevated. Plastic flake losses often occur when the compounding and extruding machine is fed via hopper loading. Additionally, plastic extrusion lumps are generated as waste during various stages of the extrusion and pelletising process, including the beginning of extrusion, cutting or pelletizing, startup cleaning extrudates, and during machine downtime

Preventing and containing plastic loss during compounding and pelletizing

- Ensure appropriate, area-specific containment measures are taken at the pelletizing line to contain pellets, flakes, and powder within paved areas.
- Provide catch trays or heavy-duty tarpaulins where suitable to facilitate the retrieval of flakes and pellets.
- Ensure the pelletizing working area is always clean and dust free.
- Immediately clean up and properly dispose of any spilled pellets.
- Provide brooms and dustpans and equip the pelletizing line working area with cordless vacuums suitable for outdoor cleaning and the collection of pellets and flakes.
- Consider using a unified, two-stage, integrated extruder to minimize the manual handling of plastic between stages (this also helps to eliminate uneven feeding).
- Use good internal control measures to detect leaks and avoid spills.
- Install sieves and mesh to collect rejected plastic, molten plastic waste and pellets.

when rejected exudates accumulate. Cooling water baths may also have microplastic particles.

4.5 Bagging, storage and warehousing, and transportation

Plastic resin pellets are typically bagged and stored before being shipped to both domestic and international buyers. Like many other recycling factories in the region, recycling factories in Vientiane store plastic pellets in woven PP bags (usually 50 kg) due to their durability and relatively better resistance to puncture and tear. As stipulated in the Plastic Recycling Factory Decree (No. 682/MOIC, 2020), it is prohibited to store waste outside of the factory area.

The bagging process is mainly done by a hopper system, as well as manually, and often sees pellet spillages. Good housekeeping and containment measures must be in place to prevent pellet losses and emissions from working areas. The storage of bagged pellets must be done properly to prevent recontamination, degradation and moisture build-up, and optimal conditions must be maintained. Poor storage conditions for plastic pellets leads to a deterioration in quality and a decline in market value, ultimately resulting in economic losses for recyclers. Plastic pellets can be stored for a long period of time for speculative inventory management or for short periods of time before being transported to buyers. For both storage systems, bags of pellets must be stored on pallets (wooden or plastic) within factory premises, typically under sheds and covered from exposure to sunshine and excessive heat. While some recyclers employ manual labour to move and stack bags of pellets, forklifts are used in large facilities to facilitate high stacking and reduce tedium.

The Decision on Industrial and Handicraft Waste Management (2012) defines the procedure for waste management, including the transportation and disposal of waste. To prevent plastic losses during bagging, storage and transporting, recycling factories should conduct a thorough evaluation to identify recurring causes of losses. They should implement specific mitigation measures, and design warehouse and handling protocols to limit pellet spills.

Preventing and containing plastic loss during bagging, storage and transportation

Bagging

- Regularly clean up spilled pellets during bagging, using equipment designed to prevent losses.
- Use puncture-resistant bags, such as reinforced or 50 kg woven PP sacks.
- Immediately move and stack filled sacks to prevent seepage.
- Provide dustpans and brooms for sweeping and collecting spilled pellets.
- Promptly seal leaking containers and hoppers, placing catch sacks at leakage points.
- Implement warehouse and handling procedures to minimize the risk of pellet spillage.
- Dispose of collected pellets in accordance with national regulations.

Storage and transport

- Allocate designated storage space for pellets, keeping areas clean, accessible and free from water, dust and sunlight exposure.
- Consider potential risks of rain, flood and rodent attacks, ensuring sacks are safeguarded during storms.
- Maintain air humidity below 80 per cent and ensure pellet stores are completely dry, especially in newly constructed spaces.
- Use pallets to elevate stored sacks above bare floors, promoting aeration and preventing ground contact.
- When faced with damp walls, use prefabricated silos or provide cladding with air space to prevent moisture.
- Inspect pallets for sharp objects and address punctures promptly, repairing or replacing damaged packages.
- Train forklift operators to prevent damage and ensure accessible cleanup kits for all staff.
- Implement handling procedures to minimize bag punctures with forklift tines.
- Stack bags on pallets in tight, interlocking patterns to enhance stability.
- Examine pellet sacks for punctures and leaks before loading and unloading.
- Load pellets on trucks with pallets in well-stacked arrangements for efficient offloading and puncture prevention.
- Avoid disposing of, or cleaning up, spilled pellets within conveying trucks during transportation; handles spills within the factory premises instead.
- Ensure pellet transport trucks are equipped with cleanup kits (broom, dustpan, repair tape and enclosed bucket) at all times.

Section 5

Waste management in plastic recycling facilities

5.1 Solid waste management in plastic recycling factories

Waste management is an essential part of routine housekeeping practices within industrial set-ups, including plastic recycling factories. Plastic recycling factories also generate large volumes of waste in different forms that need to be properly handled and discharged in an environmentally sound manner. This waste can include solid waste, hazardous waste, waste electrical and electronic equipment, wastewater, gases and particulate wastes that can pollute the air, water and soil.

Lao PDR has various environmental and industrial regulations that govern the waste disposal responsibilities of recycling factories. Factories must therefore manage, treat and dispose of their waste streams in an effective and environmentally friendly way that aligns with these rules. The Plastic Recycling Factory Decree (No. 682/MOIC, 2020) stipulates that every plastic recycling plant needs to have a solid waste management treatment system. The design of the treatment system must be submitted to MOIC to get approval before construction can begin. Wastewater from plastic recycling plants must also be treated to meet the standards of MOIC before being discharged into the environment. Article 8 of the Industrial Waste Discharge Regulation (No. 180/MOIC, 1994) requires industries that are treating their own waste to follow the standards set by the regulation. For example, plastic recycling facilities and factories generate plastic waste, organic waste, macro- and microplastics, and sludge from the washing and filtration processes. Solid waste must be handled and disposed of properly without causing harm to the environment.

Plastic waste may be produced during production breaks, machine tests or in the start-up phases of the machines. If the waste material is pure, it can be returned to the production line to be recycled. Plastic lumps and waste produced during extrusion and pelletizing may be recycled to effectively reduce the impact of the recycling process on the environment and disposal costs. Similarly, plastic rejects, labels, film flakes and pellets that cannot be returned to the recycling line must be properly disposed of in compliance with relevant regulations. Large volumes of sludge containing microplastics must also be properly disposed, with many plastic recyclers in Vientiane collecting it in woven PP sacks and disposing of it at the KM32 landfill. In addition, machine parts and certain steel components may be segregated and sold to metal scrap dealers for recycling.

Organic waste largely consists of food waste and vegetation that has been removed from the factory premises. Where large volumes of daily food waste are generated, mostly by workers, it can be sent to integrated resource recovery facilities to produce compost. Another option is to install small-scale batch biogas systems that can be fed with organic waste to generate energy for other applications within the factory. To improve solid waste management in factories, guidelines must be put in place and workers trained on the environmentally sound management and disposal of the waste generated by the factory.

Solid waste management in recycling facilities

- Develop and implement a comprehensive solid waste management strategy for the entire recycling facility.
- Ensure waste disposal methods align with national and city-level regulatory provisions for recycling factories.
- Promote waste reduction and segregation strategies among staff and in all operations.
- Provide labelled waste segregation bins at key points within the factory to facilitate proper waste sorting.
- Conduct regular training sessions for factory workers on waste reduction, segregation and the proper handling of different waste types.
- Educate staff on identifying various waste categories, including toxic and hazardous waste.
- Establish routine cleaning days for thorough working area cleanup and waste disposal.
- Introduce award schemes to motivate adherence to proper waste reduction and management practices.
- Install at least one pellet-specific waste container in each pellet-handling area.
- Prohibit loose pellets from accumulating on the ground or floors.
- Use properly labeled waste bins, assign monitors and regularly check for full bins.
- Use separate containers for recyclable and non-recyclable pellets, as well as for recyclable and non-recyclable plastics and organic waste.
- Avoid disposing of plastic-containing sludge in open soils and vegetation.
- Store and reuse emptied sacks, ensuring proper handling, storage and transport to prevent pellets from escaping.
- Encourage the recovery and recycling of plastic resin bags and stretchable plastics, when feasible.
- Dispose of packaging through incineration or in well-managed landfills in accordance with national regulations.
- Consider shredding and recycling plastic extrusion lumps to reduce landfill disposal costs.
- Send organic wastes to material recovery facilities for compost production or install batch biogas systems for organic waste conversion.
- Avoid burning waste within factory premises.

5.2 Hazardous waste management

Electronic and electrical gadgets containing multi-component plastic are often sent to recycling facilities for the recovery of hard plastic components for recycling. Electronic and electrical components, batteries, LED bulbs, LCDs, keyboards, scanners, printers, laptops, monitors and TVs etc. must be properly handled and disposed of in an environmentally sound manner. Hazardous waste components including certain machine parts and chemicals must be carefully stored and separated for disposal. If proper handling and disposal measures are not put in place, hazardous waste may be improperly dumped or stored, which poses a risk to the environment and workers. However, hazardous waste disposal must be carried out in accordance with the relevant legislation:

Environmental Protection Law (2012): Articles 37 and 38 define the management and disposal of toxic and hazardous waste, and the prohibited importing of hazardous waste.

Ministerial Instructions on Hazardous Waste Management (2015): Article 2 classifies hazardous waste based on the definition provided in the Basel Convention, while articles 4 and 5 cover the import and export of hazardous organic waste.

Hazardous and infectious waste management in recycling facilities

- Install separate collection bins for hazardous waste.
- Train and educate staff on the potential impact that improperly handling hazardous waste can have on the environment and their health.
- Plan, design and implement hazardous waste management awareness programmes for workers and staff, tailored to the types of hazardous waste received at the recycling facility.
- Implement appropriate storage mechanisms for hazardous components, avoiding prolonged outdoor exposure to sunlight and rain to prevent hazardous substances from potentially leaking into the environment.
- Ensure the proper storage and disposal of grease, petrochemical waste, solvents and chemicals.
- Collect infectious waste separately and dispose of it in compliance with relevant national legislation.

5.3 Wastewater management

Plastic recycling facilities, utilizing significant water volumes for processes like washing and cooling, discharge wastewater containing plastic particles and various contaminants. Typically, many washing steps are carried out to ensure coarse substances and pollutants are effectively removed from the plastics. Throughout the process, from pre-washing to cooling of extruded plastics during pelletizing, different volumes of wastewater are produced, each with varying levels and types of contamination. Optimizing water usage and implementing recycling measures is advantageous for recycling facilities due to the considerable expenses associated with purchasing process water. Most of the recycling factories in Vientiane use batch water flows. Whether utilizing batch or continuous water flow systems, the imperative to reuse water in a closed loop arises for cost-effective operation of a plastic washing line. Daily water savings can be attained in a closed loop water reuse system.

Wash waters from the recycling process is often loaded with high concentrations of microplastics. Without effective wastewater treatment,

Wastewater management in recycling factories

- Develop water-use reduction measures, particularly for washing processes.
- Reduce the level of plastic particles in wastewater by installing multi-stage filtration systems for specific operation effluents and facility-wide filtration units based on respective particle profiles.
- Install wastewater collection and recycling tanks to reduce water consumption and wastewater.
- Install a multi-compartment treatment tank, including a settling chamber to separate larger contaminants like soil and sand, and a reaction compartment filled with chemicals to aid flocculation and sedimentation, removing pigments and suspended residues.
- Recycle treated water using a cooling tower or by expanding and extending the cooling water tank.
- Replace normal cleaning chemicals with biological cleaning chemicals and natural detergents, calculating the right amount to minimize detergent use.
- Install a filter to collect plastic debris and dead plastic, recovering plastic from wastewater, improving wastewater quality and reducing impurities in the drainage system.
- Construct a two-compartment sump, with the first compartment for wastewater and the second for flocculation and settling (add chemicals, if needed). These measures enhance washing efficiency, reduce plastic impurities and minimize the discharge of water into the environment.

the mechanical recycling of plastic may contribute to increased microplastic emissions into the environment. Notably, wastewater from recycling process can be difficult to characterise due to the varieties of pollutants they may contain. Examples of pollutants may have high BOD and COD loading, colour microplastics, fats, grease, glue, ink, oil, active pharmaceutical ingredients, antibiotics, hormones, etc. Customised wastewater treatment solutions are best recommended. However, installing multi-stage water treatment options is crucial to capture, remove and treat wash wastewater. Primary treatments, such as multistage, multilevel filtration systems, are recommended to remove microplastics and other particulate matter. Various technologies exist for treating wastewater, but their feasibility depends on the investment cost and suitability for environmental and business conditions. While advanced recycling facilities have secondary treatment and water recovery systems, in Vientiane, basic sedimentation and oxidation holding ponds are employed.

Sludge dredging is occasionally done, but this process may not adequately remove buoyant plastic polymers. Proper wastewater management measures, in compliance with national regulations, are essential for recycling facilities in Vientiane.

5.4 Air pollution management

Air quality management is one of the key essentials of recycling factory waste management. Apart from controlling the plastic waste dust that is generated from shredding and grinding, maintaining ambient air quality is paramount for the health of workers and the environment.

The extrusion compounding pelletizing line involves melting plastic flakes, a process that releases carbon monoxide (CO), nitrogen oxides (NOx) and sulphur oxides (SOx), odours and hydrocarbons, glue and more. Another source of air pollution is the spontaneous combustion of filters, and uncontrolled combustion conditions, which can generate soot, smoke, CO, methane (CH4) and hydrocarbons; volatile organic compounds such as benzene; and volatile organic compounds, including polycyclic aromatic hydrocarbons (such as benzopyrene). Depending on the impurities on the filter mesh, heavy metals such as lead and mercury may also be generated. These are emissions that are harmful to human health and can pollute the environment. Polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) or polychlorinated biphenyls (PCBs) are unintentionally generated persistent organic pollutants that can also be emitted when burning filters outdoors. Intentional waste burning must be avoided at all costs, as it releases pollutants into the air that are then deposited on the land or enter the aquatic environment. Contaminants such as mercury, PCBs, dioxins and furans are very persistent in the environment and bio accumulative, which means they accumulate in predators at the top of the food chain. The bioaccumulation of pollutants usually occurs indirectly through contaminated water and food.

Control measures must therefore be installed to limit the generation of dust and harmful air pollutants within factory premises. Proper ventilation must also be ensured to create a more comfortable working environment.

5.5 Conclusion

These guidelines for preventing plastic pollution and pellet leakage from recycling facilities emphasize the critical importance of implementing comprehensive measures at every stage of the recycling process. From the initial reception of plastic materials, sorting, shredding, washing and drying to bagging, storage and transportation, careful adherence to best practices is essential. These guidelines stress the need for proper infrastructure, housekeeping routines and employee training to minimize the risk of plastic losses.

Key points include the use of containment measures, regular cleanup procedures, and the selection of appropriate equipment to prevent spills and leaks during various operations. Storage and transportation practices are highlighted, emphasizing the importance of designated storage areas, proper stacking, and secure loading and unloading procedures. Additionally, the guidelines stress the significance of efficient dust and pellet containment measures, waste management strategies and responsible wastewater treatment to safeguard the environment.

Ultimately, the success of these guideline relies on their consistent implementation, fostering a culture of responsibility, awareness and continuous improvement within recycling facilities. By integrating these practices into daily operations, recycling facilities can contribute significantly to minimizing plastic pollution and pellet leakage, aligning with environmental sustainability goals and regulations.

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Annex 1

Stakeholders	Roles and responsibilities
Ministry of Industry and Commerce (MOIC)	Ministry of Industry and Commerce facilitates the importation of equipment and machinery, seeds and vehicles related to the development of renewable energies, Department of Industrial play an important role on approval, monitoring and inspection processing of factory to meet environmental standard. In addition, MOIC also work on the approval of import and export products including plastic scrap.
Ministry of Public Works and Transport (MPWT)	MPWT provides construction techniques for landfills and access road to the landfills in accordance with the strategic plan, certify and supervise construction techniques for waste sorting and processing plants, introduce appropriate techniques for the use of waste transport vehicles.
Ministry of Natural Resources and Environment (MONRE)	Ministry of Natural Resources and Environment is responsible for undertaking research on the use of water resources and will collaborate with the. Further they are responsible for developing and enforcing requirements and guidelines and to minimize environment and social impacts of RE development through oversight of implementation of IEE and EIA. The Ministry of Natural Resources and Environment is the main task and responsibilities includes the preparation of environmental laws and regulations. It also intends to come up with a master plan for solid waste management as the national counterpart to some international support programmes in the solid waste sector.
Ministry of Planning and Investment (MPI)	MPI is the government agency responsible on developing strategies, Master plans, Planning for National Socio-Economic Development Plan (NSEDP), Mechanisms and Policies related to economic management, statistics, the promotion and management of domestic and foreign private investment of Lao PDR, to attract and seek assistance and international cooperation. Furthermore, MPI is the main government agency approving master project of public and private investment. Medium of small size of investment fall under Department of Planning and investment at provincial and district level. In addition, MPI play important role on developing and promoting a National Green Growth Strategy (NGGS).
Ministry of Public Health (MOH)	MOH has role on overseeing infectious waste generate from central hospitals, and clinics throughout Vientiane city to pay attention on separation of infectious waste. So that it does not mix with general waste and separate storage for the convenience of transport units for proper disposal. MOH responsible for disseminating and monitor the implementation of the decision of the Ministry of Health regarding the hospital waste management.
Vientiane City office of Management and Service/ Urban Development (UDDA)	VCOMS has role on overseeing of the municipal solid waste management such as collection, treatment and dumping at landfill. In addition, VCOMS play important role on creating and improving legislation under the law on waste management in Vientiane Capital as well as develop a pricing structure and new mechanism for waste collecting fee in comply with each period. Since, VCOMS has public private partnership module with private sector. Monitoring and evaluation performance of companies are under responsibility of VCOMS.

Policies and regulations	Key information
National Social – Economic Development Plan 9th (NSEDP) 2021	NSEDP 9th for 2021-2025 to promote green growth and climate change actions. The strategy seeks to improve waste management systems to make them more efficient and effective by developing peoples' awareness around disposal, reuse, and recycling; improving the financial mechanism of waste management; and building and improving infrastructure. This approach includes encouraging and promoting domestic and foreign investors to invest in waste- related business activities, to reutilize wastes, decrease the use of resources, and create jobs. These will be further supported through the implementation of circular economy, which has been highlighted as a key task under the 'green growth and climate action' policy directions. This sector offers economic, environmental, and social opportunities if the waste is well managed within the life cycle. Promote the circular economy model to reduce reliance on the natural resource sectors and reduce environmental degradation, including reducing solid waste and other wastes, reducing air pollution, water pollution, and noise pollution, and promoting significant waste management and recycling.
Environmental Protection Law 2012	The Environmental Protection Law defines principles, regulations and measures related to environmental management, monitoring of protection, control, preservation, and rehabilitation, with quality, of mitigating impacts and pollution created by anthropogenic loads or by nature. Article 35 Pollution Control Measures: An operator must release, discharge of wastewater, dispose, burn, burry or demolish wastes and rubbish in areas identified by regulations. Production, importation, utilization, transportation, storing and demolishing of toxic chemicals or radioactive residues shall strictly comply with the specific regulations and standards. Article 68 General Prohibitions: 4. "Burn, bury, dispose and demolish wastes, release and discharge wastewater into canals, rivers, natural water sources or any sites without treatment based on the technical standards."
Processing Manufacturing law 2013	This law defines regulation and rule on the processing manufacturing to promote activities and increasing product, employment, move forward to modern technology as well as consider on environmental protection. Chapter 6 is environmental protection which included green industry, level of risk of environmental impact of factory, environmental standard, pollution control. Every industry must ensure on control pollution such as wastewater, air pollution, solid waste, noise pollution to meet the environmental standard before discharging to environment[1]
Industrial Waste Discharge Regulation. No. 180/MOIC, 1994.	This regulation aims to manage threats from the disposal of industrial waste or wastewater that can detrimentally impact water quality, health, and human life (Article 1). Any solid materials, including plastic bags, are prohibited from being disposed of into the environment and public water sources (Article 3 number 3.3). Additionally, industries treating their waste should follow the standard set by the regulation (Article 8).

Policies and regulations	Key information
Decree on Plastic Recycling factory No. 0682, 2020	The decree was issued by MOIC regarding the operation of the plastic waste processing plant to ensure the management of the operation in accordance with the conditions and technical standards of the plant and alignment with the relevant laws and regulations, aiming to reduce the impact on the health of the workers in the factory and reduce the impact on the environment, contributing to the implementation of the socio-economic development plan according to the green and sustainable direction. This guide includes 14 articles including standards, conditions for setting up a plastic waste processing plant, technical standards of the plant, waste treatment provided to the factory, transportation of plastic waste treatment, waste import, import certificate and other requirements. It was mentioned that to establish any plastic recycling plant, EIA or IEE need to be conducted along with getting certificate and business license. It's prohibited to store waste outside of plant area. Location of the plastic recycling plant where is not located in special economic or industrial zone, it should be far away from community at least 100 meter and 250 meters from watercourse. Every plastic recycling plant needs to have solid waste management treatment system. The design of the treatment system must be submitted to MOIC to get approval before construction. If there is any pollution occurred cause by the operation. Wastewater from plastic recycling plants must be treated to meet the standard that MOIC identify before discharging to environment. Article 5 mentioned that importing plastic waste for recycling should be clean and at least 80% of importing amount should be recyclable.
Environment Impact Assessment Decree (2018)	This decree provides rules, regulations and measures on management and monitoring implementation of environmental impact assessment activities to make sure that such activities are proceeded correctly with transparency and in concerted form with purpose to protect environment, and remedy impacts on environment, Article 8: Screening of Investment Projects and Activities is the first process of environmental impact assessment. It is the process of consideration whether or not environmental impact assessment is required for the proposed investment projects and activities. The investment projects and activities that are believed that will cause less or not-severe impacts on social and natural environment will be conducted preliminary environmental impact assessment; The investment projects and activities that are believed that will cause huge or severe impacts on social and natural environment will be conducted comprehensive environmental impact.