ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.119

Plastics Waste Management in Developing Country: The Case of Ecuador

Miriam Lazo, Eng.[1,2], Estephany Adrián, Eng.[1,2], Wilmer López, Eng,[2] Alanis Menéndez, Eng,[2] Sebastián Naranjo-Silva, M.Sc.[3] and Andrés Rigail-Cedeño, Ph.D.[1,2,*]

[1]Laboratorio de Procesamiento de Plásticos, ESPOL Polytechnic University, Guayaquil P.O. Box 09-01-5863, Ecuador; mdlazo@espol.edu.ec (M.L.); eadrian@espol.edu.ec (E.A.)

[2]Facultad de Ingeniería en Mecánica y Ciencias de la Producción (FIMCP), ESPOL Polytechnic University, Guayaquil P.O. Box 09-01-5863, Ecuador; wolopez@espol.edu.ec (W.L.); akmenend@espol.edu.ec (A.M.)

[3]Basic Industries Direction, Ministry of Production, Foreign Trade, Investment and Fisheries, 170507, Quito, Ecuador; snaranjo@produccion.gob.ec

*correspondence: arigail@espol.edu.ec

Abstract*– Plastic waste is a global concern due to its influence on health, the environment, and economic development. Ecuador is in the line to reduce plastic waste, representing 11% of the urban waste generated. Ecuador is making several efforts to achieve a circular economy model that encourages plastic waste management, recycling, and reuse. This review outlines the current state of plastic waste management, legislation, the recycling industry, and research challenges in Ecuador. Although the current legal framework is explicit about incorporating recycled plastic in single-use products, the plastics industry has few options for quality recycled materials. Also, the present law includes "extended producer responsibility" for the plastics industry to be involved directly in the PET recycling process, which proved to have a successful application model. However, since waste separation is implemented in around 33% of the country, most recyclates end up in landfills. Still, plastic manufacturers are looking for ways to comply with the regulations and incorporate circular economy policies within their companies. Finally, local academic research has proven the feasibility of alternative methods of plastics recycling, such as polymer blends and natural agro-waste-reinforced recycled plastic composites to meet circular economy trends.

***Keywords*-- Plastics recovery; Mechanical recycling; Plastic waste; Plastic waste policy; Ecuador.**

I. Introduction

Plastics are essential materials found in simple everyday activities or engineering applications. Although thermoplastics were developed before World War II, plastics manufacturing was boosted after 1950 and has increased by 8.4% annually [1]. The world's plastic production reached over 380 million tons in 2020 [2] and is expected to exceed 12,000 million metric tons by 2050 [3].

Plastic materials have a fundamental role in the development of the society. Its global expansion can be analyzed into type, region, and application, as illustrated in Fig. 1. Asian countries have rapidly grown in plastics production, particularly China and Japan, followed by Europe and North America. On the other hand, packaging is the largest application segment leading plastics production. However, the versatility of plastics has made them ideal for most industrial markets at a lower cost and a relatively simple transformation process. Polyethylene (PE) and polypropylene (PP) are still the largest group of plastic produced globally, reaching about 65% of total production worldwide.

Even though Latin America presents one of the lowest regional productions (Fig. 1c), plastic materials participation in the Latin American economy has increased throughout the last four decades [4]. During this period, large petrochemicalcompanies, i.e., Braskem, Dow Chemical, LyondellBasell, and ExxonMobil, have instated in countries like Brazil, Mexico, Argentina, Colombia, and Venezuela [5]. Consequently, the availability of virgin raw material and mass consumption of single-use products promoted an increased demand for plastics in the region, reaching up to an annual 50 kg per inhabitant in México and Chile [4]. Although plastic production (as virgin raw materials) is located in a few countries, all Latin American countries, including Ecuador, have a strong plastic transformation industry.

For decades, the plastics industry in Ecuador has adapted to improve the social-economic quality of the population [6], developing products to preserve and improve productivity in several industrial fields. Nowadays, the Ecuadorian plastics industry is an essential actor supporting industrial activities

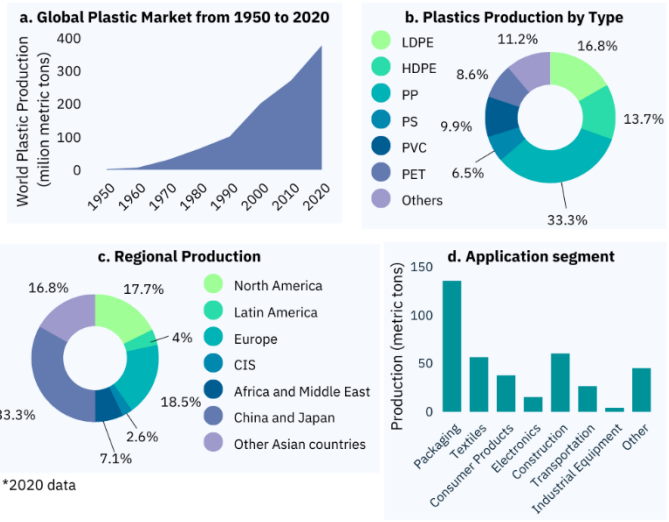

Fig. 1 Global plastics overview. Adapted from [7]–[9]

such as bananas, shrimp, and flowers. Such influence has led these industries to reach the oil industry at exportations since 2020 [10].

In this framework, accelerated growth due to its low cost and broad characteristics has led to an uncontrollable increase in plastic waste generation (Fig. 2a). According to the Environmental Investigation Agency [11], from the approximately USD 275 million tons of plastic waste generated annually, up to 12 million tons end up leaking into our oceans, causing annual environmental damage to the marine ecosystems estimated at USD 13 billion, as well as other economic losses and significant human and environmental health concerns. A differential strategy to overcome this plastic waste generation was reported by the World Economic Forum [12] with the *New Plastics Economy: Rethinking the Future of Plastics*. Over these recent years, several agreements and pacts have spread worldwide to meet the circular economy trend [13]. Being plastics recycling a primary strategy to reuse and recover plastic waste, some researchers have performed methodologies to improve the use of mixed plastics waste, the quality of recycling plastics, and critical barriers to limit the circular economy [14]–[16]. Unfortunately, the absence of adequate waste collection systems in Ecuador is a significant problem in waste management, and recyclable plastic waste is disposed of in landfills, open dumpsites, or temporary cells [17].

This review paper focuses on the state of plastic waste in Ecuador. First, the Ecuadorian legal framework in plastics waste management is analyzed, which details the primary laws and regulations related to plastic waste and plastics recycling in Ecuador. The waste management system in Ecuador and the current limitations and actions performed by industry and government are also discussed. Then, a brief section is dedicated to the Ecuadorian research challenges in plastics recycling, followed by a proposed circular model to be implemented in the country, and finally, the conclusion, with some recommendations related to plastic waste in Ecuador.

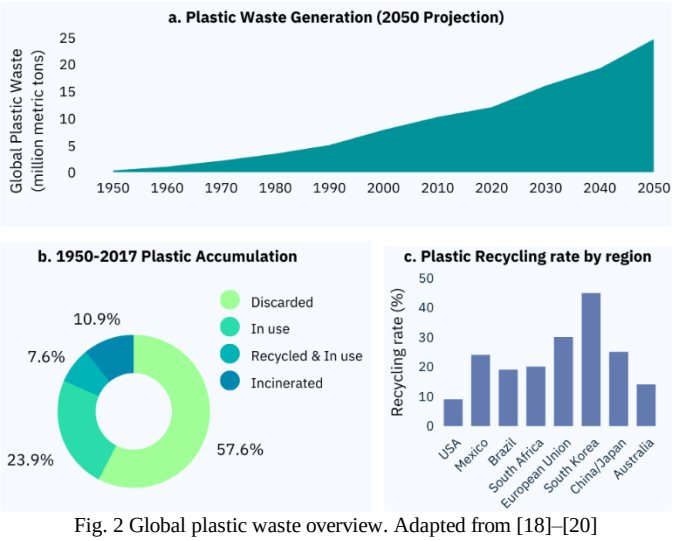

Fig. 2 Global plastic waste overview. Adapted from [18]–[20]

II. Legal Framework in Plastic Waste Management

Ecuador's journey into implementing environmental regulations starts with the Constitution, as shown in Fig. 3, by becoming the first country in the world to assign legal rights to nature [21]. Title VII, Chapter Two, Section Seven, Art. 415 on the biosphere, urban ecology, and alternative energies indicates that: "The decentralized autonomous governments will develop programs for the rational use of water, and reduction, recycling and proper treatment of solid and liquid waste*"*.

In 2010, the Organic Code of Territorial Organization, Autonomy, and Decentralization (COOTAD - for its initials in Spanish) was issued. COOTAD establishes that Decentralized Autonomous Governments (GADs - for its initials in Spanish) are directly responsible for providing waste management services and maintaining waste management operations, i.e., sanitary landfills. Also, it indicates that the Ministry of the Environment Water and Ecological Transition (MAATE - for its initials in Spanish) will provide the technical feasibility of the management by granting environmental permits and authorizations. In the following years, different laws and policies were issued to reinforce the commitment towards environmental legislation. Parallel to these regulations, ministerial agreements (MA) were developed specifically for plastic waste to provide *Instructions for the management of plastic waste for agricultural use* (MA No. 2013-021) and *Policies for plastics management in Ecuador* (MA No. 2014-019) in 2013 and 2014, respectively.

In 2019, the Regulation of the Organic Code of the Environment (RCODA - for its initials in Spanish) was published, where the following are appointed:

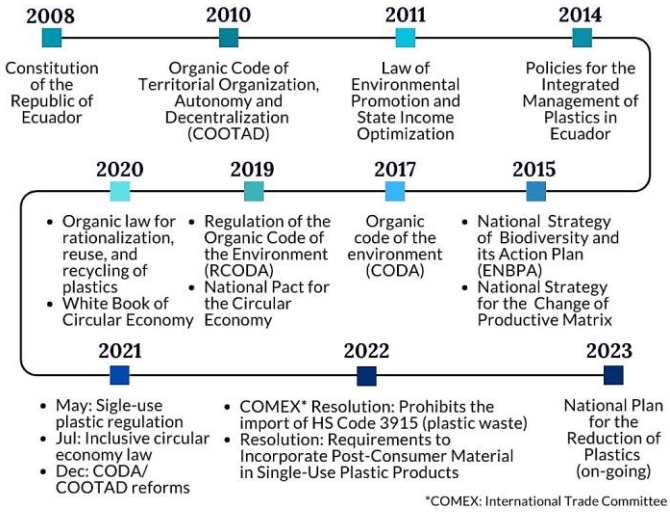

Fig. 3 Timeline for plastic waste management legislation

:

- Responsibilities of different parties (GADs, Ministries, Companies).
- Authorizations are required through registration or environmental licenses.
- Responsibilities of base recyclers/waste pickers (inclusive recycling).

Another specific plastic waste legislation was disseminated in 2020 with the Organic Law to rationalize, reuse, and recycle single-use plastics. This law focuses on single-use plastics with gradually imposed restrictions. Higher goals for recycled raw material usage and prohibitions are established after 18, 36, and 48 months of the organic law allocation, as displayed in Table I. Protected areas, however, restricted the use/entry of single-use plastics with the issuance of the law.

The Inclusive Circular Economy Law considers new responsibilities for GADs and the industry. Moreover, the rights of the informal recyclers, like the need for safety equipment and technical assistance, are indicated. Secondary regulations are expected to be generated from this regulation:

- National Circular Economy Strategy;
- List of priority products: products originating from mass consumption and do not have treatment causing adverse environmental impacts. Within this list, specific regulations are contemplated, such as the responsibility extended to the producer and other policies where the principles of circular economy are applied (eco-design, reuse, among others);
- Circular economy information system: Circular economy-related information will be linked to priority products, compiling data on policies applicable to each of them.

In 2022, resolutions regarding plastic waste and recycled plastic material were issued. The International Trade Committee emitted a Resolution (No. 015-2022) through which plastic waste import, first restricted to exceptional cases in the 2020 organic law, is currently prohibited. This banning decision originated from the fact that Ecuador imported 18,288 tons in 2019 and 8,089 tons in 2020 (even with a global pandemic) [22], while 85% of its waste [23] is disposed into landfills. On the other hand, a ministerial agreement (MA No. MAATE-2022-067) established instructions on extended responsibility in managing electrical and electronic waste. Also, a resolution (No. MPCEIP-SCIT-2022-0138-R) was released on the requirements single-use plastic importers, producers, and recyclers must follow to incorporate post-consumer recycled material in their products.

The MAATE 2023 scope, regarding plastic waste, centers on a National Plan for the Reduction of Plastics. The MAATE has gathered seven committees to assess or guide the development of the National Plan. Actors involved in these committees are university faculty members, GADs directives, base recyclers representatives, and plastic industry managers, among others. The creation of this plan has its due date in 2025. With the National Plan, guides on waste characterization and source separation will be developed as tools for GADs. Additionally, in 2023, a ministerial agreement on the definition of biodegradable plastic in Ecuador will be released.

TABLE I
PERIODICAL INCREASE OF RECYCLED MATERIAL CONTENT ON SPECIFIC SINGLE-USE PLASTIC PRODUCTS

Product	18 months	36 months	48 months
Bags	50%	55%	60%
EPS food containers	8%	12%	18%
Cups/food containers	10%	25%	30%
Cutlery	10%	25%	30%
PET bottles	5%	15%	30%

Digital Object Identifier: (only for full papers, inserted by LEIRD).
ISSN, ISBN: (to be inserted by LEIRD).
DO NOT REMOVE

III. WASTE MANAGEMENT IN ECUADOR

According to the Ecuadorian Ministry of Environment, Water and Ecological Transition, a general description of municipal waste management can be divided into four sections:

- Project Implementation: authorizations through permits to any project (construction or commercial business) to adjust to environmental regulations.
- Inorganic residue utilization: involves recirculating recyclable material into the economic system.
- Inclusive Recycling: Most of the recollection is performed by informal recyclers.
- Organic Waste Treatment: Only 33% of GADs do any treatment for organic waste.

Fig. 4 presents the approximate household waste distribution in Ecuador. The total yearly waste collection corresponds to 4,983,162.5 tons, where 14.8% are collected separately for non-recyclable and recyclable waste [17], and 11.4% of the 13,652.5 daily tons collected belong to plastic [24]. A study by Hidalgo et al. [25] showed that household plastic waste generation in Guayaquil, Ecuador is approximately 0.31, 0.18, and 0.23 kg per day for low, middle, and high socio-economic groups, respectively. This data suggests that socio-economic characteristics strongly influence plastics consumption/disposal.

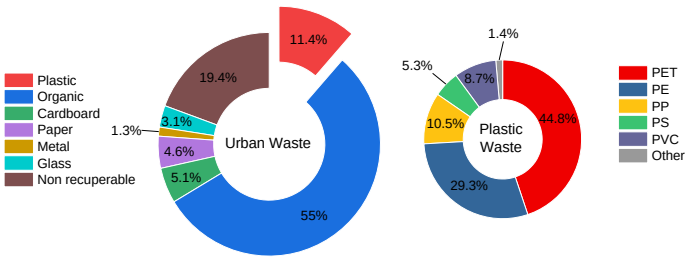

Fig. 4 Ecuadorian household waste distribution and estimated Guayaquil plastic waste distribution. Adapted from [24], [26]

In Autonomous Decentralized Municipal Governments (GADM - for its initials in Spanish), 51.6% of the municipalities have landfills, 29.9% dispose of their waste in temporary cells, and 18.6% in open dumpsites or ecosystems [17]. The National Program for Integral Solid Waste Management established a plan to eradicate uncontrolled dumpsites by the end of 2017. However, from 2018 to 2021, numbers have only been reduced by about 2% [27].

Ecuador has 221 GADs, of which only Pichincha and Guayas, two of the most populated provinces, generate around 54.5% of waste nationwide [28]. By 2021, 76% of municipalities directly managed urban solid waste, compared to 5.4% of GADs that managed it through a municipal institution or association (Fig. 5). Large cities like Quito, Guayaquil, and Cuenca manage urban solid waste through municipal companies. However, several GADs are composed of small and micro municipalities that have joined to assemble commonwealths to share Solid Waste Management, among others. Although smaller cities include essential waste management (collection, sweeping, and disposal), it is common to see citizens involved in raising awareness among neighbors about environmentally friendly habits, such as waste separation and recycling, and waste collection activities in public spaces.

Ecuador seeks to improve its waste management system, including inorganic recycling and organic composting processes, as shown in the proposed model in Fig. 6. However, the infrastructure for recycling has not been established efficiently, considering the recycling rate has only reached 6-8% [29], and recycling centers are mainly seen as disposal facilities. The informal recycling sector is the backbone of the Ecuadorian recycling system and most developing countries [30]. Although several cities already implement source separation [17], most of the population does not have a recycling culture. Therefore, recycling facilities depend largely on informal recyclers and recyclable industrial output.

A. *Plastic Waste Management*

Plastic mechanical recycling involves processing plastic waste to be reincorporated into the economic system. According to ISO 15270 *Guidelines for the recovery and recycling of plastic waste*, the general model should include collection, sorting, pretreatment, and heat transformation, as shown in Fig. 7. In Ecuador, these steps are performed separately by different actors, including informal recyclers. Consequently, some recycled plastics may not meet the producer's quality requirements.

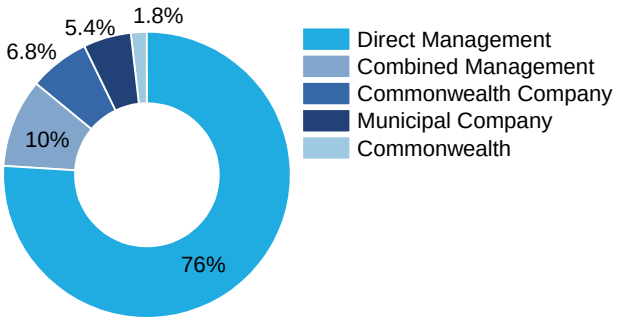

Fig. 5 How local governments manage urban waste. Adapted from [23]

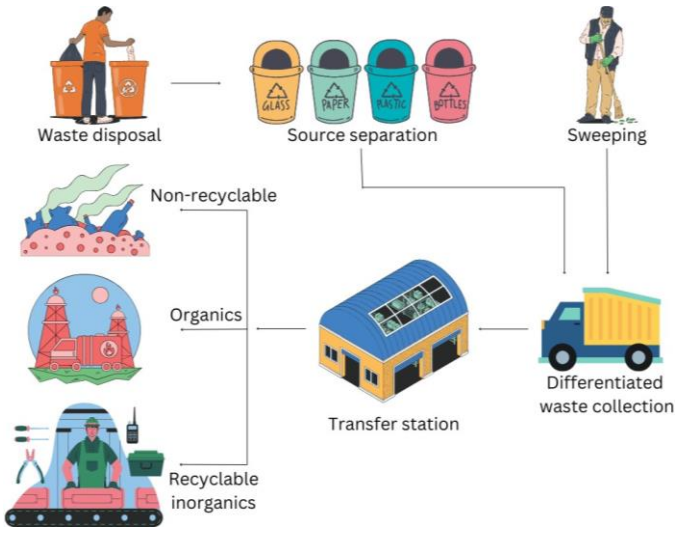

Fig. 6 Waste management proposed model. Adapted from [23]

The Ecuadorian recycling industry was born, with *Grupo Mario Bravo* (GMB) as a pioneer in 1970 [31]. GMB association owns four companies for different recycling lines: metal, paper/cardboard, plastic agro-waste, and polyethylene terephthalate (PET) bottles [32]. In Ecuador, PET bottle recycling has been highly developed among the plastics recycling line, reaching food-grade quality [33]. Because of the single-use plastics regulations, in 2011, a redeemable tax (up to $0.02 per bottle) was imposed on PET importers/distributors; the tax value was then returned to whoever collected the discarded bottle. This tax improved the collection rate to 80% [34] since waste pickers found PET bottles more valuable. The top PET recycling companies in the country are Intercia, Enkador, and Reciplásticos (GMB). Besides the plastic transformation process, these companies perform sorting and pretreatment of the collected bottles. Additionally, they have exported tons of rPET pellets and, recently, rPET preforms

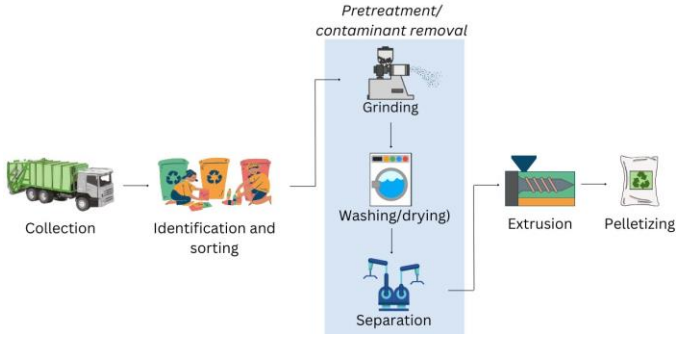

Fig. 7 Plastics mechanical recycling general model

[35]. PET recyclers also work closely with informal recyclers, especially those over 65 years old, to give them a better way of life.

The reality is that most local governments oversee waste collection and disposal but do not guarantee the recovery of recyclable materials. Therefore, the existing recycling centers are private companies, like GIRA, created in response to single-use materials regulations. In contrast with other recycling companies, GIRA incentivizes consumers to separate their waste at home and involves them in the recycling process. More than 100 drop-off centers [36] are distributed nationwide in shopping centers and convenience stores for cardboard, glass, paper, PET, rigid/flexible plastics, tetra pak, metal, expanded polystyrene (EPS), and PE/PP bottle caps. GIRA serves mainly as a transfer station to sort recyclables and sell them to companies dedicated to its recycling. Plastics, except for PET, receive another treatment before commercializing:

- Rigid plastics and EPS are ground, washed, and dried.
- Flexible plastics receive the same pretreatment before undergoing extrusion and pelletizing.

Polyethylene and polypropylene are the second leading plastics in the Ecuadorian recycling industry, although their recovery rate is around 15% [37]. Companies like Novared and Nutec have invested in technology and infrastructure to give the plastic industry a standardized product. They distinguish from other local recyclers because of their research and development departments and have cooperated with academic institutions. NUTEC exported 25 tons of PE pellets to Bolivia last year [38], becoming the first Ecuadorian PE recycler to do so in such volume. As big companies, they have a solid social responsibility, implementing training schools for their employees and technical assistance to their suppliers to improve the quality of raw materials [39], [40].

The plastic industry and the Ecuadorian Plastic Association (ASEPLAS - for its initials in Spanish) have been working to promote using recycled materials to avoid a complete plastic ban. The actual environmental regulations were established for single-use plastic products. However, manufacturers use regrinds and recyclates in most of their products. Important plastic companies like Flexiplast have incorporated zero-waste policies in their production lines: all their scraps are ground and reprocessed. Besides regrinding practices, Flexiplast has dedicated a whole production line to EPS recycling, pelletizing the EPS scrap with the disposable plates/cups used inside their facilities. Such is the case of Empaqplast (Fig. 8), PICA, and Plastlit, who have invested in recycling technology for PE, PP, and polystyrene (PS), respectively.

Hidalgo-Crespo et al. [41] studied the feasibility of a circular economy model for EPS household waste recycling in Plastit (Guayaquil, Ecuador). The research involved recovery, treatment, and processing of post-consumer EPS into sheet

Fig. 8 PE recycling line: regrinding (left), and extrusion pelletizing (right) at Empaqplast (Quito, Ecuador). Source: Empaqplast (Personal communication)

rolls for thermoforming. Although results showed slightly lower resistance values in samples containing post-consumer EPS, the microbiological analysis showed no presence of microorganisms. Migration tests also proved to be below the limits set by the Ecuadorian Technical Standard (INEN). Nevertheless, authors remarked that the actual limitations of EPS recycling are:

- Lack of household separation.
- No monetary incentive for waste pickers.
- The low density of the material (98% air).

The latter prevents informal recyclers from collecting the material as it will occupy a significant amount of space during transportation that could be used to carry glass, metal, or PET.

Other forms of plastic waste management, like co-processing, have appeared, given the need to treat mixed materials, such as plastic aluminum foils and multi-layer films, that cannot be separated. Co-processing is a heat treatment process for waste and energy recovery, often used in the cement industry for clinker production as an alternative waste treatment [42]. Geocycle uses this process to recover energy from unrecyclable waste for cement manufacturing [43]. Under this coprocessing, the negative impact of cement manufacturing is reduced, and the carbon footprint of this process is lower than landfilling [44]. Nonetheless, co-processors insist co-processing should be the alternative when no other treatment for non-recyclable materials can be applied.

IV. Current Limitations and Actions

Ecuador is working to develop a potential market for recyclable materials, such as metal, cardboard, paper, and plastic (most commercialized today). A survey conducted by MAATE in 12,072 homes about awareness and environmental responsibility showed an increase from 47% to 62% for household waste classification in 2017 and 2019, respectively [45]. Also, the main type of waste separated in the country is plastic, representing about 47% of the total waste. The same survey illustrates that the responsibility to rescue the environment deteriorates due to all homes (60%), government (50%), businesses (59%), and home respondents (57%). Although the consciousness about recycling and the environment is increasing, most Ecuadorian families still do not

have a recycling awareness, and the few recycling activities are due to labor shortages that force people to work with garbage trying to obtain valuable elements to sell to recyclers later.

There is a "gap" between society's needs and waste management from the Decentralized Autonomous Governments in Ecuador. This situation can be defined as the root of the recycling problem since recycling should be promoted in homes, food businesses, and education systems. In addition, the current legal framework does not encourage citizens or the GADs to separate waste at home. The local governments can manage the waste without the necessity of its previous separation. Legally, GADs are only obliged to collect and dispose of the waste in the best way. Therefore, the recycling business industry must work together to cover all the necessary processes, such as collection, separation, treatment, processing, and marketing. However, the lack of associativity limits the negotiation power to promote the growth of recycling as an industry since large amounts of money are required as capital.

On the other hand, many more inconveniences arise that limit the development of the recycling business in the country. Only high-size companies can afford efficient mechanical recycling technology. This absence of technology prevents small companies from complying with current regulations regarding single-use material or circular economy laws. Moreover, there is a lack of technical laboratories to support the plastics industry concerning recyclability testing or migration analysis for plastic products destined for the food industry. Investing in technology for the whole industry should be a priority decision, especially in other big cities besides Guayaquil or Quito.

Among other limitations, the low educational level of environmental managers disables local governments from improving their system. This scarcity of qualified personnel is because careers such as environmental engineering or master's degrees in sustainable development and circular economy have not been well received. Thus, a few recycling or plastics industry educational programs have established one or two professionals who manage to recycle appropriately, making the most of resources and technologies.

In the recycling industry, there is a tendency to move forward with the circular economy. After the COVID-19 pandemic and the economic crisis, the local sector appeared interested in replacing the linear economy with a circular economic system. The circular economy seeks the preservation of natural resources while contributing to reducing the environmental impact of development, increasing the efficiency of the use of resources, and improving the well-being of all interested parties. The industry's carbon footprint in its production and post-production processes is also considered. Under this precedent, in recent years, the Ecuadorian industry has experienced a concept called non-technological eco-innovation: an innovation of the organizational and social nature that allows a transition towards a circularity model through research and innovation that drives significant changes in models of consumption, production, and the creation of sustainable products [46]. Examples of this type of innovation are:

- The use of recycled products as raw materials;
- Reforming the production line to reduce waste and residues generated during the internal and external processes of the industry;
- Investment and research in projects aimed at generating or modifying products or services (aimed at fulfilling the pillars of sustainable development).

Some actions have been carried out to meet the circular economy. These actions have been focused on reducing virgin plastics consumption, increasing post-consumer plastics recovery, developing plastic product traceability systems in the country, and enhancing the quality of recycled materials [47]. Like any other Latin American country, the informal sector supports the recycled system. About 50,000 people are estimated to be working in this informal sector; this sector will be the key to recycling 20% of total waste by 2025 [48]. The informal sector has been progressively incorporated into the system, and the dignification of this activity to support the circular economy in Ecuador has been made through a pact for inclusive recycling [39], [49]. For the consumer, the willingness to use recycled products and recycling has been supported by several businesses [50], [51], as shown in Fig. 9.

Although Ecuador shows little progress in implementing a circular recycling model, there are successful case studies [52] indicating that higher recycling levels can be achieved. One of them would be Santa Cruz (Galapagos Islands, Ecuador). A volume-based waste fee (VWF) system and incentives had been implemented for differentiated waste collection. That is, special bags should be acquired for waste disposition: blue recyclable bags have no cost, while black (non-recyclables) and green (organic) bags do. Also, if the authorized bag is not used, the collection truck does not take it, and they are susceptible to receiving a financial fine. This model allowed Santa Cruz to recover 50% of their waste. A similar model was implemented by the Cañar, Biblián, El Tambo, and Suscal commonwealth, with a recovery rate of 90%. These successful stories indicate what Ecuador needs to do to achieve circularity: (1) implement a differentiated collection system, and (2) impose a system of

Fig. 9 Recycling spots at (a) urban parks, (b) shopping centers, and (c) food establishments

incentives and fines to facilitate the cultural transition.

In 2022, the government established a plastic cluster to encourage the efficiency and sustainability of plastics in Ecuador. The plastic cluster is an umbrella to address all initiatives of the plastics sector toward plastics sustainability. This initiative was developed parallel to a Korean Consulting on the Strategies for EPS and PP recycling as part of a Knowledge Sharing Program (KSP) [53]. During the KSP, several actors, such as plastic manufacturers, academic researchers, and public figures, visited South Korea to learn about their circularity model of plastics. The interim report [54] proposed a model not only for EPS and PP but a general to-be model for a circular economy.

V. Research and Development Challenges

Part of available post-consumer PE films come from the agricultural industry, commonly polyethylene of different types and grades. In outdoor applications, the polymer degradation because they have been exposed to UV light and environmental conditions. Consequently, PE's properties will vary from film to film. However, its mechanical recycling is possible given proper treatment, contaminant removal, washing, and drying [55]. Local manufacturers, such as Paraíso del Ecuador [56] and Plasticonsumo [57], have successfully incorporated PE post-consumer films into their products up to a 100%.

Alternatives to traditional plastics recycling have been studied locally to give added value to the material or reduce energy demand during the transformation process. One of the most common techniques is to increase available recycled raw materials by blending two different polymers with the help of coupling agents. Commercial compatibilizers, such as block copolymers or maleic anhydride grafted polymers, allow the plastic industry to manufacture products using immiscible polymers. Local studies [58]–[60] analyzed the feasibility of processing recycled high-density polyethylene (rHDPE) blends, rHDPE/rPP and rHDPE/rPET, as these materials cannot be entirely separated when recycling PET bottles. The use of olefin block copolymers (OBC), in combination with organoclays as rheological modifiers, enhanced rHDPE/PP impact energy and improved processing characteristics [59]. Fig. 10a shows that specific energy consumption (SEC) could be reduced up to 50% in rHDPE/PP blends with the addition of nanoclays (C20A) and the correct coupling agent at 10 rpm [60]. The study also indicated that at higher screw speeds, SEC could be optimized even more with C20A rheological modifiers and compatibilizers.

Other studies [61], [62] on rHDPE/rice husk demonstrated the importance of coupling agents in the composite's properties, processability, and energy consumption, as seen in Fig. 10b. Besides reducing material and energy costs, the carbon footprint of agro-fillers is much lower than conventional plastics recycling. Several local studies have been

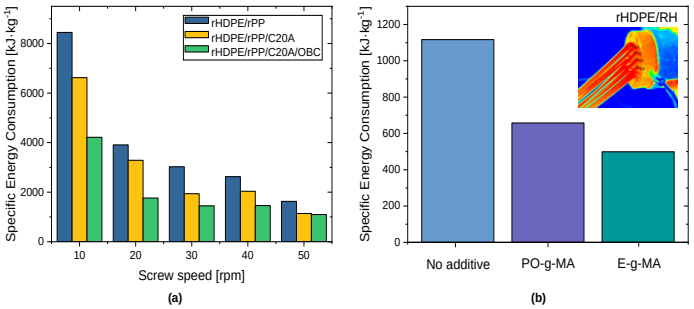

Fig. 10 Specific energy consumption for (a) rHDPE/rPP blends with C20A and OBC processed at different screw speeds and (b) rHDPE reinforced with rice husk (RH) using maleic anhydride grafted elastomer (PO-g-MA) and ethylene-glycidyl methacrylate copolymer (E-g-MA). Adapted from [60], [62]

conducted on using agro-waste as a recycled plastic reinforcement. Fillers such as toquilla straw [63] and bamboo fibers [64], among others [65], have also been considered. In 2021, Ecuadorian agricultural production reached 26,529 kilotons [66]. As Ecuador is an agricultural country, agro-waste also becomes a pollution issue. With the circular economy and the global sustainability approach, the Ecuadorian plastic industry has opted to manufacture products with agro-industrial fillers. For example, an eco-friendly line of PP home appliances reinforced with wheat fiber (Fig 11a).

The scientific community and environmental activists have shown concern about the recyclability of these reinforced plastics. Consequently, research on the antioxidant activity of agro-waste, such as coffee grounds and turmeric, has been performed [67]. Results show the potential of antioxidant-rich agro-fillers to enhance thermal stability on the composites, like commercial antioxidants. Because of its natural resources [66], Ecuador could explore this research area with coffee, cocoa bean, and barley by-products [68], [69]. The challenges are to incorporate high amounts of agro-waste to become a more sustainable material and decrease the dependence on synthetic polymers.

The single-use plastics regulations have also encouraged replacing traditional plastic with biobased polymers. Thermoplastic starch and polylactide (PLA) can be found as substitute materials in convenience stores nationwide, as seen in Fig. 11b. Additionally, bioplastics have been the scope of local academic research to enhance their properties [70], [71] and study possible biorefinery processes [72]. However, since

Fig. 11 Commercial products using (a) agro-industrial reinforcements, (b) starch-based biodegradable plastics

the country does not have compost facilities, the local industry has questioned this option [73]. In addition, if the consumer is not well-informed about the correct disposition of biopolymers, they could contaminate the plastic recycling waste stream [74].

VI. Plastic Resource Circulation Model

According to the UN environmental report "Turning off the Tap: How the world can end plastic pollution and Create a circular economy" [75], the first step to reducing plastic pollution is eliminating unnecessary plastics, such as excessive packaging. However, it is also essential to encourage the reuse of plastics, promote recycling and look for greener alternatives to replace single-use plastics. Although these changes must be driven by government policies and transformations in the plastics industry [76], the consumer is a crucial element in the circularity model. A circular economy model for Ecuador is possible, as suggested by Rivas [52], who outlined the key milestones that needed to be achieved: (1) volume-based waste fee systems, (2) source separation, (3) incentive systems and fines, and (4) use of available technologies to promote recycling. During the 2022 KSP [54], a circulation model was suggested in the short and long-term to adequate the waste management system and reinforce the competitiveness in the Ecuadorian recycling industry (Fig. 12). South Korea introduced this model in 1995, and in 2012, the recycling rate increased from 24% to 59%. What has been critical to this success is the volume-based waste fee (VWF) system implemented. VWF is considered pro-environmental behavior and positively affects the recycling rate [77].

The basis of this model includes the Extended Producer Responsibility (EPR) system, volume-based waste fee system, and household waste recycling policy. The EPR operation system encourages producers to reduce, reuse, and recycle waste, inducing ecological and economical activities through eco-design, manufacturing, distribution, consumption, and disposal of products. This system promotes recycling and a socio-economic system for resource circulation. Items subject to the EPR system mainly include packaging materials.

The basis of this model includes the EPR system, volume-based waste fee system, and household waste recycling policy. The EPR operation system encourages producers to reduce, reuse, and recycle waste, inducing ecological and economical activities through eco-design, manufacturing, distribution, consumption, and disposal of products. This system promotes recycling and a socio-economic system for resource circulation. Items subject to the EPR system mainly include packaging materials.

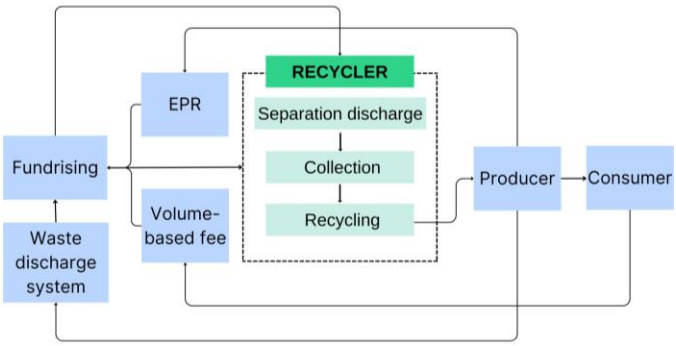

Fig. 12 Proposed plastic resource circularity model. Adapted from [54]

The VWF system is designed to reduce plastic waste and, to some extent, to separate recyclables, requiring the consumer to bear a cost equal to the amount of waste thrown away. This system contains the principle that polluters pay: the person who causes environmental pollution bears the cost of removing the environmental pollution. With this VWF system, the household waste policy was introduced. In the case of the South Korean zero waste project [78], households are vital in the recycling waste stream. Koreans must clean, sort, and dispose of their waste in specific areas. These areas include fixed/movable recycling bins and recycling stations. Then, districts are in charge of collecting and processing plastic waste.

VII. Conclusions

Plastics are essential materials supporting the Ecuadorian economy, from developing rural or urban communities to making exporting non-petroleum products feasible. Thus, its management after use has challenged local and central government. Environmental regulations applicable to single-use plastics appear to be the first milestone in reducing and recycling plastic waste nationwide. The plastics recycling industry is not new to Ecuador, as it has existed for over five decades. Mechanical recycling is the key to the circular model in underdeveloped countries but must be accompanied by chemical recycling to decrease the waste quantities.

What has already been working in Asian countries like Japan and South Korea is not a complete plastic ban but VWF systems, sorting facilities in every neighborhood, and policies applicable to producers and consumers. A plastic ban is not a solution for our economy due to consumer behaviors, food safety, and economic implications in Ecuador. Economic drives are imperative in plastic waste management to improve plastic waste separation and collection. PET recycling has reached about 80% of the recycling rate due to redeemable tax, and technological investment has allowed obtaining FDA grade and increasing PET exportations. Also, the volume-based waste fee system is successfully running in Santa Cruz, Galapagos. Both examples have proved that adopting EPR and VWF systems with household waste separation in Ecuador is possible. Source separation is not optional. Having differentiated collection would allow the recycling industry to assign the investment previously used for sorting (and cleaning) in technology, recycling lines, and eco-design practices that would improve the recycling chain and recycled finished goods. The South Korean model has proven that higher recycling rates can only be achieved when households and other interested parties are trained and involved in recycling.

Private plastic companies have started incorporating circularity production models and recycling lines to comply with the existing policies and promote a recycling culture among their employees and customers. In a circular approach, producers must incentivize consumers to use products that contribute to sustainable development and consider the extended producer responsibility criteria to determine new or improved production processes. Producers and consumers must be oriented toward the same goal for the recycling industry and circular model. However, even if this situation is present in the plastic recycling industry in Ecuador, it is not enough. While a private company incentivizes consumers, the government can legally impose. Although local governments are in charge of deciding upon waste management in their cities, the central government must create a drive to push GADs to adopt the Santa Cruz circularity model. Therefore, a joint venture between the government and the industry is compulsory for implementing adequate sorting facilities, recycling systems, or discharge stations. That is government investment, legal framework, and the industries' know-how, technology, and consumer incentives.

Ecuador must develop its model; some discussions have been addressed here. A holistic framework must include policies incorporating: the consumer's participation, a manufacturing approach supported by eco-design and quality standards, economic drivers from fee systems to promote a recycling contribution of the producers and recycling subsidy of the recyclers, incentives to finance recycling technologies and social/technical education and develop stakeholders' acceptability and cooperation to the whole value chain. Also, the Ecuadorian academy is open to new developments to reduce the negative impact of inadequate plastic recycling. Further work should be done between the industry and the academy, not only to promote the use of alternative polymers but mainly to improve the recyclability of traditional plastics that, in the short and medium run, are the ones affordable to the Ecuadorian economy.

ACKNOWLEDGMENT

Authors would like to express their deepest gratitude to the Korea Trade-Investment Promotion Agency (KOTRA), the Ecuadorian Plastic Association (ASEPLAS), the Ecuadorian Ministry of Production, Foreign Trade, Investment and Fisheries, the Ecuadorian Ministry of Environment, Water and Ecological Transition (MAATE), Empaqplast, GIRA, and Geocycle, for their support during our research.

REFERENCES

[1] S. Huang *et al.*, "Plastic Waste Management Strategies and Their Environmental Aspects: A Scientometric Analysis and Comprehensive Review," *Int. J. Environ. Res. Public Heal. 2022, Vol. 19, Page 4556*, vol. 19, no. 8, p. 4556, Apr. 2022, doi: 10.3390/IJERPH19084556.

[2] H. Onay *et al.*, "Decade of microplastic alteration in the southeastern black sea: An example of seahorse gastrointestinal tracts," *Environ. Res.*, vol. 218, p. 115001, Feb. 2023, doi: 10.1016/j.envres.2022.115001.

[3] A. Soni *et al.*, "Valorization of Post-Consumers Plastics and Agro-Waste in Sustainable Polymeric Composites for Tribological Applications," *Waste and Biomass Valorization*, Mar. 2023, doi: 10.1007/s12649-023-02103-w.

[4] C. Bianco, F. Isso, and M. Moskat, "Plásticos en América Latina: Breve reseña de su producción, consumo e impactos ambientales," 2021. .

[5] M. Moskat, C. Bianco, and F. Isso, "Plastics Industry and Market in Latin America and the Caribbean, April 2021," 2021. .

[6] C. P. Padilla, D. X. Arévalo, M. A. Bustamante, and C. L. Vidal, "Responsabilidad Social Empresarial y Desempeño Financiero en la Industria del Plástico en Ecuador," *Inf. tecnológica*, vol. 28, no. 4, pp. 93–102, 2017, doi: 10.4067/S0718-07642017000400012.

[7] C. W. S. Yeung, J. Y. Q. Teo, X. J. Loh, and J. Y. C. Lim, "Polyolefins and Polystyrene as Chemical Resources for a Sustainable Future: Challenges, Advances, and Prospects," *ACS Mater. Lett.*, vol. 3, no. 12, pp. 1660–1676, Dec. 2021, doi: 10.1021/acsmaterialslett.1c00490.

[8] M. Shen, W. Huang, M. Chen, B. Song, G. Zeng, and Y. Zhang, "(Micro)plastic crisis: Un-ignorable contribution to global greenhouse gas emissions and climate change," *J. Clean. Prod.*, vol. 254, p. 120138, May 2020, doi: 10.1016/j.jclepro.2020.120138.

[9] F. Muneer, "Plastics Versus Bioplastics," in *Degradation of Plastics*, 2021, pp. 193–237.

[10] The Observatory of Economic Complexity, "Ecuador (ECU) Exports, Imports, and Trade Partners," 2021. .

[11] Environmental Investigation Agency UK, "Toward a new global agreement to address plastic pollution," *Convention on Plastic Pollution*. 2020.

[12] Ellen MacArthur Foundation and World Economic Forum, "The New Plastics Economy: Rethinking the future of plastics," *Ellen MacArthur Found.*, no. January, p. 120, 2016.

[13] Ellen MacArthur Foundation, "The Plastics Pact Network," *The Ellen MacArthur Foundation's Plastics Pact Network*, 2021. .

[14] K. Ragaert, L. Delva, and K. Van Geem, "Mechanical and chemical recycling of solid plastic waste," *Waste Manag.*, vol. 69, pp. 24–58, Nov. 2017, doi: 10.1016/j.wasman.2017.07.044.

[15] K. Ragaert *et al.*, "Design from recycling: A complex mixed plastic waste case study," *Resour. Conserv. Recycl.*, vol. 155, p. 104646, Apr. 2020, doi: 10.1016/j.resconrec.2019.104646.

[16] M. Lisiecki, A. Damgaard, K. Ragaert, and T. F. Astrup, "Circular economy initiatives are no guarantee for increased plastic circularity: A framework for the systematic comparison of initiatives," *Resour. Conserv. Recycl.*, vol. 197, p. 107072, Oct. 2023, doi: 10.1016/j.resconrec.2023.107072.

[17] Instituto Nacional de Estadística y Censo, "Boletín Técnico No 05-2021-GAD Municipales," *Gestión de Residuos Sólidos*, 2022. .

[18] United Nations Environment Programme, *From pollution to solution: A global assessment of marine litter and plastic pollution*. 2021.

[19] British Plastics Federation, "Global Recycling Numbers," *Plastics Recycling*, 2018. .

[20] T. Poddar, N. De, and S. Sarkar, "Efficient Engineering Techniques for Segregation and Management of Non-Biodegradable Wastes: Saving the Earth by Replenishing its Dearth," *Int. J. Sustain. Energy Environ. Res.*, vol. 9, no. 2, pp. 123–137, 2020, doi: 10.18488/journal.13.2020.92.123.137.

[21] J. G. Portilla-Jiménez, "Análisis del Marco Normativo de Economía Circular en Ecuador Orientado al Sector de los Plásticos," *FIGEMPA Investig. y Desarro.*, vol. 13, no. 1, pp. 38–47, Feb. 2022, doi: 10.29166/revfig.v13i1.3364.

[22] Universidad Andina Simón Bolívar, Alianza Global para Alternativas a la Incineración, and Alianza Basura Cero Ecuador, *La partida 3915: Importación de desechos plásticos en Ecuador*.

Digital Object Identifier: (only for full papers, inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).
DO NOT REMOVE

Quito, Ecuador: Universidad Andina Simón Bolívar, Sede Ecuador, 2021.
[23] Instituto Nacional de Estadística y Censo, "Estadística de Información Ambiental Económica en Gobiernos Autónomos Descentralizados Municipales," 2022.
[24] Instituto Nacional de Estadística y Censo, "Tabulados de la Estadística de Información Ambiental Económica en Gobiernos Autónomos Descentralizados Municipales 2021," 2022.
[25] J. Hidalgo, J. L. Amaya, F. Jervis, and C. Moreira, "Influence of socio-economic factors on household solid waste (HSW) generation of the city of Guayaquil, Ecuador.," 2019, doi: 10.18687/LACCEI2019.1.1.24.
[26] J. Hidalgo-Crespo, J. L. Amaya, M. Soto, and L. Caamaño-Gordillo, "Domestic Plastic Waste in the city of Guayaquil: Generation Rate and Classification," 2021, doi: http://dx.doi.org/10.18687/LACCEI2021.1.1.168.
[27] Instituto Nacional de Estadística y Censo, "Series Históricas 2018-2021," 2022.
[28] Instituto Nacional de Estadística y Censo, "Indicadores de Gestión Integral de Residuos Sólidos," 2022.
[29] M. F. Solíz Torres, J. S. Durango Cordero, J. L. Solano Peláez, and M. A. Yépez Fuentes, *Cartografía de los residuos sólidos en Ecuador 2020*. Quito: a Universidad Andina Simón Bolívar, Sede Ecuador, 2020.
[30] H. Hettiarachchi, S. Ryu, S. Caucci, and R. Silva, "Municipal Solid Waste Management in Latin America and the Caribbean: Issues and Potential Solutions from the Governance Perspective," *Recycling*, vol. 3, no. 2, p. 19, May 2018, doi: 10.3390/recycling3020019.
[31] M. E. Bravo Baño, "Análisis del reciclaje en el Ecuador," *GMB - Grupo Mario Bravo*, 2020. .
[32] Asociación Ecuatoriana de Plásticos, "Mario Bravo Baño (+) 50 años de legado a la industria del reciclaje," *Ind. plásticas comprometidas con el medio Ambient.*, vol. 1, no. 1, pp. 12–13, 2022.
[33] C. Lambré *et al.*, "Safety assessment of the process Enkador, based on the Vacurema Prime technology, used to recycle post-consumer PET into food contact materials," *EFSA J.*, vol. 20, no. 3, Mar. 2022, doi: 10.2903/j.efsa.2022.7188.
[34] R. Zambrano, "Más del 80% de botellas plásticas PET se recogen en Ecuador, pero hay preocupación en la industria por futuro incierto del impuesto redimible," *El Universo*, Guayaquil, May 2022.
[35] S. Ayala Sarmiento, "¡Enkador siempre primero! Ya exporta preformas de botellas PET recicladas," *Forbes Ecuador*, Quito, Ecuador, 2022.
[36] Asociación Ecuatoriana de Plásticos, "GIRA: valorizando el plástico por medio del reciclaje," *Ind. plásticas comprometidas con el medio Ambient.*, vol. 1, no. 1, pp. 24–25, 2022.
[37] L. Zambrano, "Ecuador exporta polietileno reciclado," *Expreso*, 2022. .
[38] B. Jumbo, "Sus fundas de plásticos recicladas van a Bolivia," *Revista Líderes*, 2022. .
[39] Asociación Ecuatoriana de Plásticos, "Novared: un modelo de negocio de impacto positivo al planeta y la sociedad," *Ind. plásticas comprometidas con el medio Ambient.*, vol. 1, no. 1, pp. 32–33, 2022.
[40] Asociación Ecuatoriana de Plásticos, "Recycle: el mejor reciclado del Ecuador," *Ind. plásticas comprometidas con el medio Ambient.*, vol. 1, no. 1, pp. 34–35, 2022.
[41] J. Hidalgo-Crespo, F. X. Jervis, C. M. Moreira, M. Soto, and J. L. Amaya, "Introduction of the circular economy to expanded polystyrene household waste: A case study from an Ecuadorian plastic manufacturer," *Procedia CIRP*, vol. 90, pp. 49–54, 2020, doi: https://doi.org/10.1016/j.procir.2020.01.089.
[42] C. Ciobanu, P. Tudor, I.-A. Istrate, and G. Voicu, "Assessment of Environmental Pollution in Cement Plant Areas in Romania by Co-Processing Waste in Clinker Kilns," *Energies*, vol. 15, no. 7, p. 2656, Apr. 2022, doi: 10.3390/en15072656.
[43] A. Prakash and R. R. Palkar, "Co-processing of plastic waste in a cement kiln: a better option," *Environ. Sci. Pollut. Res.*, Nov. 2021, doi: 10.1007/s11356-021-17725-7.
[44] R. Baidya and S. K. Ghosh, "Low carbon cement manufacturing in India by co-processing of alternative fuel and raw materials," *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 41, no. 21, pp. 2561–2572, Nov. 2019, doi: 10.1080/15567036.2018.1555630.
[45] Instituto Nacional de Estadística y Censo, "Información Ambiental en Hogares," *ESPND 2019*, 2020. .
[46] United Nations Environment Programme, *The Business Case for Eco-innovation*, 2nd ed. Nairobi, Kenya, 2021.
[47] Ministerio de Producción Comercio Exterior Inversiones y Pesca, *Libro Blanco de la Economía Circular de Ecuador*. 2020.
[48] R. Zambrano, "'En Ecuador hemos dejado a los recicladores para que con hacha y machete vayan abriendo camino, los hemos mirado mal y dado la espalda, esto tiene que cambiar', dice Gustavo Manrique, ministro de Ambiente," *El Universo*, Guayaquil, May 2022.
[49] "ReciVeci busca incentivar y optimizar acceso de recicladores a servicios de salud y bienestar," *Gestión Digital*, 2023.
[50] A. Gómez, "GIRA, una propuesta integral e innovadora de economía circular," *Integra*, vol. 72, 2023.
[51] S. Reyes and C. Jara, "ECOHOME, reciclaje a domicilio," *Integra*, vol. 68, 2022.
[52] L. Rivas, "¿Cómo resolver el problema de los residuos en América Latina?," *Integra*, vol. 72, 2023.
[53] A. Rigail-Cedeño, "Experiencias de Corea del Sur en el Reciclado de Plásticos y el Manejo de Desechos Sólidos," *Integra*, 2022.
[54] Korea Trade-Investment Promotion Agency (KOTRA), "Tecnología de Producción Eficiente, Métodos y Maquinaria Innovadora para Productos Reciclados a Base de Poliestireno y Polipropileno Expandido," 2023.
[55] F. Cadena, M. B. Aldás, A. D. Aguilar, A. Inga, and D. Cando, "Technical possibilities for recycling plastics from agribusiness," *Prog. Rubber, Plast. Recycl. Technol.*, vol. 37, no. 4, pp. 378–393, Nov. 2021, doi: 10.1177/14777606211019420.
[56] Asociación Ecuatoriana de Plásticos, "Paraíso del Ecuador materializa su compromiso ambiental a través de acciones tangibles," *Ind. plásticas comprometidas con el medio Ambient.*, vol. 1, no. 1, pp. 39–40, 2022.
[57] Asociación Ecuatoriana de Plásticos, "Plasticonsumo y su filosofía eco-productiva," *Ind. plásticas comprometidas con el medio Ambient.*, vol. 1, no. 1, pp. 47–48, 2022.
[58] A. F. Rigail-Cedeño, A. Diaz-Barrios, J. Gallardo-Bastidas, S. Ullaguari-Loor, and N. Morales-Fuentes, "Recycled HDPE/PET Clay Nanocomposites," *Key Eng. Mater.*, vol. 821, pp. 67–73, Sep. 2019, doi: 10.4028/www.scientific.net/KEM.821.67.
[59] A. F. Rigail-Cedeño *et al.*, "The effect of olefin block copolymer and organoclays in recycled HDPE/PP nanocomposites," in *AIP Conference Proceedings*, 2020, vol. 2205, doi: 10.1063/1.5142988.
[60] A. F. Rigail-Cedeño, J. Vera-Sorroche, G. García-Mejía, and R. Intriago, "Effect of the Intercalation and Dispersion of Organoclays on Energy Demand in the Extrusion of Recycled HDPE/PP Nanocomposites," *Energies*, vol. 15, no. 3, p. 859, Jan. 2022, doi: 10.3390/en15030859.
[61] A. Rigail-Cedeño *et al.*, "Processability and Physical Properties of Compatibilized Recycled HDPE/Rice Husk Biocomposites," *J. Manuf. Mater. Process.*, vol. 6, no. 4, p. 67, Jun. 2022, doi: 10.3390/jmmp6040067.
[62] A. F. Rigail-Cedeño, D. Cabrera-Alava, J. Vera-Sorroche, M. Lazo, E. Adrian, and R. Perugachi, "Effect of compatibilization agents and rice husk on the energy demand on the extrusion of recycled high-density polyethylene composites," *Energy Reports*, vol. 8, pp. 548–555, Nov. 2022, doi: 10.1016/j.egyr.2022.07.101.
[63] L. C. Morales Robalino, Á. A. Valencia Burgos, and M. E. Dueñas Barberán, "Aplicación de fibras vegetales y plástico PET reciclado en

el diseño de láminas decorativas," *YACHANA, Rev. Científica*, vol. 8, no. 2, pp. 99–108, 2019.
[64] J. V. Montesdeoca-Contreras, C. A. Paltan-Zhingre, T. F. Munoz-Cuenca, J. I. Fajardo-Seminario, L. M. Lopez-Lopez, and D. R. Lasso-Lazo, "Study of natural fibers as filler in a polymeric matrix to make environment friendly materials," in *2015 IEEE NW Russia Young Researchers in Electrical and Electronic Engineering Conference (EIConRusNW)*, Feb. 2015, pp. 332–335, doi: 10.1109/EIConRusNW.2015.7102292.
[65] J. Fajardo, L. Valarezo, L. López, and A. Sarmiento, "Experiencies in obtaining polymeric composites reinforced with natural fiber from Ecuador," *Ingenius*, no. 9, Jun. 2013, doi: 10.17163/ings.n9.2013.04.
[66] Agricultural Public Information System (SIPA), "Surface and Production - INEC," 2022.
[67] K. A. Iyer, L. Zhang, and J. M. Torkelson, "Direct Use of Natural Antioxidant-rich Agro-wastes as Thermal Stabilizer for Polymer: Processing and Recycling," *ACS Sustain. Chem. Eng.*, vol. 4, no. 3, pp. 881–889, Mar. 2016, doi: 10.1021/acssuschemeng.5b00945.
[68] C. Jimenez-Lopez *et al.*, "Agriculture waste valorisation as a source of antioxidant phenolic compounds within a circular and sustainable bioeconomy," *Food Funct.*, vol. 11, no. 6, pp. 4853–4877, 2020, doi: 10.1039/D0FO00937G.
[69] O. Rojo-Poveda, L. Barbosa-Pereira, G. Zeppa, and C. Stévigny, "Cocoa Bean Shell—A By-Product with Nutritional Properties and Biofunctional Potential," *Nutrients*, vol. 12, no. 4, p. 1123, Apr. 2020, doi: 10.3390/nu12041123.
[70] R. Salazar, V. Salas-Gomez, A. A. Alvarado, and H. Baykara, "Preparation, Characterization and Evaluation of Antibacterial Properties of Polylactide-Polyethylene Glycol-Chitosan Active Composite Films," *Polymers (Basel).*, vol. 14, no. 11, p. 2266, Jun. 2022, doi: 10.3390/polym14112266.
[71] S. Santacruz, C. Rivadeneira, and M. Castro, "Edible films based on starch and chitosan. Effect of starch source and concentration, plasticizer, surfactant's hydrophobic tail and mechanical treatment," *Food Hydrocoll.*, vol. 49, pp. 89–94, Jul. 2015, doi: 10.1016/j.foodhyd.2015.03.019.
[72] M. Fiallos-Cárdenas, S. Pérez-Martínez, and A. D. Ramirez, "Prospectives for the development of a circular bioeconomy around the banana value chain," *Sustain. Prod. Consum.*, vol. 30, pp. 541–555, Mar. 2022, doi: 10.1016/j.spc.2021.12.014.
[73] J. Mórtola Valero, "Letter to Santiago Guarderas," *Comisiones del Concejo Metropolitano*, 2022. .
[74] A. Méndez Prieto, "Análisis del entorno tecno-ecológico de la bolsa plástica y sus alternativas," *Integra*, vol. 60, pp. 18–23, 2020.
[75] United Nations Environment Programme, "Turning off the Tap: How the world can end plastic pollution and create a circular economy," 2023.
[76] J. Mortola, "El clúster de plástico y la sostenibilidad de la industria," *Integra*, 2023.
[77] S. Park, "Factors influencing the recycling rate under the volume-based waste fee system in South Korea," *Waste Manag.*, vol. 74, pp. 43–51, Apr. 2018, doi: 10.1016/j.wasman.2018.01.008.
[78] J.-E. Seo, "Seoul promotes zero waste, and many are eager to help," *Korean JoongAng Daily*, 2022.