MARINE POLLUTION BY PLASTICS

A COMPREHENSIVE ANALYSIS

by MarViva Foundation

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This publication has been prepared within the framework of the project **“Strengthening coastal cities and local governments in Costa Rica and Panama to fight against marine litter by rejecting single-use plastics and improving waste management systems”**, financed by the Bureau of Oceans and International Environmental and Scientific Affairs (OES), of the United States Department of State.

Plastic waste pollutes for years © Shutterstock

Presentation

Our vision

The MarViva Foundation addresses the problem of plastic pollution with a comprehensive approach towards the life cycle, promoting the reduction of plastic production, use and consumption, through the strengthening of regulatory frameworks, with special emphasis on initiatives directed towards single-use, unnecessary and/or non-recyclable plastics. For this reason, since 2014, we have advocated for different bills in Costa Rica, Panama and Colombia, of which eight have already become national regulations and five are in the process of being formalized.

Among the main technical considerations that MarViva weighs to support the need to approve legislative initiatives, are:

1 - The best way to manage single-use plastic waste is not to produce it. Therefore, measures to discourage the production, use and consumption of these materials are key to reduce the amount of waste that cannot be reincorporated into the production chain.

2 - Prohibitions, along with other measures that promote a life-cycle approach to the problem, do not translate into economic decline.

3 - Single-use plastics contaminate throughout their life cycle.

4 - Oxo-degradable plastics (OXO), marketed as biodegradable and compostable, have the same environmental impacts as petrochemical plastics, and perhaps some still unknown. Consequently, they are not effective alternatives to traditional plastic.

Recognizing the benefits brought by plastics to humanity throughout history, the approach of MarViva Foundation is to evaluate, with transparency and considering environmental, social and economic variables, the scope and limitations of strategies based on isolated, non-structural and/or disjointed actions. Two examples are the strategies that only view plastic pollution as a waste management problem (e.g. promotion of recycling only) or those that promote changes in the form of consumption, without scientific support (e.g. the use of bio-based plastics).

We therefore advocate that States, companies and organizations make the necessary investments in research and innovation, and that the formulation of public policies be based on the best available scientific information, leaving politics, prejudices, and preconceived ideas without technical support aside from the discussion. The purpose of public and private decisions must be the prevention of plastic pollution.

As a result, a change of behavior and structure is expected in the forms of production, consumption, use and management of plastics. Because the solution to marine pollution by disposable plastics will hardly be found in isolated actions, MarViva Foundation proposes regulations such as:

1 - Elimination of the production of non-recyclable plastics.

2 - Reduction and prohibition of the production of unnecessary plastics, that is, those that do not add any value to the product or service, that exist according to their low cost but not according to any specific purpose, which in themselves have no value (e.g. party supplies, artificial foliage, packaging).

3 - Investment in research and production of low or no environmental impact, scientifically supported substitute materials.

4 - Innovative designs that allow the reuse and reduction of the use of plastics.

5 - Investment in waste management systems, with special emphasis on final disposal and infrastructure for the fair and effective separation, transportation and recycling of waste.

MarViva Foundation promotes better governance schemes for the prevention of plastic pollution at the local, national, regional, and global levels, and accompanies these processes with communication campaigns in the three countries where it operates: Costa Rica, Panama and Colombia. At the same time, it works to strengthen capacities, both for public and private stakeholders, to increase citizen awareness regarding the negative impacts of plastic waste on marine and coastal systems. Likewise, it encourages the implementation of good practices among commercial establishments, supported by voluntary commitments to reduce disposable plastic. In this way, at the time this contribution comes to light, more than 65 commercial establishments and businesses in Costa Rica, Panama and Colombia will have joined the #ChaoPlásticoDesechable campaign.

The objective of this publication is to present scientific information on plastic, its life cycle and the various environmental impacts it produces, seeking to shed light on the most relevant variables of the single-use plastic pollution problem. To this end, the target audience is the civil society in general, with particular attention to those responsible for the formulation of public policies in Costa Rica, Panama and Colombia.

Acronyms and abbreviations

AAUD	Urban and Home Cleaning Authority (Autoridad de Aseo Urbano y Domiciliario)
ABS	Acrylonitrile Butadiene Stirene
ANCON	National Association for Nature Conservation (Asociación Nacional para la Conservación de la Naturaleza)
AS	Australian Standards
ASTM	American Society for Testing and Materials
B.O.T	Barrier or Trash
BC	before Christ
BFR	Brominated flame retardants
BP	bisphenol
BPA	bisphenol A
bpd	Barrels per day
CA	cellulose acetate
CEN	European Committee for Standardization (Comité Europeo de Normalización)
CGSM	Ciénaga Grande de Santa Marta
CIMAR	Center for Research in Marine Sciences and Limnology (Centro de Investigación en Ciencias del Mar y Limnología)
CIPRONA	Research Center of Natural Products (Centro de Investigación de Productos Naturales)
COBSEA	Coordinating Body on the Seas of East Asia
CSWMP	Comprehensive Solid Waste Management Plans
CSWS	Council for Solid Waste Solutions
DIAN	Directorate of National Taxes and Customs of Colombia (Dirección de Impuestos y Aduanas Nacionales de Colombia)
EBTS	Ecological Barriers to Trap solids
ECHA	European Chemicals Agency
EPS	Expanded polystyrene
ETP	Eastern Tropical Pacific
FOB	Money value of a commodity in the port of departure of its country of origin. It is the value at which the goods are sold at the factory plus expenses (e.g. internal transport, exit taxes, cargo, among others) to bring it to the port of departure.
GDP	Gross Domestic Product
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GMA	Greater Metropolitan Area
GQSP	Global Quality and Standards Program
HDPE	High Density Polyethylene
IDB	Inter-American Development Bank
INEC	National Institute of Statistics and Census (Instituto Nacional de Estadística y Censo)
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
kg	Kilograms

LDPE	low-density polyethylene
LLDPE	linear low-density polyethylene
m^2	square meter
MADS	Ministry of Environment and Sustainable Development (Ministerio de Ambiente y Desarrollo Sostenible)
MARPOL	International Convention for the Prevention of Pollution from Ships
mm	millimeters
n.d.	no date
OXO	Oxo-degradable plastics
PBT	polybutylene terephthalate
PC	polycarbonate
PCB	polychlorinated biphenyls
PE	polyethylene
PET	polyethylene terephthalate
PFAS	Perfluorinated compounds
PFHx	perfluorohexanesulfonic acid
PGN	Procurator-General of the Nation (Procuraduría General de la Nación)
PHA	polyhydroxyalkanoates
PLA	polylactic acid
PMMA	polymethyl methacrylate
POP	persistent organic pollutants
PP	polypropylene
PROCOMER	Export Promotion Agency of Costa Rica (Promotora de Comercio Exterior de Costa Rica)
PS	polystyrene
PUR	polyurethane
PVC	vinyl polychloride
RCM	renewable, compostable, compostable in marine environment
RIC	Resin Identification Code
SDGs	Sustainable Development Goals
SICA	Central American Integration System (Sistema de la Integración Centroamericana)
SIEX	External Trade Statistic System (Sistema Estadístico de Comercio Exterior)
SIS	Single Information System
SPI	Society of the Plastic Industry
SSPD	Superintendency of Residential Public Services (Superintendencia de Servicios Públicos Domiciliarios)
t	tons
TEC	Technological Institute of Costa Rica (Tecnológico de Costa Rica)
UCR	University of Costa Rica
UNA	National University (Universidad Nacional)
UNEA	United Nations Environment Assembly
UNED	National State Distance University (Universidad Nacional Estatal a Distancia)
UNEP	United Nations Environment Programme
UNO	United Nations Organization
USD	US Dollars
UV	Ultraviolet
WHO	World Health Organization
µm	micrometer

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Large amount of plastic waste reaches rivers and seas every day © Shutterstock

Executive Summary

Plastic, as an artificially generated polymer, can be considered recent in human history. Its origins go back about 150 years, when a substitute was sought to satisfy the demand for ivory, and its production volumes would increase until becoming the source of one of the greatest environmental crises on the planet. However, polymers or long chains of molecules were already found in nature in the form of silk, rubber, and other natural materials.

The flexibility and high durability of plastics have played a critical role in human development, allowing medical and technological advances of great relevance. However, the characteristics that have made them beneficial have also made them harmful, allowing more than 250 million tons of plastic waste to accumulate and pollute the entire ocean (The Pew Charitable Trust, 2020). Contrary to what is normally thought, the negative impact of plastics does not only occur when they are discarded; it is already present when in use.

When produced or while accumulating, plastics used in toys, food packaging and everyday products contaminate the environment and release chemicals that are transferred through the food web and release toxic substances (e.g. phthalates or bisphenols), which can have negative impacts on human health (Flaws et al., 2020).

This document provides a comprehensive view on marine plastic pollution, which addresses all aspects of the life cycle of this material in the regional context of Costa Rica, Panama and Colombia. From the analysis of existing information, it could be determined that the prevention of pollution by plastic waste, both in general and single-use plastics in particular, focusedonly on waste management and leaving aside changes in production and consumption systems, is a costly and inefficient approach.

Recycling is conceived by many as the most effective way to handle plastic waste and is widely promoted as part of circular economy models. Although recycling justifies the excessive and unnecessary consumption of some plastics, the reality is that not all plastics can be recycled, since they require certain characteristics to reenter the production chain. Many of these characteristics lack sufficient studies and yet States are issuing regulations for their use without the technical information to support them. In fact, the quality of the plastics consumed today is lost every time they go through a recycling process, breaking with the principle of perpetuity in a circular model.

Additionally, the amount plastic waste for recycling grows faster than the capacity of waste management and treatment systems, increasing the accumulation in the environment.

To reduce the negative perception of plastic, many companies have started to produce bio-based plastics. This type of plastic is advertised as an alternative to fossil-based plastics, promising to easily degrade in the environment. These products are being designed and manufactured with the same durability characteristics as fossil-based plastics and, although promoted as biodegradable or compostable, the true conditions required for their biodegradation or compostability are not revealed. In this case, the proposed solution continues to be part of the problem. In Latin America, consumers face significant gaps in information on biodegradability under natural conditions and the chemical additives contained in these products, reducing their ability to measure the impact of these products on the environment.

A 36% of the plastics produced annually in the world are for single use. These are completely unnecessary and doing without them would contribute considerably to the reduction of pollution (UNEP, 2018b). However, these changes require legislative foundations to drive actions towards structural change, generate joint responsibilities and changes in the behavior of the people involved in the production and consumption cycle.

This publication aims to provide the reader with a broad context to achieve a better understanding of elements such as production, use, consumption and disposal of plastics, to support behavioral changes that can mitigate this global problem. The document is divided into five parts: the first contains a summary of the history of plastics, the evolution of the industry and statistics of the problem at present. The second part describes the types of plastic raw materials, fossil and non-fossil, that are currently used, as well as their functionality and impact; followed by a third chapter that estimates the stages of production, consumption and disposal of plastics in Colombia, Costa Rica and Panama. The fourth part illustrates the impacts of pollution on the health of oceans and humans, emphasizing the three countries in question, and the fifth part presents the current discussions that involve the international, regional, and national approach to the problem.

Reusable plastic containers © Shutterstock

1 The History of plastics: milestones and impacts

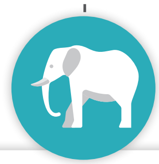
1.1. Origin

The word plastic comes from the Greek word plastikos and describes the ability of a material to mould or take various shapes (PlasticsEurope, 2021). The plastics we know today contain long chains of molecules called polymers, which immitate the natural polymers found in fibers such as silk or wool, characterized by their high flexibility.

In the region, humans have benefited from natural polymers since 1600 BC Mesoamerica. At that time, the inhabitants of the Central American territory extracted latex from the *Castilla elastica* (rubber) tree (Figure 1) and shaped into a solid ball used in a game used to settle land and value disputes (Hosler et al., 1999). They also manufactured human figurines, axe handles and medicines, demonstrating the versatility of these material (Hosler et al., 1999). Also in this period, if packaging was required, pumpkins, shells, and leaves obtained in nature were used. Later, containers started to be made using hollow trunks, woven plants, and animal organs. Fabrics came from animal skins and, as weaving was perfected, baskets were made for food storage (Hook and Heimlich, 2017).

1600
before Christ (BC)

Latex is extracted from the *Castilla elastica* (rubber) tree and molded into a solid form to create balls that were used in a game in which land and values were disputed.



19th Century
Industrial Revolution

Demand for animal horns and rubber is increasing.

Demand for natural materials such as ivory, tortoiseshell, animal horns and rubber increased during the industrial revolution in the 19th century (Britannica, 2019). This put species such as elephants and turtles at risk (Britannica, 2019). To respond to this problem, in 1862, the metallurgist and British inventor Alexander Parkes, presented "Parkesine" at the London International Exhibition, a substance resulting from mixing vegetable cellulose and nitric acid, which promised to be a substitute and to supply the demand for these animal-based materials (Parkes et al., 1865; Britannica, 2019).

Parkesine became the starting point for the American inventor John Wesley Hyatt who, in 1863, accepted the challenge of the firm Phelan & Collender to find a material that would replace the ivory used for billiard balls for a reward of USD 10,000. Despite warnings of an impending explosion, Hyatt mixed camphor with nitrocellulose, heated it, compressed it into a mold, and after cooling it he obtained a hard, shiny material that his brother called "celluloid." However, celluloid's high volatility and degradation under sunlight, imposed restrictions on its use in terms of durability and resistance (Meikle, 1995; Mulder and Knot, 2001 and Geyer, 2020). Around this same time, in 1859, Colonel Edwin L. Drake made the first drilling for oil, a product that replaced whale oil at a time when they were on the brink of extinction, and would come to play an important role in the production of plastics (Schwarcs, 2017).

Another important development occurred in 1872, when the German, Adolf Von Baeyer, described the reaction of phenol and formaldehyde, the basis for generating a substitute for shellac, produced by the worm *Kerria lacca*. Shellack was used in its simple form to provide a final finish and protect wood and metal items, such as portrait holders and chests, among others. It could also be mixed with sawdust and shaped using heat and pressure to make containers for daguerreotypes, the photographs of the time (Freinkel, 2011a; Plastic History Society, 2015).

In 1907, the Belgian-American chemist Leo Baekeland created a machine to control exhaust gases from the von Baeyer reaction and, thanks to this procedure, came up with the first synthetic heat-resistant polymer: the phenol-formaldehyde resin, which he baptized as Bakelite (Bakelite Museum, n.d.; Geyer, 2020). In 1910, Baekeland founded the General Bakelite Company, to produce Bakelite extensively and market it worldwide as "the material of a thousand uses", replacing shellac and being used in the production of knobs, dials, circuit boards, radio cabinets and electrical systems for cars, maintaining its dominance until the 1930s, when it began to be combined with other phenolic resins to produce low-cost jewelry (American Chemical Society, 1993; Meikle, 1995; Britannica, 2009).

1859
Colonel Edwin L. Drake

Carries out the first drilling to extract oil, a product that later replaced whale oil.

1862
Alexander Parkes

Invents a mixture of vegetable cellulose treated with nitric acid, which promises to become a substitute and supply the demand for materials of animal origin.

1863
John Wesley

Create a hard and shiny material to replace the ivory used in billiard balls. It was named "celluloid".

1907
Leo Bakelyte

Invents the first heat-resistant synthetic polymer: the phenol-formaldehyde resin, which he named bakelite.

When the Frenchman Henri Victor Regnault discovered polyvinyl chloride (PVC) in 1838, he found no use for it. But in 1912, the German chemist Fritz Klatte invented a new method to polymerize it, using sunlight. However, this discovery remained without any particular use until 1920, when the American chemist Waldo Semon, of the BF Goodrich company, managed to add plasticity and flexibility to PVC and began to produce it commercially in 1930 (Mulder and Knot, 2001; Mülhaupt, 2004).

Also in 1920, another great discovery shook the international scientific community, when the German organic chemist Hermann Staudinger demonstrated that, through different reactions it was possible to join small molecules to form what he called macromolecules. Staudinger called this reaction a “polymerization,” in which several repeating units are joined by covalent bonds (e.g. electron-sharing atoms), which require a large amount of energy to split. This new technique was the foundation of the durability contributed by polymers to plastics and was the key to handle them with great precision to produce a wide variety of plastic materials that we know today (American Chemical Society and Gesellschaft Deutscher Chemiker, 1999; Mulder and Knot, 2001).

In 1927, DuPont placed its bets on funding pure research, hiring Wallace Hume Carothers as head of the chemistry department. In their experimental laboratories were born materials such as neoprene and the first polyester superpolymer, nylon, also called polymer 66 due to its molecular composition (Wolfe, 2008; DuPont, 2021). In 1938, DuPont began the construction of a plant for mass producing nylon and introduced the new material to the American market with a pioneering product: women’s pantyhose. The product was so successful that the products were sold out on the same day they hit the stores. However, the advent of war interrupted the event, since all nylon production was then destined to the armed conflict (Meikle, 1995; Wolfe, 2008; Freinkel, 2011a).

In 1933, the British Reginald Gibson and Eric Fawcett synthesized what is currently the world’s highest-produced plastic, without which the packaging industry would not exist: polyethylene (PE) (Freinkel, 2011b). By the late 1930s, plastic was already being produced from gas and oil. DuPont, Monsanto, Resinox, Celanese and Dow were expanding into the plastic production. During World War II (1939-1945), PE played a decisive role as cable insulation for the radars that were installed, for the first time in history, on British aircraft. This gave them a decisive advantage as they were able to detect enemy bombers that used to attack at night, as well as ships and submarines on the surface (Meikle, 1995; Hinsley, 2015).

1910
Leo Bakelyte

Brings bakelite to the market which is known as “the material of a thousand uses”.

1920
Waldo Semon

Manages to add plasticity and flexibility to PVC (discovered by Henri Victor Regnault in 1838), the second most widely used plastic resin in the world today.

Hermann Staudinger

Demonstrates that through different reactions it was possible to bind small molecules to form larger ones. He called this reaction polymerization.

1927
Wallace Hume Carothers

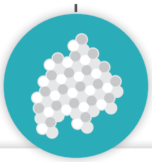
In his experimental laboratories he produced neoprene and the first polyester superpolymer, nylon, also called polymer 66.

1933
Reginald Gibson and Eric Fawcett

They synthesized what is currently the most widely produced plastic in the world, without which the packaging industry would not exist: polyethylene (PE).

1938

Plastic is already being produced using gas and oil. DuPont, Monsanto, Resinox, Celanese and Dow are expanding into the plastic production.



1941

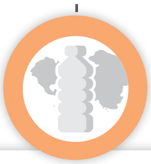
Ray McIntire

Discovers polystyrene foam, which acts as thermal and moisture insulation.

1946

James Watson Hendry

Develops an injection machine that increases the speed of production and the quality of products for food storage and packaging, which by the 1950s were present in every.



1950

Worldwide, half a million tons of plastic are produced annually.

The advent of war also popularized nylon and PE as raw materials for producing equipment such as helmets and parachutes, as well as vinyl and plexiglass, used in aircraft cabins (Glenn, 2020). Teflon, patented by DuPont in 1941 and used to make the atomic bomb's volatile gas containers, in the postwar it was marketed as non-stick material for cookware (Williams, 2006; Keats, 2018). The war gave a decisive boost to the plastics industry, which came to replace high-demand natural materials such as rubber.

Research on polymers was mostly carried out for commercial purposes with the aim of producing commonly used products at an affordable price (Meikle, 1995; García, 2009; Davis, 2015). In 1941, chemical engineer Ray McIntire of the Dow Chemical Company discovered polystyrene foam, which served as both thermal and moisture insulation. From this discovery, in 1954, the Kooper Company developed expanded polystyrene (EPS), which was then processed to become what we now call styrofoam, giving an additional boost to the disposable packaging industry (Cansler, 2018; Kay, 2020).

In 1946, the American James Watson Hendry developed an injection moulding machine that increased the production speed and quality of products for food storage and packaging, which by the 1950s were present in all American households. It was during this decade that thermosets (three-dimensional chain polymers, difficult to recycle) began to be replaced by thermoplastics (which can be melted and reused industrially). Producers compensated for the shortage of benzene (from coal) with oil and natural gas, triggering large-scale production (Meikle, 1995; Geyer et al., 2017; Geyer, 2020) and the development of new technologies. In 1965, DuPont chemist Stephanie Louise Kwolek developed the first liquid crystal polymer, which led to a fiber stronger than steel, Kevlar, used for bulletproof vests (DuPont, 2021). Oil extraction, a precursor to industrial technological advances, is today responsible for both the crisis of accelerated global climate change and plastic pollution (Kistler and Muffett, 2019).

1.2. Impacts

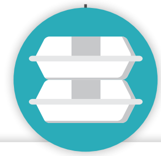
As the industry grew, its negative impacts became more apparent (Figure 1). In the late 1950s, there were already reports of sea turtles ingesting plastics and, in the early 1960s, polymers began to be detected in the digestive system of seabirds (CIEL, 2017c). Additionally, plastic waste began to be visible on the streets and in the environment, bringing with it a negative perception of the products and the industry that produced them (Meikel, 1995; Freinkel, 2011b; Clapp, 2012). In response, multiple campaigns were created in which plastic pollution was explained as the result of bad behavior on the part of consumers (Keep America Beautiful, 1968).

The plastics industry proposed recycling as a potential solution to the increasing amount of plastic waste in the 1970s (Meikel, 1995). In this same year, Gary Anderson, a professor at the University of Southern California, created the original recycling symbol in a contest funded by the Container Corporation of America (Center for Energy Efficiency, 2020). Later, in 1972, the first plastic recycling plant was built in Conshohocken, Pennsylvania. By the end of the 1980s, a USD 50 million campaign was launched, targeting US citizens, with the goal of communicating that plastic can be and is already being recycled (Frontline, 2020).

As part of this effort, the plastic-producing industry in the United States (the largest at the time), created the Council for Solid Waste Solutions (CSWS), with the aim of motivating municipalities to invest in plastic waste collection programs and labeling products with the recycling symbol (Frontline, 2020). However, in 1973, it was mentioned in a report written by the Society of the Plastic Industry (SPI), that there were doubts about the economic viability of recycling and that the process did not seem viable on a large scale (The Society of Plastics Industry, 1973; Frontline, 2020).

The presence of plastic material in the North Atlantic was recorded for the first time in the early 1970s, triggering research into its impacts on marine life and ushering in a new era of awareness and policy development such as the International Convention for the Prevention of Pollution from Ships (MARPOL), adopted in 1973. That same year, several investigations financed by petrochemical and manufacturing companies were presented, which evidenced the negative impacts not only of the presence of plastic waste in the sea, but also of its association with highly toxic chemicals such as polychlorinated biphenyls (PCBs), demonstrating that the industry has never been oblivious to the implicit threat of the long durability of post-consumer plastics, nor to their presence on the surface, as well as in beaches and marine sediments (Ryan, 2015; CIEL, 2017c).

Given the already evident problem, in 1984, the first workshop on the Impacts and Fate of Marine Debris was held in Honolulu (Hawaii). It was followed by the Sixth International Symposium on Ocean Waste Disposal in Pacific Grove, California. These meetings allowed for the impact of marine litter to be clearly elucidated, and then expanded to the problems of bycatch of marine species and sources of marine litter on land. In 1989, discussions on technology-based solutions, laws and policies,



1954
Kooper Company

Developed expanded polystyrene (EPS), which was later processed to become what we now call styrofoam.

1958

First reports of sea turtles ingesting plastics and, in the early 1960s, it was also detected in the digestive system of sea birds. Plastic waste is beginning to be visible on the streets and in the environment.

1970

The plastics industry proposes recycling as a potential solution to the growing amount of plastic waste.

Gary Anderson creates the original recycling symbol in a contest funded by the Container Corporation of America (Center for Energy Efficiency, 2020).

Early 1970s

The presence of plastic material in the North Atlantic is recorded for the first time.

and the first estimates of the costs of marine litter pollution were brought forward during the Second International Conference on Marine Debris, again in Honolulu (Ryan, 2015).

Although in the 1990s research on plastic and its threats to the environment seemed to slow down as production continued to grow, consumers began to detect the environmental impacts it caused and showed greater interest in minimizing them (Ryan, 2015; European Bioplastics, 2019; Geyer, 2020). In 1997, sailor Charles Moore discovered a large aggregation of floating plastic waste, now called the Pacific northeast plastic island, currently composed of 79,000 tons of abandoned fishing gear and 1.8 billion pieces of plastic (Parker, 2018).

At the beginning of the 21st century, complaints about the presence of microplastics in the marine environment reactivated scientific research. These fragments were found in practically all the world's oceans, in unimagined places, such as in the air of remote marine areas, at the bottom of the Mariana Trench and even in the Antarctic ice (Ryan, 2015; UN Environment, 2018a, WWF, 2019a; Trainic et al., 2020). It is estimated that in the sea there are approximately 5.25 trillion floating plastic particles and 14 million tons of microplastics residing in deep zone sediments. Plastic waste concentrations in the ocean are so high, that it is possible to detect macroplastic patches by satellite, with 86% accuracy (Eriksen et al., 2014; Mattsson et al., 2015; Barrett et al., 2020).

All these particles originate from the millions of tons of plastic waste (between 8 and 12.7 tons) driven annually by rivers into the ocean (Lebreton et al., 2017; Rochman, 2018). Only 20% of the plastic that enters the ocean comes from direct sources, such as the fishing and/or aquaculture industry, maritime transport, industrial marine activities, and tourism (Andrady, 2011; Lavender, 2017; Lebreton et al., 2017). Plastic bags, fishing gear and food containers make up more than 80% of litter on beaches and plastic fragments make up 90% of the debris found on the seabed, with variations in different geographical points (Galgani et al., 2015), harming wildlife and damaging ecosystem functions and services (The Pew Charitable Trust, 2020).

The actions and complaints of thousands of civil society organizations joined together to activate political action and, in 2011, during the Fifth International Conference on Marine Litter, it was agreed to develop a strategy with guidelines to help countries reduce the impacts of litter from marine, terrestrial and accumulation area sources: the Honolulu Strategy (UNEP and NOAA, 2011).

In 2019, the Basel Convention, an international treaty in which 186 countries commit to the implementation of controls for the

1972

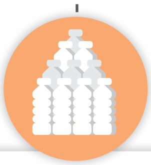
The first plastic recycling plant was created in Conshohocken, Pennsylvania. By the end of the 1980s, a campaign was launched communicating that plastic can be, and is already being, recycled.

1973

A report written by the Society of the Plastic Industry glimpses doubts about the economic viability of recycling, especially on a large scale.

1984

The first workshop on the Impacts and Fate of Marine Debris was held in Honolulu (Hawaii).



Between 1950 and 2017

A total of 8.3 billion tons of plastic is generated.

transboundary movement of hazardous waste and its disposal, included plastic on its list of potentially hazardous materials (Annex VIII of the Convention, category A3210) and offered guidance on proper waste management according to type of polymer (Annex IX of the Convention, category B3011) (UN Environment and Basel Convention, 2019). As it is legally binding, countries will have to comply with the commitments suggested by the treaty, which represents an important step to mitigating the problem. Additionally, delegates from several countries to the United Nations Organization (UNO) support the establishment of an international treaty focused exclusively on marine litter and microplastics, similar to the one established to reduce the gap in the ozone layer because they consider the current legal framework for plastic pollution to be fragmented and ineffective (MacFarlane et al., 2020).

1.3. Production process

The global production of plastics has grown exponentially over the last 60 years, from half a million tons per year in 1950 (Avio et al., 2017) to 359 million tons in 2018 (PlasticsEurope, 2019; WWF, 2019a). This represents an annual growth rate of 8.4%, which exceeds, in total volume and growth rate, most artificial materials, except those widely used in construction, such as cement and steel (Geyer et al., 2017). It is estimated that a total of 8.3 billion tons of plastic was generated between 1950 and 2017. Most of this production (92%) comes from fossil hydrocarbons and only 8% from recycled waste.

Currently, between 4 and 8% of the oil extracted is used in the production of plastics and the petrochemical industry expects this percentage to rise up to 20% in 2050 (CIEL, 2018; Nielsen et al., 2020) (Figure 1). The production of ethylene and propylene, key raw materials to produce the most used plastics, is estimated to increase between 2.6% and 4.0% per year until 2025, respectively. China is the world leader in propylene production, and the boom in liquid natural gas production in the United States, puts it at the forefront in ethylene production (CIEL, 2017a, 2017b; Kistler and Muffett, 2019). If these projections are met, by 2040 the accumulation of greenhouse gases related to the production of plastics could constitute 19% of the total carbon budgeted as a target to remain below the 1.5°C global temperature established in

Until 2017

Approximately 12% of the plastic produced was incinerated and 8% was recycled, of which only 10% was recycled more than once.

2018

359 million tons per year (world production of plastics).

2019

The Basel Convention, an international treaty in which 186 countries commit to the implementation of controls for the transboundary movement of hazardous waste and its disposal, includes plastic on its list of potentially hazardous materials.

Currently

Between 4% and 8% of the oil extracted is used in the production of plastics, a figure that could amount to 20% by 2050, according to the expectations of the petrochemical industry.

the Paris Agreement (United Nations Framework Convention on Climate Change, 2015). Additionally, the amount of plastic that will eventually accumulate in the oceans could triple (Pew Charitable Trust, 2020).

1.4. Demand

In terms of the current demand for plastics, packaging leads overall consumption (36%), followed by construction (16%) and textiles (14%) (Geyer, 2020; Geyer et al., 2017). North America, China and Western Europe consume 21, 20 and 18% of the total annual production, respectively. The most used polymers are polypropylene (PP; 16%) for textiles and packaging lids; low density and linear low-density polyethylene (LDPE, LLDPE; 12%) for plastic bags; PVC for construction (11%); high density polyethylene (HDPE; 10%) for disposable plastic packaging, and polyethylene terephthalate (PET; 5%) mainly used for bottled beverages, which account for approximately 50% of total plastic use (UN Environment, 2018b; Geyer, 2020).

In the 1970s, 100% of plastic was discarded after a single use. Given the obvious presence of plastic waste, the same industry proposed recycling and incineration started as well (Ritchie, 2018; Science History Institute, n.d.). Until 2017, approximately 12% of the plastic produced was incinerated and 8% was recycled, and only 10% of that was recycled more than once. Therefore, at this rate, it is estimated that by 2040 incineration will increase to 18%, recycling rates to 13% and the generation of plastic waste discharged into the ocean will only decrease by 7% (Ritchie, 2018; Pew Charitable Trust, 2020).

Reuse, recycle, incinerate, and deposit in landfills are the only options available today for plastic waste management, each technique with the challenges it represents in terms of costs, demand for remanufactured products and work processes. It is estimated that currently 76% of the 9,200 million tons of plastics generated between 1950 and 2017 are found in landfills, dumps or in the environment (Geyer, 2020). In 2010 alone, 192 countries generated 275 million tons of plastic waste, of which between 8 and 12.7 million tons ended up in the ocean (Jambeck et al., 2015). In view of these figures, it is necessary to apply drastic changes to the entire management model, otherwise, it is estimated that by 2040, 29 million tons

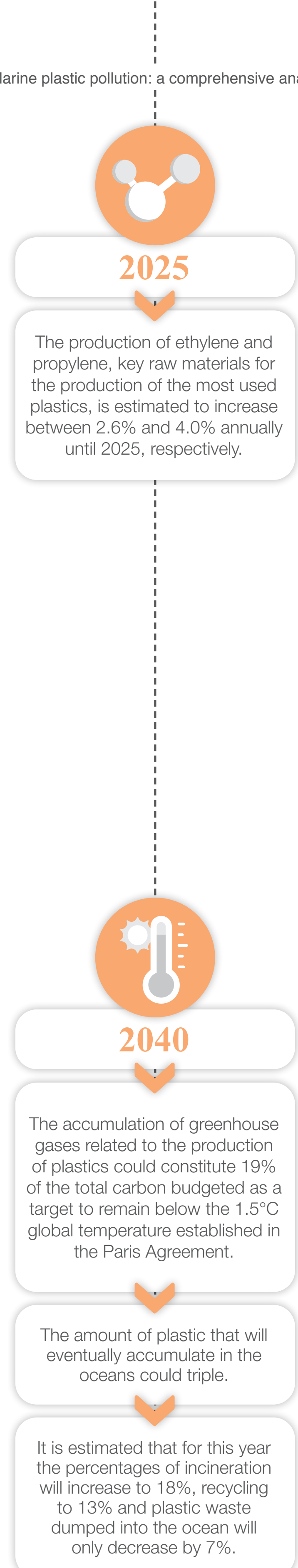


Figure 1 - History of plastic, milestones, and impacts (Source: Prepared by the authors, based on various information sources)

of plastic waste will be entering the ocean each year (The Pew Charitable Trust, 2020).

The evident presence of plastics, fragments, and chemicals in all marine ecosystems, including the poles, as well as their entry into marine and terrestrial food webs, and affecting human health, reflects the weakness in the development and implementation of updated strategies manifested in public policies (González-Aravena, 2018; UNEP, 2018b; WWF, 2019b; HEAL, 2020; The Pew Charitable Trust, 2020).

The plastic pollution crisis worsened with the arrival of the pandemic caused by the spread of the Covid-19 virus in 2020, because the consumption of single-use plastics increased under the premise of being the safest option to avoid contagion. However, so far there is no scientific evidence to support this claim. The negative impact increased due to weaknesses of waste systems to manage this increase in waste, and the absence of alternative materials that can be discarded without impacting the terrestrial and marine ecosystems of the planet (De Blasio and Fallon, 2021).

Plastic waste pollution © Shutterstock

2 Types of plastics

2.1. Definition and characteristics of plastics

The word plastic refers to a physical state of matter, characterized by great fluidity and very high viscosity. The plastic state is found in nature in the form of cellulose, natural resins, casein of animal origin, natural latex, among others (Crawford and Quinn, 2017). The constant use of the term plastic made it popular and today designates high molecular weight synthetic polymers derived from oil, natural gas, coal, and some organic materials (Jasso-Gastinel et al., 2017; CIEL, 2018), which are part of a diverse family of materials that vary in flexibility and durability as a response to temperature, pressure and concentration during the production process (PlasticsEurope, 2019).

2.1.1. Fossil-based plastics

The raw materials for fossil-based plastics are oil, natural gas and carbon (Figure 2). Through refining, distillation, and chemical transformation processes, they are broken into chains of molecules or monomers called olefins. When joined, these molecules form 100% synthetic polymers, in other words, artificially made. In the case of oil, the results of refining are naphtha and ethane, while in the case of gas and coal are propane and methanol, respectively (Figure 2). These products undergo a cracking process[1] and, depending on their origin, break down into smaller molecules (monomers) such as benzene (mainly from oil), ethylene and polypropylene (from both gas and coal). Styrene results from the chemical reaction between benzene and ethylene. Next, monomers are subjected to a chemical process called polymerization, which joins the monomers to form polymers or resins, which are then molded with pressure and heat into packaging materials, bags and tableware, using different resins (Figure 2). Post-consumer disposal can be adequate (blue column) or inadequate (orange column) and each cell indicates the number of tons handled per year in each category, including the 31 million tons recovered to be converted back into recyclable polymers, such as polypropylene and polyethylene (National GeoFigure, 2018; Baheti, 2020).

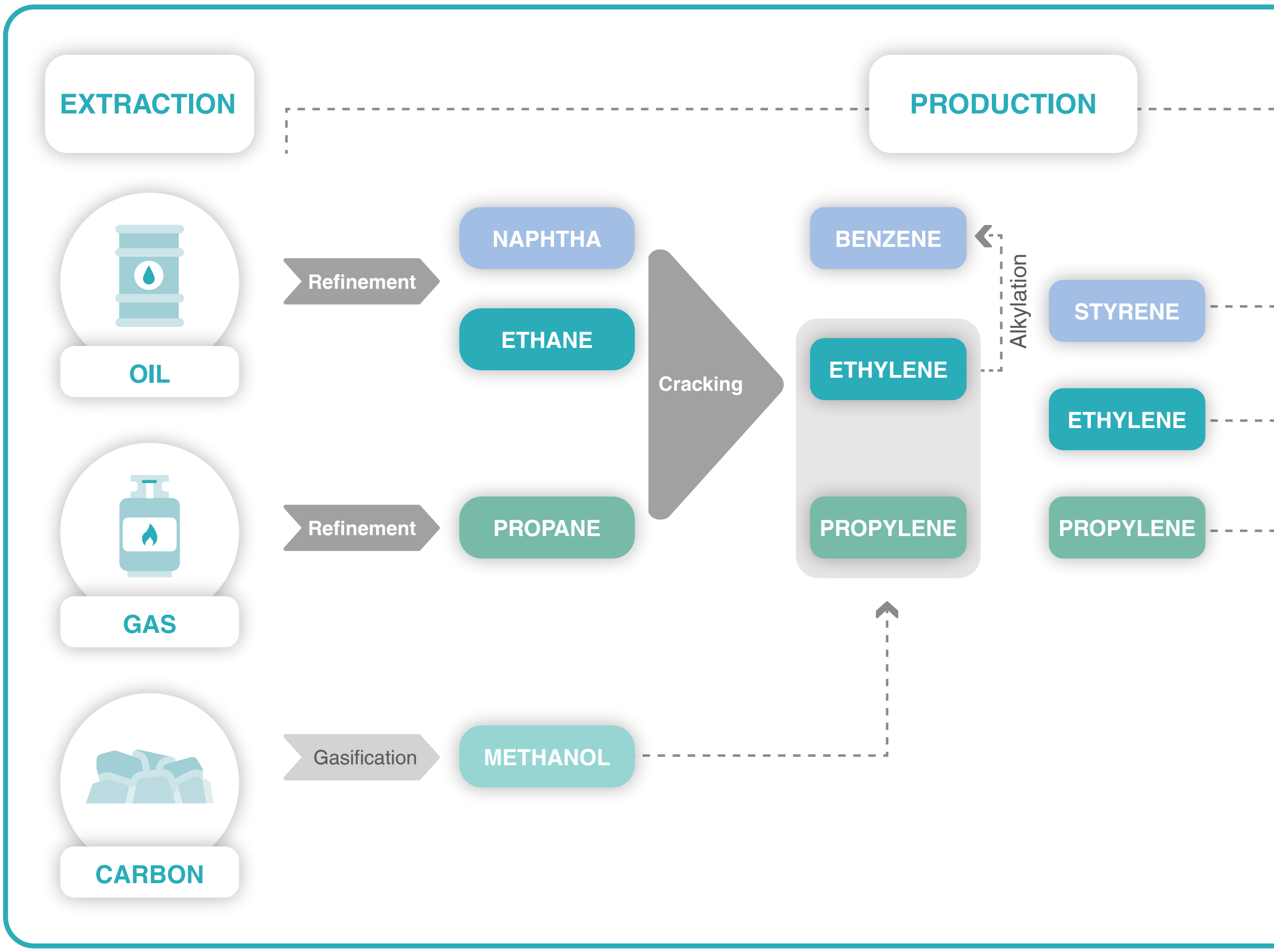


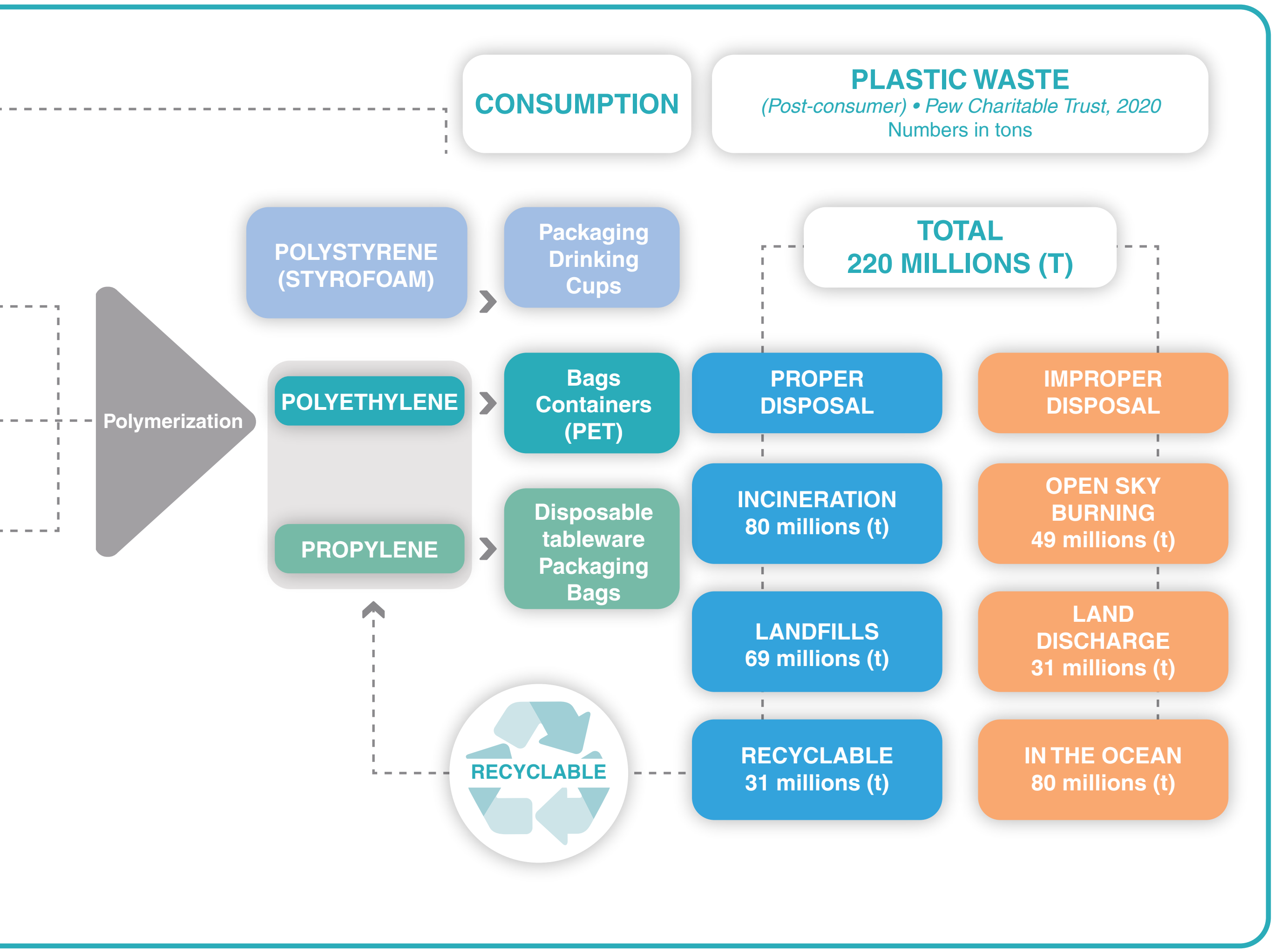
Figure 2 - Life cycle of fossil-based plastics (Source: National GeoFigure, 2018; Baheti, 2020)

1 Industrial chemical process by which heavier oil hydrocarbons are dissociated at high temperature and pressure in order to obtain a higher proportion of light products that can be mixed with fuels.

The most produced monomers are ethylene, propylene, and styrene, which when polymerized become polyethylene (PE), polypropylene (PP) and polystyrene (PS). At the end of the process, the polymers are cooled and cut into pre-production granules or pellets. The type of monomer from which it originates, the proximity of the chains or polymers and the force between the molecules, determine the rigidity, resistance and melting point of the plastic (CIEL, 2017c; Gabriel, 2018; Kistler and Muffett, 2019; GQSP, 2020; Science History Institute, n.d.).

2.1.1.1. Additives

To increase their resistance to heat, degradation and bacteria, plastics are combined with chemical additives (Table 1). The most widely used chemical additives are plasticizers (bisphenols, phthalates and alkylphenols), flame retardants (brominated flame retardants) and fillers (phthalates), which make up 75% of the annual production



of additives for plastics. Plasticizers weaken the strength of polymer chains and give more flexibility to these low-cost, highly plastic, moldable materials. Likewise, some types of plastics include more additives than others, depending on their future use. However, additives can incorporate an extra load of toxicity to the material. Since they are not bound to the polymer structure, more than 100 hazardous chemicals associated with these additives can easily leak into the environment or food, and even disrupt the endocrine system (Groh et al., 2019; Flaws et al., 2020; Geyer, 2020; American Chemistry Council, n.d.).

Table 1 - List of chemical additives present in plastics, with potential harmful effects for human health (Source: Greenpeace, 2004; Flaws et al., 2020)

CHEMICAL ADDITIVES	MAIN USES	EXPOSURE ROUTES	TOXICITY CONCERNS
Bisphenols (BP)	They are in epoxy resins and polycarbonate plastics, in reusable food, beverage, and water bottle containers, in linings of food cans, sports equipment, medications, eyeglass lenses, and plastic water pipes.	By filtration of materials that are in contact with the food and beverages consumed. They can also be found in sewage, groundwater, and freshwater bodies. In addition, they are found in the sand on beaches, where marine plastic debris abounds.	It is listed as a substance of concern by the European Union, and hundreds of chemical studies have shown it to be toxic.
Ftalatos	Used to produce or promote flexibility and reduce brittleness in plastics. Also, as plasticizers in PVC construction, medical, and consumer products, as matrices and solvents in personal care products, and as fillers in drugs and dietary supplements, food and beverage packaging, and children's toys.	They leach into the environment and into products that humans use and consume, items like food packaging, cosmetics, body care products, and toys. Also, by oral ingestion from food containers and the use of cosmetic products.	Some phthalates are restricted in the European Union and are classified as substances of very high concern.
Alquilfenoles	They are present in personal care products, pesticides, detergents, industrial cleaners, latex paints, and many different types of plastics. Used as ultraviolet (UV) stabilizers and heat stabilizers for PVC in water pipes and floors. They are also used to spread substances such as paints and coatings on surfaces. Some are approved for use as indirect food contact substances.	They can seep through drinking water pipes. In addition, due to their numerous applications, they are always in contact with humans.	They are bio-accumulative compounds. Nonylphenol (a type of alkylphenol) has recently been classified in the European Union as a toxic substance.
Brominated Flame Retardants (BFR)	To reduce flammability of plastic products. They are used in polystyrenes, foams and epoxy resins, used to manufacture electronic housings and cable linings, textiles, carpets, foams for furniture, construction materials. Are found commonly in plastic toys for children.	They are filtered from the products and are present in the domestic dust. Young children ingest this chemical through plastics toys. Plastic waste processing is an important source of human exposure.	They are included in the Stockholm Convention on persistent organic pollutants (POP). Nevertheless, the Stockholm Convention allows for some BFRs to remain In plastic materials for recycling.

CHEMICAL ADDITIVES	MAIN USES	EXPOSURE ROUTES	TOXICITY CONCERNS
Perfluorinated Compounds (PFAS)	Widely used in water and stain resistant clothing, food contact wrappers, lubricants, carpet treatments, paints, kitchen utensils and as dispersants in fire-fighting foams, as well as in other industrial and consumer applications.	Due to their use, they can contaminate drinking and groundwater. Most people are exposed while drinking tap water. They also leak into local water systems. In addition, PFAS leak from wrappers and cookware into food.	They are included in the Stockholm Convention on POPs. Technical experts of the convention have even recommended PFHx used as a substitute, to be included in the list.
Dioxins	They are by-products of industrial and combustion processes, generated during the production of plastic materials with BFR, as well as when incinerated or heated in a recycling process, to reshape them into new products.	They can be filtered orally, dermally and by inhalation. They are fat soluble. They adhere to the soil and can accumulate in the fatty tissues of animals and humans.	Considered the most toxic substances in the world. There is no safe level of exposure to dioxins.
UV Stabilizers	To protect plastic construction materials, auto parts, waxes and paints from deterioration due to UV radiation.	They can be filtered into food from packaging materials. They have also been found in domestic dust.	Many are found in the candidate list of substances of very high concern of the European Chemicals Agency (ECHA), due to its bio accumulative persistent, and toxic nature. The Swiss government has recently submitted a proposal to the Stockholm Convention for including UV-328 as a persistent organic pollutant.
Lead and Cadmium	As pigments, stabilizers and catalysts. Are found in a variety of plastic products, including shoes, bath products, mats, plastic toys and electronics, housings for consumer electronic products, such as televisions and personal computers, and soft PVC plastics, such as those used in toys, toys packaging and car seats.	Babies and children can be exposed to lead in toys and other domestic products due to their normal behavior of bringing their hands to their mouths.	Are toxic metals. There are no levels of safe exposure to lead.

2.1.1.2. Classification according to heat reaction

According to their reaction to heat, plastics are classified into thermosets and **thermoplastics**. Thermosets undergo chemical changes when they are heated, which prevents them from re-melting or reforming, while thermoplastics can melt with heat, remodel, and freeze repeatedly and unlimited times, making them the most in-demand resins (PlasticsEurope, 2019).

Among the **thermoplastics** of greatest importance and use are PE, polycarbonate (PC), PP, PVC, PET, EPS and PS. For their part, the most used **thermosets** are polyurethane (PUR), unsaturated polyesters, epoxy resin, melamine resin and vinyl esters. Lesser-known plastics include silicone, phenol (formaldehyde resins), urea (formaldehyde resins), phenolic resins, and acrylic resins (PlasticsEurope, 2019).

2.1.1.3. Classification according to type of resin

In general, plastics are classified into seven groups (Table 2), which include more than 80,000 existing resins, which are identified according to the Resin Identification Code (RIC) (ASTM, 2020). The codes were developed as a guide by the recycling industry, with numbers enclosed in arrows that rotate clockwise to form a triangle, but do not indicate whether a package is recyclable or not. It is simply a classification that indicates the type of resin or plastic used (American Chemistry Council, n.d.).

Table 2 - Resin identification codes (RIC), type of plastic, percentage of production for Europe and uses (Source: PlasticsEurope, 2019)

CODE	RESIN NAME	GROUP	USES
1	Polyethylene terephthalate (PET)	Thermoplastics	Beverage bottles, cups, etc.
2	High-density polyethylene (HDPE)	Thermoplastics	Toys, milk bottles, cleaning supplies, etc.
3	Polyvinyl chloride (PVC)	Thermoplastics	Window frames, profiles, floor and wall coverings, pipes, cable insulation, hoses, etc.
4	Low density polyethylene (LDPE)	Thermoplastics	Bags, can rings, pipes, containers, agricultural and food packaging film, etc.
5	Polypropylene (PP)	Thermoplastics	ndustrial fibers, hinged lids, microwavable food containers, candy wrappers, auto parts, pipes, auto parts, banknotes, etc.
6	Expanded polystyrene (EPS)	Thermoplastics	Plastic utensils, food containers (dairy, fish), polystyrene foam, building insulation, electrical and electronic equipment, interior lining for refrigerators, eyeglass frames, etc.
7	Other plastics: Polyurethane (PUR), Acrylonitrile Butadiene Styrene (ABS), Polybutylene Terephthalate (PBT), Polycarbonate (PC), Methyl Polymethacrylate (PMMA), Polylactic Acid (PLA), among others.	Thermoplastics and thermosets	Building insulation, pillows, and mattresses, insulating foams for refrigerators (PUR). Car wheel hub caps (ABS); optical fibers (PBT); eyeglass lenses, roofing sheets (PC); touch screens (PMMA); telecommunication cable coating (PTFE); and many others in the aerospace industry, medical implants, surgical devices, membranes, valves and seals, protective coatings, etc.

2.1.2. Bio-based plastics

The production of bio-based plastics consists of the processing of plant biomass, which is then refined, fermented, and transformed to produce resins that will be converted into plastics (OECD, 2013). Like their conventional counterparts, bio-based plastics include similar chemical additives (Flaws et al., 2020). The main bio-based polymers produced are polylactic acid (PLA) (Figure 3) and polyhydroxyalkanoates (PHA) (Figure 4), which are obtained from starch or cellulose (Gilbert et al., 2015; European Bioplastics and Nova Institute, 2019). PHAs are polymers produced directly from fermentation, that is, they are synthesized by microorganisms. Additionally, although PLAS come from a natural base, they undergo a chemical process and at the end of their life cycle require industrial composting processes, with the incorporation of microorganisms, like plastics of compostable fossil origin (García et al., 2013; OECD, 2013; Biosphere, 2018).

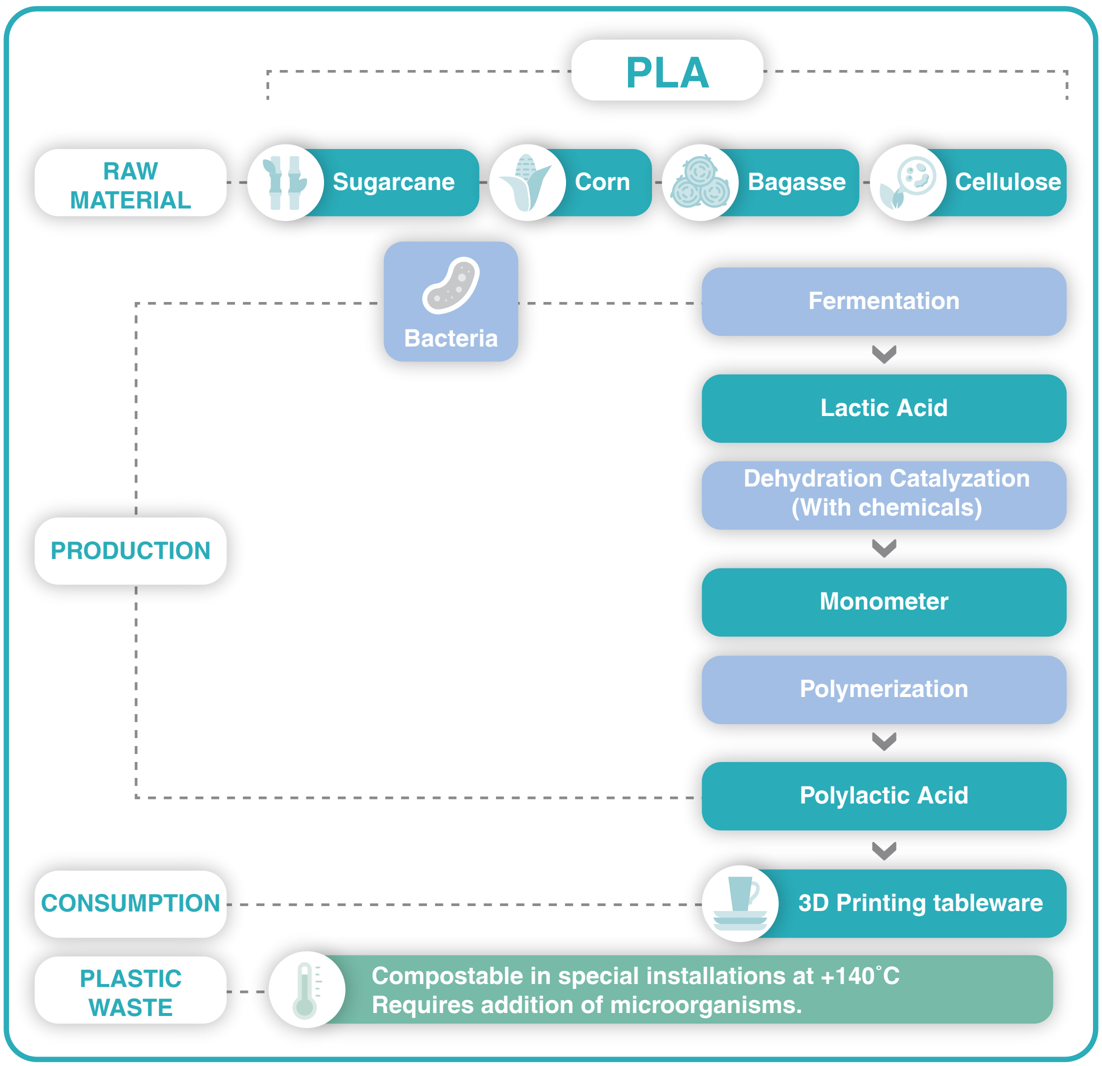


Figure 3 - Life cycle of plastic created from biomass. This raw material, after being fermented by microorganisms, undergoes chemical processes that in the end produce polylactic acid (PLA) (Source: Cho, 2017; Lucia, 2019)

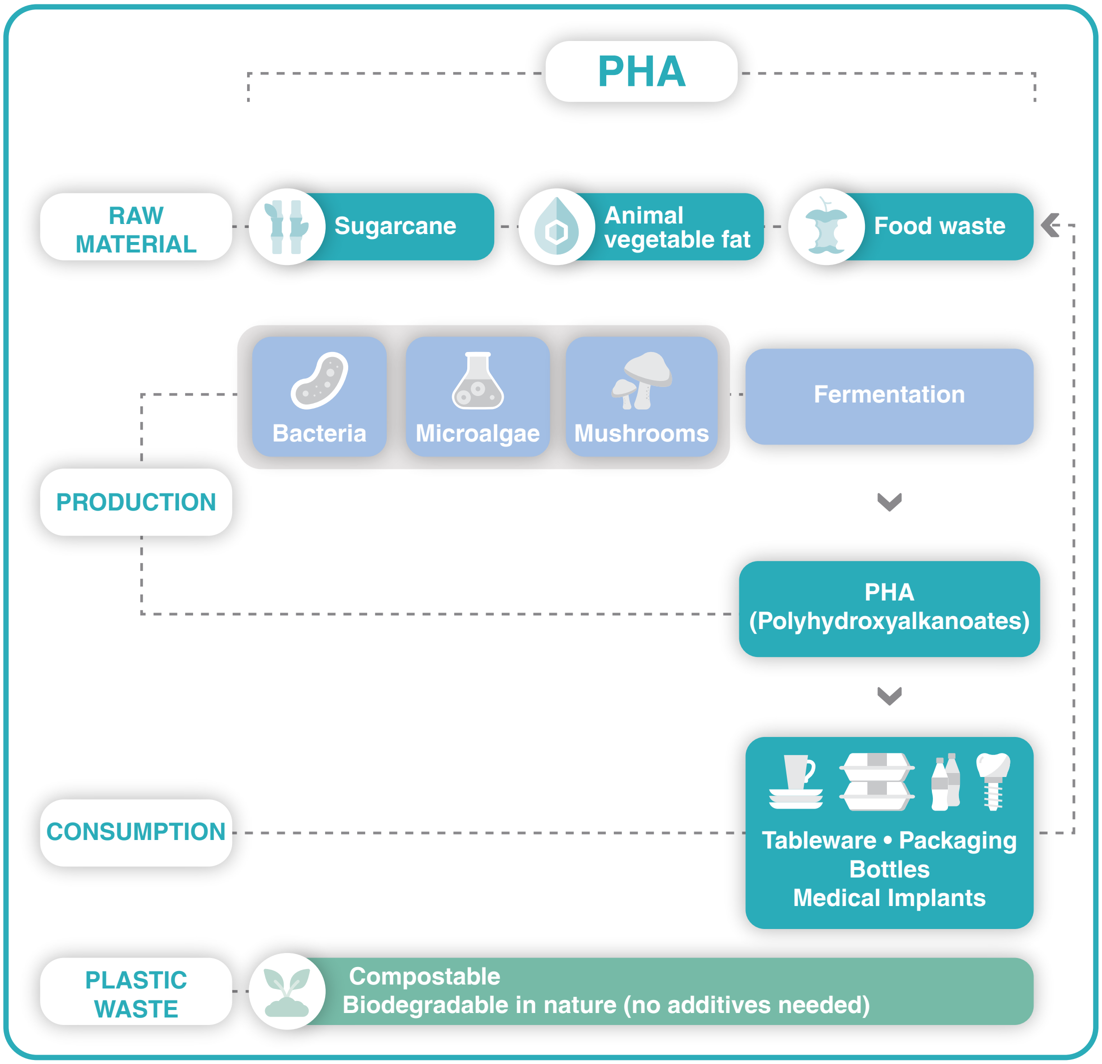


Figure 4 - Life cycle of a plastic created from lactic acid found in renewable sources, which when exposed to certain microorganisms produces Polyhydroxyalkanoate (PHA) (Source: Cho, 2017; Lucia, 2019)

Other bio-based plastics are polyester elastomers or bio-based technical performance polymers (European Bioplastics, 2019). These plastics have the same properties as their fossil-based versions and, at times, are mixed with petrochemicals. Although they can be recycled mechanically, they usually require high temperature industrial processes, implying an environmental impact like that of their fossil counterpart (Kistler and Muffett, 2019).

The bio-based plastics industry is divided in two types of products: biodegradable and compostable materials (PHA and PLA), and highly durable bio-based materials (polyester elastomers). On that basis, the final or post-consumption disposal options for this type of waste would be: composting for compostable biodegradables (depending on the specific type of bio-based plastic) and monomer recovery or incineration for non-compostable ones; options that are not very different from those available to dispose of plastic waste of fossil origin, which has the same limitations (OECD, 2013).

In 2019, 3.8 million tons of polymers of biological origin were produced, equivalent to 1% of the world's production of petrochemical plastics. The biggest installed capacity to produce bio-based plastics is in Asia (45%), followed by Europe (26%), North America (18%) and South America (11%).

A 53% (2 million tons) of the total production of biobased plastics went to the packaging sector in 2019 (Narancic et al., 2018). Other sectors such as automotive, transportation and construction have incorporated them, increasing the demand. PHA shows the greatest increase when used in flexible packaging (44%), rigid packaging (15%) and agriculture (13%). Regarding the use of other plastics of biological origin in other markets, in this same year the textile sector presented the highest demand (20%), with the use of polytrimethylene terephthalate (PET) and cellulose acetate (CA) (European Bioplastics and Nova Institute, 2019). Although this increased use in the textile industry may be an option to reduce the high levels of plastic pollution it produces, there is once again confusion regarding these plastics, since PET and CA, which are of plant origin, are not biodegradable in natural and/or home environments.

When studying plastics, fundamental concepts should also be analyzed: *biodegradability and compostability.*

1 - **Biodegradability:** is the biological decomposition process carried out by living organisms in natural environments (Tokiwa et al., 2009). Plastics of petrochemical origin do not biodegrade under natural conditions, since there is no organism in nature that can destroy the chemical chains of polymers that make up these elements (OECD, 2018). Similarly, bioplastics require specific temperature and relative humidity conditions to achieve this process.

2 - **Compostability:** is a condition necessary to make plastics biodegradable. In this case, the materials completely disintegrate in an average time of three months and can facilitate plant growth (OECD, 2013). Composting plastic, of any origin and susceptible to this process, requires special controlled conditions (e.g. prolonged temperatures above 50°C). Therefore, it is determined that there is no plastic that is compostable in natural environments (Sivan, 2011; Kubowicz and Booth, 2017).

By understanding these concepts, it is possible to establish that the origin of plastics (fossil or biological), does not determine their ability to reintegrate into the environment naturally, since even those that are produced using organic materials (bio-based), instead of petroleum require special sites with controlled conditions to facilitate their decomposition (Avio et al., 2017; Geyer et al., 2017).

If they achieve widespread consumption, like plastics of petrochemical origin, they will only contribute to the deficiencies in solid waste management and, especially, to the great plastic pollution problem in Latin America and the rest of the world. Bearing in mind that bio-based plastics cannot be recycled or reused, due to their special characteristics that will be analyzed in section 5.2.2. (Gall and Thompson, 2015; Grau et al., 2015).

2.1.2.1. Biodegradability and composting of bio-based plastics

The degradation of plastic involves physical or chemical changes caused by a photonic, thermal, hydrolytic, or biological degradation, which transforms its mechanical, optical, or electrical characteristics, fragmentation, discoloration, among others (Shah et al., 2008; Jasso-Gastinel et al., 2017). Biological degradation refers to degradation and assimilation by microorganisms, fungi, and bacteria, also called biodegradability (Singh and Sharma, 2008; Andrady, 2017; Scalenghe, 2018).

Although the general idea is that the biodegradability of bio-based plastics affects their durability in the environment, thus reducing their impact when they become waste (Beltrán-Sanahuja et al., 2020), the reality, already discussed, is that these materials do not degrade in the natural environment (OECD, 2018). For example, the decomposition of PLA in a landfill, at a temperature of 20°C, would take 100 years (OECD, 2013). And the situation would be similar for bio-based products such as mixed thermoplastic starches, which would require temperatures between 50 and 60°C to degrade (Tokiwa and Calabia, 2006), as well as sufficient oxygenation. Therefore, if bio-based plastics are not managed correctly in industrial facilities, they produce the same environmental impact as regular plastics (Gilbert et al., 2015).

Unfortunately, the indiscriminate use of the term “biodegradable” has resulted in misleading interpretations, in which the consumer assumes, or is encouraged to assume, that all plastics of biological origin can biodegrade, not to mention that in many cases, for this to take place, controlled conditions of high temperatures in specialized sites are required (Sivan, 2011; Kubowicz and Booth, 2017). This impacts consumer behavior, since labeling products as “biodegradable” tends to increase the production of waste that ends up in the environment (UNEP, 2015).

This is the case with oxo-degradable plastics, which are promoted as biodegradable, when they are conventional plastics with a prooxidant additive that accelerates fragmentation into particles, which still remain in the environment. As they do not meet compostability conditions, oxo-degradable plastics cannot be considered bio-based or biodegradable plastics (Kubowicz and Booth, 2017; New Plastics Economy, 2017).

A study carried out by the Research Center of Natural Products (CIPRONA, by its acronym in Spanish) of the University of Costa Rica (UCR), concluded that the PLA and OXO products used in Costa Rica were not compostable under the conditions studied, therefore, they could not be qualified as biodegradable according to the terms established by the standards IS/ISO20200:2004 and the Australian AS 5810-2010 for home composting. After one year and six months of experimentation, OXO, PLA and PE products showed no sign of degradation. After an additional 180 days of composting, the only material that was partially degraded under the Australian AS 5810-2010 standard was paper ((Universidad de Costa Rica, 2020).

Many of the regulations for the use and disposal of plastic materials are based on incomplete and even erroneous information. For example, to inform users about the consumption of plastic, Costa Rica promotes the RCM classification (renewable, compostable, compostable in marine environment), which aims to easily identify substitute materials to conventional plastics that have less impact on the environment (Ministerio de Salud de Costa Rica et al., 2017).

According to the proposal, contained in the National Strategy for the Replacement of Single-Use Plastics by Compostable and Renewable Alternatives, the classification would be based on ASTM standards (American Society of Tests and Materials) 6400, 6488, 7081-5 and the standard of the European Committee for Standardization CEN13432 (Ministerio de Salud de Costa Rica et al., 2017). However, standards such as D6400 and EN13432 indicate that the material is compostable at the industrial level and in a controlled manner; therefore, no result is obtained from practicing it at the domestic level. In addition, this strategy has weak foundations since the ASTM 7081-5 standard is no longer in force and ASTM 6488 does not apply to plastics. Although the terminology of biodegradability and compostability is widely used in the advertising of bioplastics, many classifications are misleading if they are not tied to specific standards. If a material or product is advertised as biodegradable, more information should be provided about the time, level of biodegradation and environmental conditions required for its natural degradation (PlasticsEurope, 2019).

The biodegradability of plastics has also been evaluated in marine environments under certain defined and controlled environmental conditions, where bio-based plastics such as PHA show greater degradability than conventional plastics, without conclusions on the time it would take to complete the process (Emadian et al., 2017; Beltrán-Sanahuja et al., 2020). In other experiments, researchers have observed that polymers tend to degrade more rapidly in less polluted ocean environments. However, not all biodegradable materials have the same rate of degradation, and it seems to be higher in the bottom than in the water column, probably due to a lower concentration of bacteria in the latter (Thellen et al., 2008; Beltrán-Sanahuja et al., 2020).

Plastic waste accumulates in the region © Shutterstock

3 Plastics in the region: Costa Rica, Panama, and Colombia

The global fossil plastic industry was valued at USD 522.6 billion in 2019 and is expected to double its production between 2020 and 2040 (Figure 5; Grand View Research, 2020; The Pew Charitable Trust, 2020). Costa Rica, Colombia and Panama are no strangers to this industry and, in order to understand the life cycle of plastics in these three countries, information on the different stages of the cycle is presented below: i) production; ii) international trade focused on products classified under tariff headings[2] 3923 (articles for transportation or plastic packaging; plastic caps, lids, capsules and other sealing devices) and 3924 (plastic tableware, kitchenware, household items and toiletries) and iii) management and regulations.

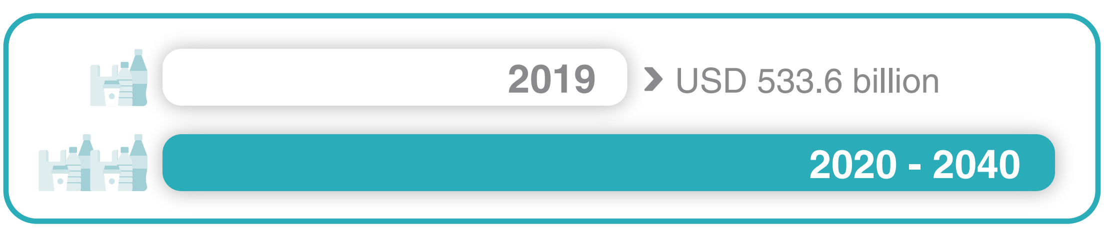


Figure 5 - Value of the global fossil plastic industry for 2019 and projection of the increase in plastic production for the period 2020-2040 (Source: Prepared by the authors, based on information consulted in Grand View Research, 2020 and The Pew Charitable Trust, 2020)

2 International numerical code identifying products to be imported using the harmonized system.

3.1. COSTA RICA

Factory producing plastic bottles © Shutterstock

3.1.1. Production, import and export of plastics

The national fossil-based plastics manufacturing industry imports its raw material mainly from the United States, China, and El Salvador. This sector includes 160 companies dedicated to the transformation of plastic, with an estimated production of USD 194 million in 2018 (Coto, 2019). In particular, the manufacturing sector of disposable plastics (bags, containers, plastic for palletizing, etc.) includes 56 companies. The main resin used in Costa Rica is polyethylene (HDPE and LDPE), used by 68% of companies, followed by PP (45%), PVC (9%), PS (9%) and PET (9%). The main markets for manufactured articles by sector are food (50%), final consumption (41%) and pharmaceutical chemicals (23%) (Figure 6; Box, 2019).

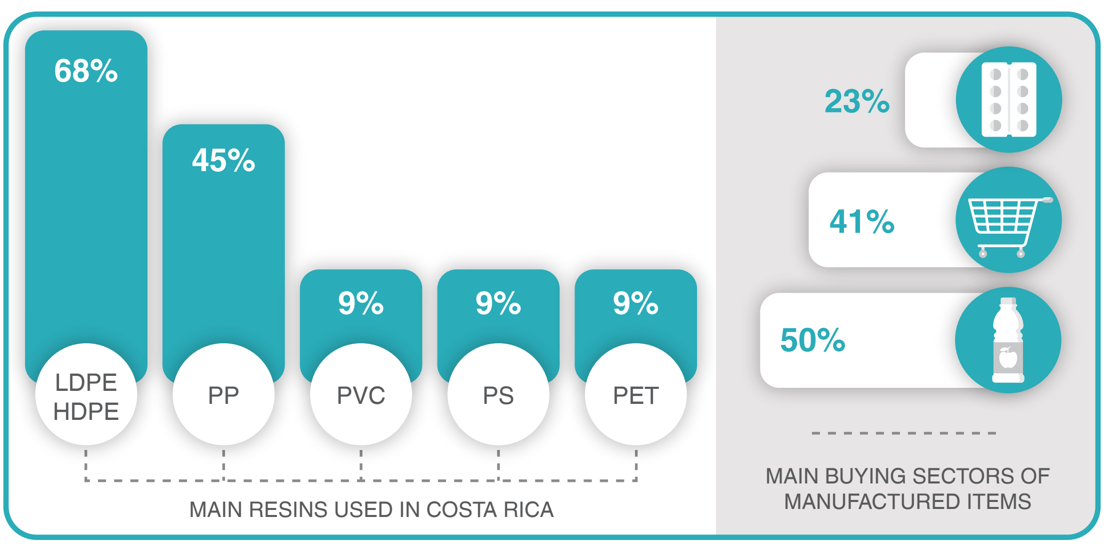


Figure 6 - Graph of manufacturing industry in Costa Rica (Source: Coto, 2019)

Plastic bottle packaging in the distribution process © Shutterstock

In relation to the production of plastics of biological origin, different public universities such as the UCR, the National University (UNA, by its acronym in Spanish), the Technological Institute of Costa Rica (TEC, by its acronym in Spanish) and the National State Distance University (UNED, by its acronym in Spanish), are leading research to produce locally bio-based plastics from banana and pineapple agro-industrial waste, due to their potential use in the Costa Rican market (O'Neal, 2018). Likewise, the Export Promotion Agency of Costa Rica (PROCOMER, by its acronym in Spanish) estimates that 77% of companies use plastics commercially known as "friendly", among those promoted as recycled, biodegradable and/or compostable. These companies pay for their materials a surcharge between 60 and 240% with respect to traditional resins, which discourages company reconversion and forces them to seek markets with the capacity to pay their surcharge (Coto, 2019).

According to the UCR, Costa Rica is the largest importer of raw materials and manufactured plastic items in Central America. The growth in the use of these products has caused monthly imports to double between 2011 and 2019, going from half a million to one million dollars per month, representing 1.8% of the Gross Domestic Product (GDP) in 2019. A total of 131 plastics importing companies have been identified: 51.9% micro and small, 26% medium and 19.1% large (Universidad de Costa Rica et al., 2019).

In terms of exports, in 2019 Costa Rica exported an equivalent of 176,592 tons of plastic materials and their products, with a FOB value of USD 669,718,931 (Recomex, 2020). The export sector is represented by a total of 343 companies that export more than 200 types of plastic products to about 80 destinations (Coto, 2019; Soto, 2019).

3.1.2. Consumption

In Costa Rica, 323,000 tons of plastic materials are consumed annually, of which more than 50% are packaging materials and consumer products that were discarded after one use. For example, nearly 700 million single-use plastic bottles are produced annually (Figure 7; Universidad de Costa Rica et al., 2019). Production capacity is concentrated on packaging and containers supplied by 64% of the companies, followed by bags (50%), film for pallets (18%), disposable tableware (14%) and strapping (9%) (O'neal, 2018; Coto, 2019; El Mundo, 2019b).

Figure 7 - Plastic materials consumed in Costa Rica each year (Source: Prepared by the authors, based on information from Universidad de Costa Rica et al., 2019)

3.1.3. Plastic waste management

It is estimated that 4,000 tons of solid waste are produced daily in Costa Rica. In 2018, households contributed 72.7% of waste and others (such as shops, schools, universities) contributed 27.3%. Of the total waste, 92.8% receives some treatment: 3.7% is recycled, 0.3% is composted, 0.2% is incinerated, 88.6% goes to sanitary landfills and dumps, and 7.2% is disposed of in an uncontrolled manner, or directly into the environment (Figure 8; (Ministerio de Salud de Costa Rica et al., 2017; Soto, 2019).

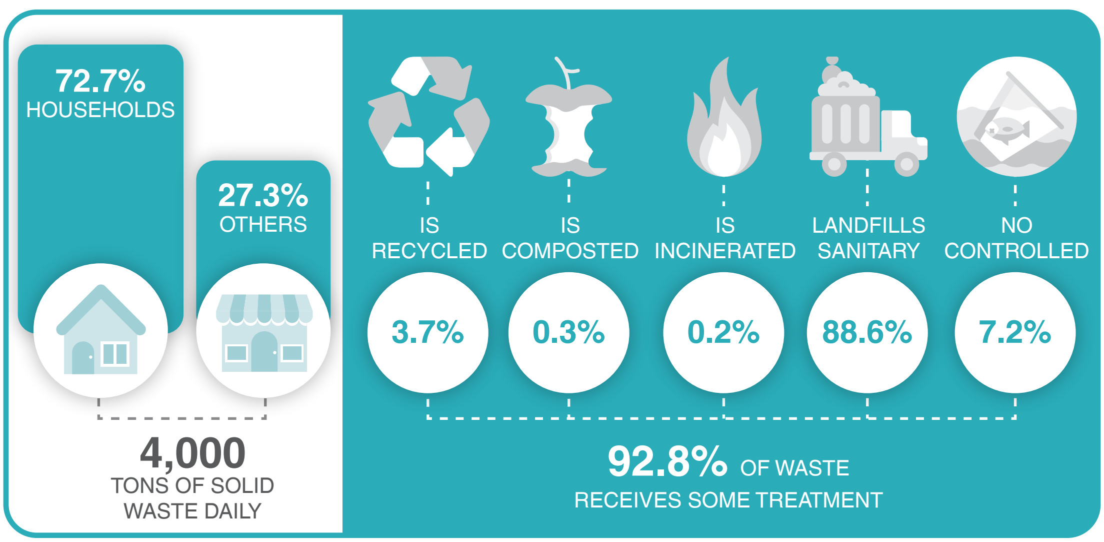


Figure 8 - Solid waste produced in Costa Rica (Source: Ministerio de Salud de Costa Rica et al., 2017)

Plastics account for 13.7% (550 tons per day) of the total waste generated. About 160,600 tons of plastics end up in Costa Rica's natural environments each year, putting biodiversity at risk (Figure 9; Universidad de Costa Rica et al., 2019). In addition, it is estimated that 80% (440 tons per day) of plastic waste is thrown into the sea every day in the country, equivalent to 35 garbage trucks per day. A 11% (60.5 tons per day) remains in dumps and in the terrestrial or river environment. Finally, only 9% (49.5 tons) of the plastic waste produced in Costa Rica is recovered for recycling (Ministerio de Salud de Costa Rica et al., 2017; Grajales, 2018; El Mundo, 2019b; Universidad de Costa Rica et al., 2019; 360 soluciones verdes, 2020).

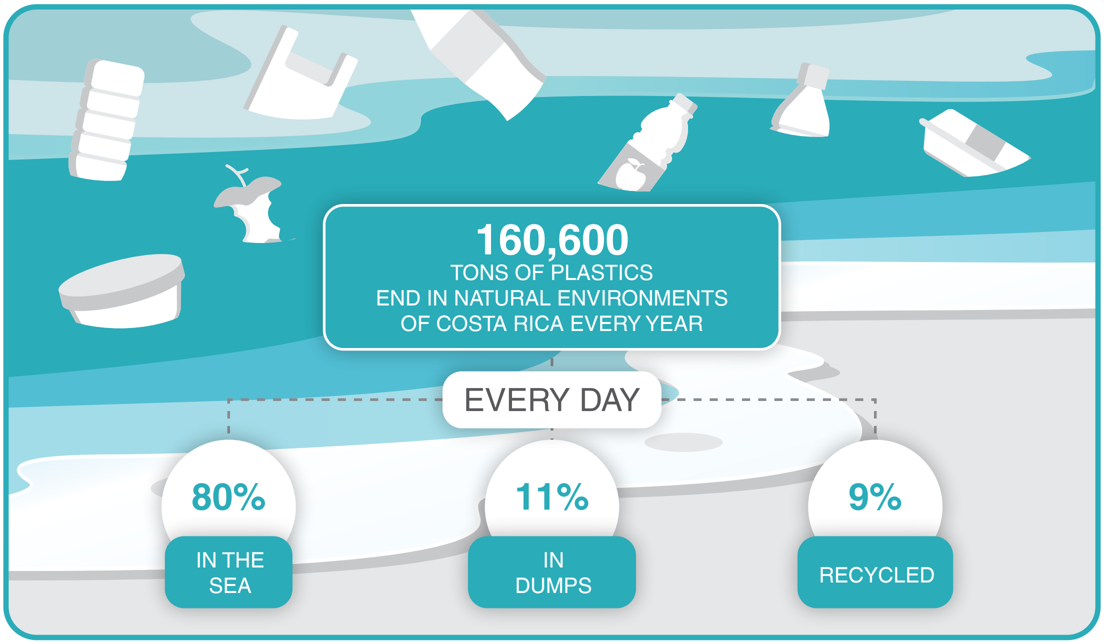


Figure 9 - Tons of plastic produced in Costa Rica (Source: Universidad de Costa Rica et al., 2019)

3.1.3.1. Landfills and dumps

In Costa Rica there are 36 garbage dumps, all of which are in the process of being closed, many of them are linked to 22 municipalities in predominantly rural areas. There are also eight active landfills, most of them serving urban cantons (360 soluciones verdes, 2020). In addition, solid waste burning and inappropriate disposal of materials in rivers, wastelands and, therefore, the eventual pollution of the sea (Soto, 2019) persist.

However, in recent years there have been improvements in solid waste management in Costa Rica, from 75% of waste disposed of in landfills in 2014, to 87% in 2017. At the same time, recovery for valorization increased from 1.3% in 2015 to 6.1% in 2017. In terms of dump use, it decreased from 25% in 2014 to 7% in 2018. Another positive step in the last decade is the transformation of dumps into sanitary landfills in urban areas of the country (Soto, 2019; Ministerio de Salud de Costa Rica et al., 2017).

However, the challenges are still significant. Eighty-seven of the country's 481 districts do not provide municipal collection and they resort to inappropriate practices such as burning garbage, dumping on land or water bodies. Also, the shortcomings of waste information systems in the country are evident and the Ministry of Health does not have an integrated platform with multi-year metrics and data, making it impossible to know with certainty the situation of the country with respect to quantities of materials disposed (Soto, 2019). Figure 10 contains a graphic representation of the life cycle of plastic in Costa Rica, from the import of raw materials to waste management.

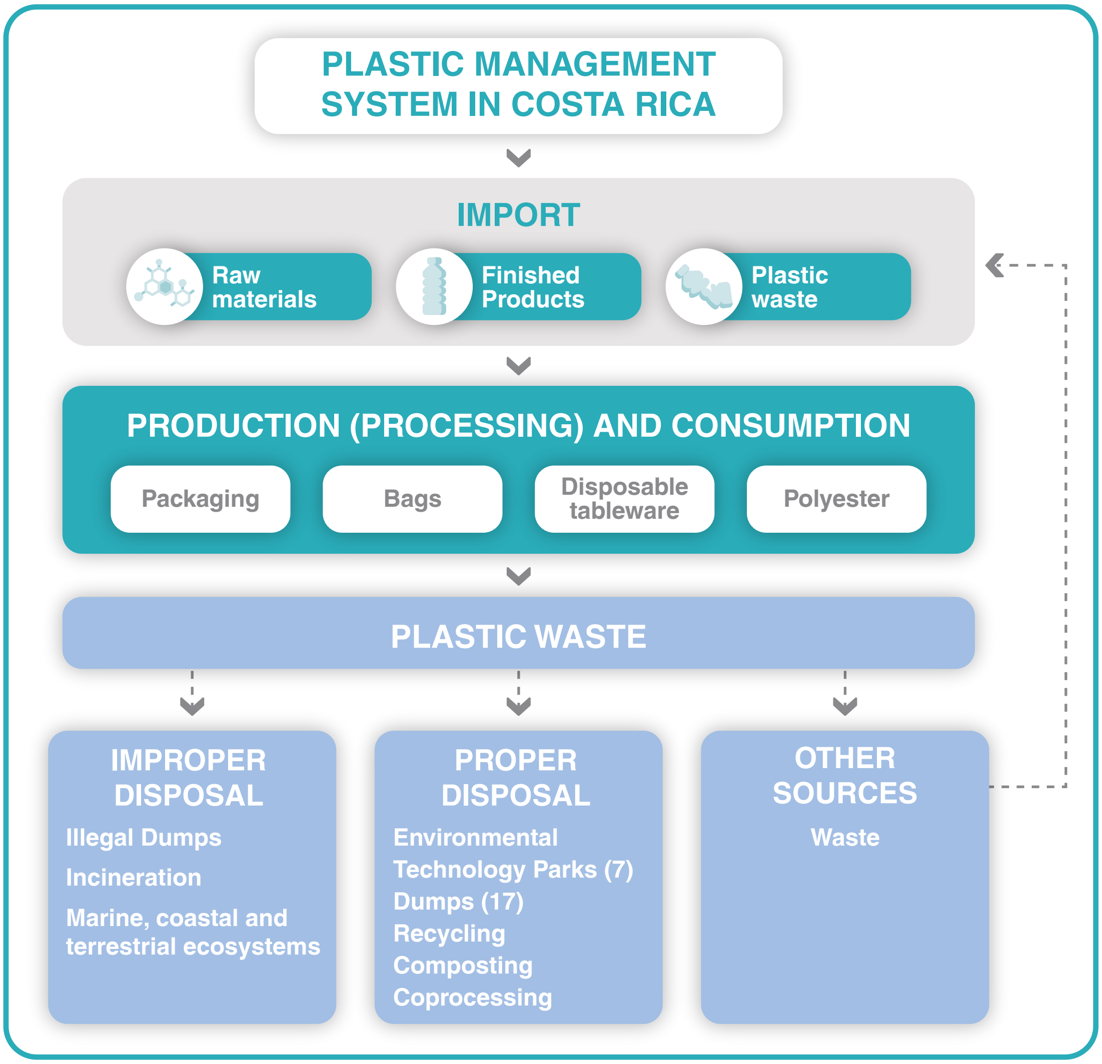


Figure 10 - Plastic management system in Costa Rica (Source: Prepared by the authors, based on information consulted for this research)

3.1.4. Regulations and policies for plastic waste management

At the regulatory level, Costa Rica has the Law to Combat Plastic Pollution and Protect the Environment (Law 9786, 2019), which prohibits new acquisitions or purchases within public administration institutions, state companies and municipalities of single-use plastic items, including disposable plates, cups, forks, knives, spoons, straws and stirrers, as well as others used mainly for food consumption. This law also prohibits the marketing of certain types of straws and single-use plastic bags.

On the other hand, there is also a Law that prohibits selling and delivering EPS bottles and containers to any commercial establishment (Law 9703, 2019), except in cases where, for reasons of conservation or protection of the products, the use of alternative materials is not environmentally viable. This law also regulates EPS used for packaging of household and related appliances, as well as in industrial uses.

From the executive, the National Strategy for the Substitution of Single-Use Plastics has been promoted and is in force. It includes education campaigns, inventory of raw materials as possible plastic substitutes and monitoring of municipalities to discourage single-use plastics (Ministerio de Salud de Costa Rica et at., 2017). Lastly, a series of executive guidelines have been issued to prohibit selling and bringing single-use plastics in protected wild areas, regulate the use and purchase of plastics in public institutions and, finally, a technical standard to regulate plastic product labeling.

One of the main limitations of the Costa Rican legislation is the authorization to replace single-use plastic materials with what is known as “low-impact” bio-based plastics, without considering the limitations on the biodegradability and recyclability of this type of plastics.

3.2. PANAMA

3.2.1. Production, import and export of plastics

Panama imports raw materials for plastic production from the United States, Mexico, Colombia, Argentina, and China. Between 2015 and 2019, Panama imported an average of 160,704 tons of products such as resins, intermediate products, and plastic manufactures, grouped in chapter 39 of the Harmonized Commodity Description and Coding System. Of the raw materials imported, on average 333,338 tons of plastic are produced annually (Figure 11) and in 2018, 324,011 tons were produced (FAS Panama, 2020).

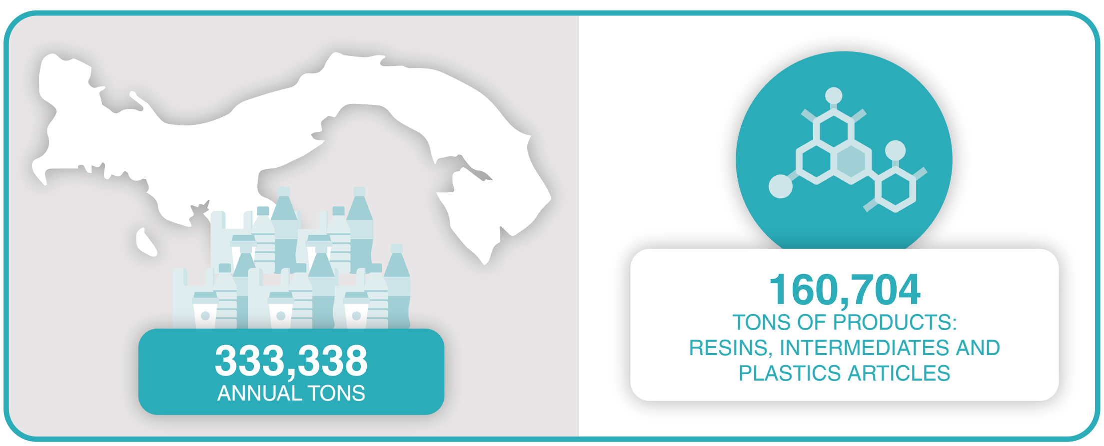


Figure 11 - Plastic materials produced in Panama each year (Source: FAS Panama, 2020

Between 2015 and 2019, imports of single-use plastic products or similar (headings 3923 and 3924 of the tariff system) totaled 260,050 tons, where 79% corresponded to the subheading of articles for plastic transport or packaging (3923); that is, commercial use packaging for an average value of USD 116,056,378 per year. In contrast, exports of this same heading were equivalent to 1,158 tons, with an average value of USD 872,100 per year.

According to statistics on imports of domestic use products, such as disposable tableware and hygiene articles or plastic toiletries (3924), 55,077 tons entered the country between 2015 and 2019, with an average value of USD 43,568,721. Product exports under this heading, in the same period, corresponded to 1,915 tons, with an average value of USD 1,338,804 per year.

3.2.2. Consumption

In Panama, on average, 333,338 tons of plastics are generated every year; however, there are no direct records of consumption (FAS Panama, 2020). The value of imports and high waste production per capita (see next section) show high levels of internal consumption of these products and their dependence on the external market. A study carried out in the 2000s indicated that 70% of the economic activity related to plastics was concentrated in the cities of Panama and Colón, where the market for PET products for the packaging industry was the fastest growing (Cámara de Comercio de Guatemala, 2010).

3.2.3. Plastic waste management

After Chile, Panama is the second country in the Americas in solid waste per capita. According to data from the Inter-American Development Bank (IDB), daily waste in Panama is 1.03 kilograms (kg)/person, of which 12% corresponds to plastics, equivalent to 191,580 tons per year of this type of waste produced by the total population. In 2020, 77,285 tons of plastic were improperly managed in the country, and 87% (67,672 tons) presented management issues in coastal areas.

Hills of accumulated garbage demonstrate problems in the waste disposal system on the outskirts of Panama City © Shutterstock

Following current management trends, it is projected that by 2050 these values will reach 115,958 tons of plastic waste improperly managed, discarding material in dumps and landfills and/or contaminating marine ecosystems. It is estimated that 17.2% and 22.2% of solid waste are plastics of domestic and industrial origin, respectively (Figure 12; INECO and Autoridad de Aseo, 2017; Brooks et al., 2020; Christiansen, 2020).

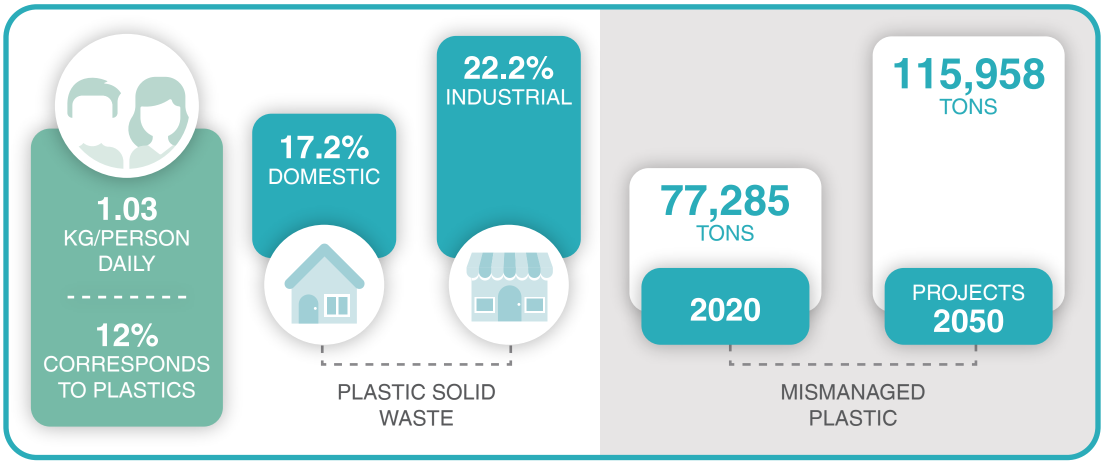


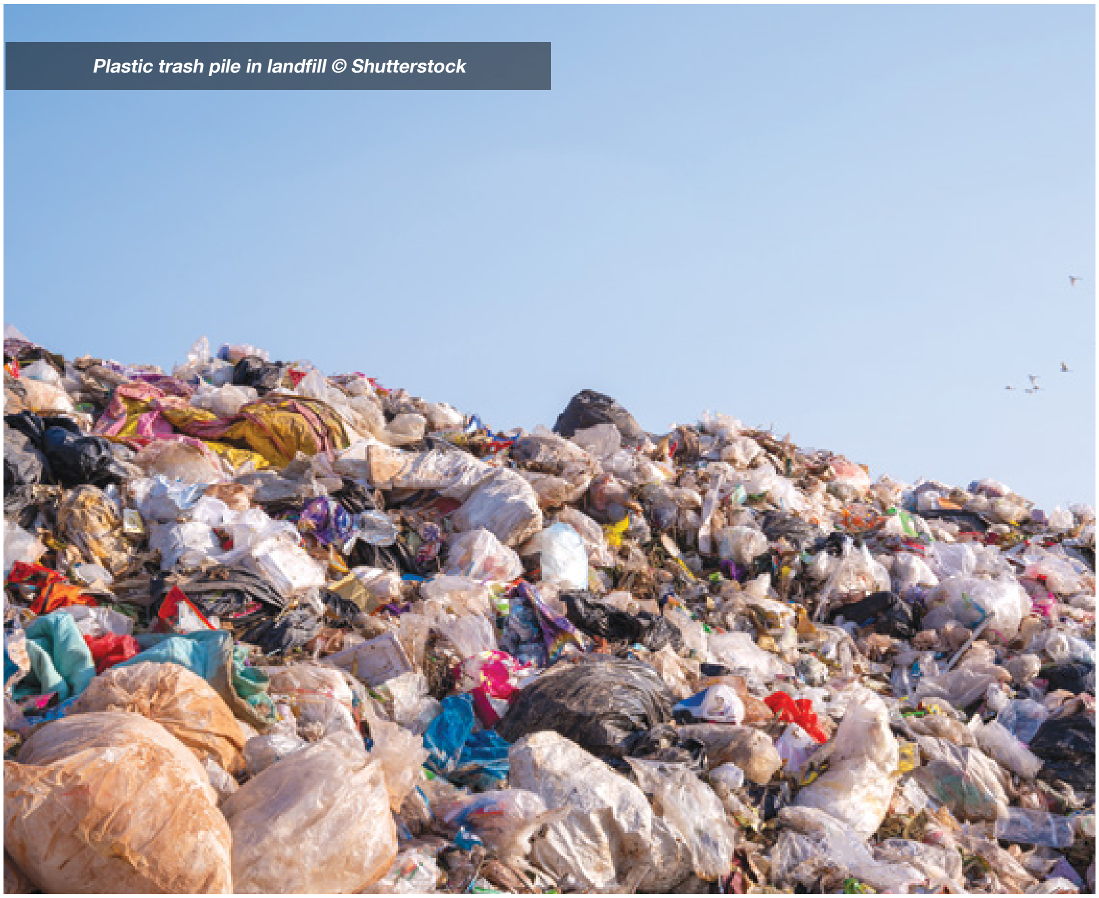
Figure 12 - Types of waste generated in Panama (Source: INECO and Autoridad de Aseo, 2017; Brooks et al., 2020; Christiansen, 2020)

Each of the 13 territorial units in which the country is divided (10 provinces and 3 indigenous regions) manages waste autonomously, while the large cities (Panama and Colón) generate the largest volumes (Christiansen, 2020). At least 58% of the population does not separate waste for subsequent disposal and, even if they did, there is no infrastructure to collect it separately. Both municipalities that collect (32.1%), and those that do not, deposit waste in dumps or sanitary landfills, incinerate or leave waste in the natural environment (Rodríguez, 2019; Christiansen, 2020), since there are no physical conditions for adequate final disposal.

3.2.3.1. Landfills and dumps

Of the approximately 4,375 tons of waste produced daily in Panama, only 57.8% end up in sanitary landfills or managed dumps. The remaining waste ends up in water bodies, the sea, urban soil, or improvised dumps (Figure 13; Christiansen, 2020).

Figure 13 - Daily plastic waste management in Panama (Source: Chritiansen, 2020)


Plastic trash pile in landfill © Shutterstock

There are 62 disposal sites in the country, of which only two are landfills with appropriate facilities: Cerro Patacón in the province of Panama, and Río de Jesús, in the province of Veraguas (INECO and Autoridad de Aseo, 2017). The remaining 60 are open-air dumps, in many cases, without appropriate controls and lacking environmental mitigation programs, posing a threat to nearby water wells and mangrove ecosystems, given absence of measures to prevent the filtration of pollutants (INECO and Autoridad de Aseo, 2017; Rodríguez, 2019; Christiansen, 2020).

In some final waste disposal sites, such as Bocas del Toro and Cerro Patacón, the differentiated recovery is informal and carried out by the so-called “pepenadores” (segregators), people who go through waste looking for things to sell and as a means of subsistence. The activity involves an estimated 600 people exposed to diseases, exploitation, and abuse (INECO and Autoridad de Aseo, 2017; Christiansen, 2020). Of the 2,300 tons of waste that reach Cerro Patacón each day, 2% is recovered (Alcaldía de Panamá, 2015).

In Panama, some retaining barriers or floating traps have been installed, such as the EBTS (Ecological Barriers to Trap Solids), installed by the Ministry of the Environment in the rivers Cárdenas, Tocumén, Juan Díaz and Puente del Rey. The Ministry plans to install throughout the country 500 of these barriers manufactured by persons deprived of their liberty (Palacio, 2019). Likewise, Marea Verde Foundation installed in the Matías Hernández River, which flows into the Mangrove of the Bay of Panama, a barrier system called B.O.T (Barrier or Trash) to keep the garbage from flowing down the river system. According to a classification of barrier captures carried out in 2019, 46.7% corresponds to plastic bottles and disposable EPS containers, with

PET bottles being the most abundant (29.1%), followed by disposable EPS products. (17.2%), ABS (6.5%), textiles (6.4%) and HDPE (6.3%) (Marea Verde, 2019).

Currently there are three projects aimed at the rehabilitation of the dump in the district of Boquete in Chiriqui, and the Aguadulce and Penonomé dumps in Coclé, all in good progress (75, 85 and 88%, respectively) (Alcaldía de Panamá, 2015).

3.2.3.2. Differentiated recovery of plastic waste

In general, data on the collection of recycling waste is lacking since the country does not require records for local movements. However, it is estimated that between 70 and 80% of the waste that reaches the Cerro Patacón dump is recyclable. An experimental study in Chiriquí reported that the amount of plastic waste that could be recovered from each of the homes in the province could increase to 26.0 kg of plastic per month (Aparicio et al., 2020).

Another source has identified that, of the plastic waste being produced, PET bottles are among the most prevalent (Marea Verde, 2019). There are several examples to support this claim. For example, the collection center of the FAS Panama Foundation, reports receiving between 40,000 and 70,000 PET bottles every year. Similarly, 30% of the plastics captured by the floating barrier installed in the Matías Hernández River correspond to PET bottles and, finally, in a day cleaning 58 beaches in the country, 43,000 PET bottles were collected (FAS Panama, 2020). This situation requires special attention, since besides indicating behavioral deficiencies in the population, the competition with virgin plastics is reducing the financial viability of recycling PET and HDPE bottles. In 2019, of the 23,308 tons of materials recovered, only 19,890 tons (85%) could be returned to the market while there were no interested buyers for the rest (Arosemena and Del Cid, 2016; Marea Verde, 2019).

However, the results of the Zero Garbage Program of the Municipality of Panama denote important changes reflected in the first pilot, where 340 tons of recyclable material were recovered between 2015 and 2019 (Loayza, 2019). During the implementation of the program, recycling stations were enabled in the districts of Bethany, Chilibre and Tocumen, in addition to a composting center for organic waste in the “Chitré Recyclable Collection Center” (INECO and Autoridad de Aseo, 2017). This program, established for the period 2015-2035, aims to improve waste disposal by implementing reduction, reuse and, ultimately, recycling practices. The lines of work include: i) improve the local and national legal framework through the implementation of existing regulations and ii) strengthen capacities and promote new regulations (Alcaldía de Panamá, 2015). This effort has been reflected in two pioneering laws in Latin America, which prohibit polyethylene bags and single-use plastics (refer to section 3.2.4.).

More recently, a cooperation agreement signed between the Ministry of the Environment, the Panama Mayor’s Office, the Urban and Home Cleaning Authority (AAUD, by its acronym in Spanish), National Association for Nature Conservation (ANCON, by its acronym in Spanish), and private companies as Cervecería Nacional and Coca Cola, is promoting a program called “Recycle for your Future” (Recicla por tu Futuro), establishing recycling stations throughout the country and enhancing the Zero Waste initiative (reciclaportufuturo.org). Additionally, there are private companies such as RECIMETAL S.A., FAS Panama, Panama Recycling, Greenlife Recycling, among others, that recover plastics and carry out awareness campaigns (Rodríguez, 2019). There are also the Clean Point and Drive Thru initiatives, of the Costa Recicla Foundation, in which recycling stations are installed and recyclable materials are recovered every month, allowing citizens to deliver waste such as cardboard, tetrapak, aluminium cans, cans of preserves and glass bottles (green, amber, and clear) from their vehicles (Fundación Costa Recicla, 2019).

Figure 14 summarizes the life cycle of plastic in Panama, according to the information obtained for this publication.

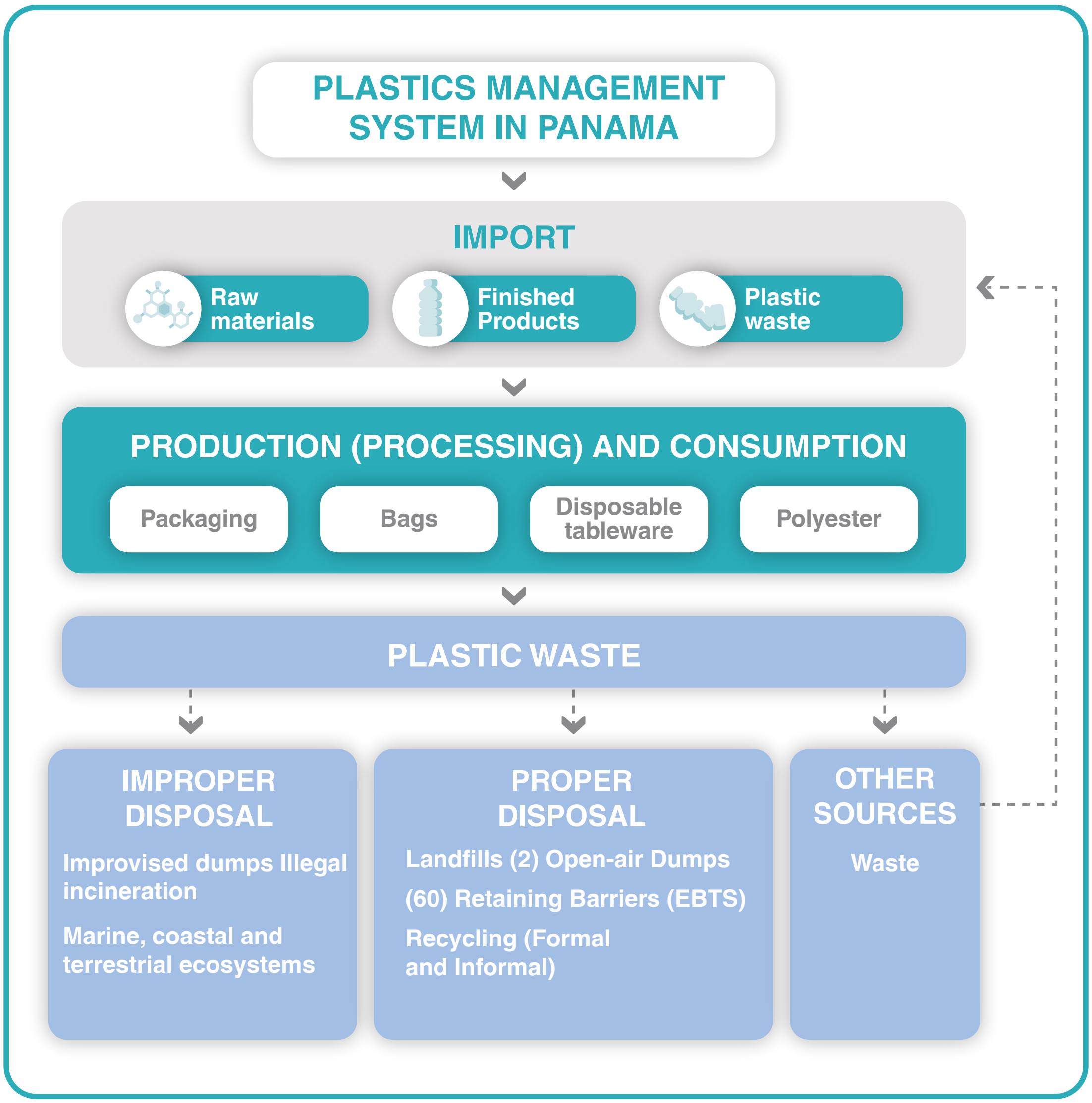


Figure 14 - Plastics management system in Panama (Source: Prepared by the authors, from information obtained for this research)

3.2.4. Regional regulations and policies for plastic waste management

In Panama, different laws have been adopted aimed at combating plastic pollution and eliminating the consumption of single-use items. During the World Ocean Summit (2017) and within the framework of the #MaresLimpios (Clean Seas) initiative: ¡Cambia la Marea del Plástico! (Change the plastic tide), Panama pledged to develop an action plan focused on marine litter management. The draft of the Marine Litter Action Plan for Panama was presented in 2020 and includes an indicator of systems and management, to establish a baseline to measure progress in reducing marine litter and its impacts (Ministerio de Ambiente de Panamá, 2020).

Law 1 (2018) promotes the use of reusable bags and, in turn, prohibits polyethylene bags used in supermarkets, warehouses, self-service stores and shops in general, except for bags that contain food or finished or prepared wet products, as long as there are no substitutes compatible with the minimization of environmental impact. This standard is complemented by Resolution 24 (2019), issued by the Ministry of Commerce and Industries, which establishes the procedure to verify the presence or absence of polyethylene in bags imported and marketed in Panama.

Likewise, Law 6 (2018), establishes integrated management of solid waste in public institutions. It includes among other objectives, waste reduction and reuse, integrates concepts of responsible consumption and creates sustainable solutions by eliminating purchases of products that impact the environment after being discarded (for example, expanded polyester packaging).

Law 33 (2018), establishes the Zero Waste Policy and its action framework for comprehensive waste management, recognizing principles such as extended producer responsibility, and waste management hierarchy. It also contemplates measures to reduce generation, applicable to national, municipal, regional authorities, businesses, and the public; and it even provides for State established goals for the elimination of disposable post-consumer containers, prioritizing the elimination of EPS.

More recently, pioneering Law 187 (2020), regulates the reduction and progressive replacement of single-use plastics throughout the country, integrating this objective into the environmental policy of the Panamanian State, in addition to contemplating the creation of a National Strategic Plan for the Reduction of Single-Use Plastics, under the responsibility of the Ministry of the Environment, which must develop, implement, and update it as required. The Law contains concrete measures for the gradual replacement of 11 disposable plastic products by sustainable alternatives with a lower impact on the environment and health, except for those that cannot be replaced by disposable bioplastics.

3.3. COLOMBIA

3.3.1. Production, import and export of plastics

Colombia produces plastic resins from oil, natural gas, and coal. The country's four refineries have a crude oil processing capacity of approximately 450,000 barrels per day (bpd). The production of raw materials for plastics focuses on refineries in Barrancabermeja and Cartagena which, together, have a refining capacity of 415,000 barrels per day (bpd), representing a high potential for the plastic industry (Invierta en Colombia, n.d.; Sáenz, 2018).

In 2019, Colombia produced 1.36 million tons of plastic resins. PP and PVC polymer plants account for 74% of the total resin production (Figure 15). The rest correspond to PS, LDPE, and recycled PET, among others (Acoplásticos, 2020). Colombia also imports a considerable number of plastics. In 2019 alone, 51,470 tons were imported, of which 7% correspond to single-use plastics (DIAN, 2020; GSQP, 2020).

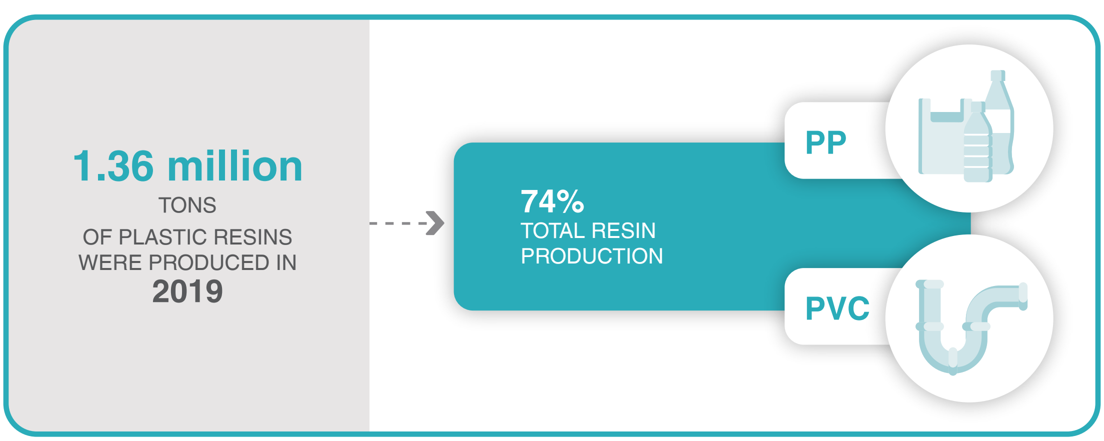


Figure 15 - Resin production in Colombia for the year 2019 (Source: Acoplásticos, 2020)

It is estimated that in 2017, the production of plastic bags in Colombia, including marked, unmarked, and vacuum packaging plastic bags, exceeded 60 thousand tons. Single-use plastics, such as straws and lids, reached a production of 2 thousand and 23 thousand tons per year, respectively (DANE, 2018; Greenpeace, 2019). In 2018, the national consumption of single-use plastics was 891 thousand tons. In 2019, more than 41.7 billion plastic packaging units were produced in the country (GQSP, 2020).

Regarding the production of polymers derived from biological or renewable sources, such as corn starch and other vegetables, although the production potential in Colombia for this type of materials is recognized (Acoplásticos, 2018) and there are companies and enterprises dedicated to this field (e.g. InterEcológicas, Compostpack and Ecobioplast), at the national level there is no public statistical system to record the values of this market.

Records between 2015 and 2019, of the External Trade Statistic System (SIEX, by its acronym in Spanish) of the Directorate of National Taxes and Customs of Colombia (DIAN, by its acronym in Spanish), indicate that both imports and exports of plastics under tariff headlines corresponding to single use or similar, have been increasing. Products for food packaging (classified under tariff heading 3923) are traded internationally in larger quantities than disposable household products (plates, cutlery, etc.) (classified under tariff heading 3924).

A 79% of exports in 2019 were made to Brazil (40%), India (10%) and the United States (7%). In the same year, 64% of the 756 thousand tons of plastics exported corresponded to resins for processing and the remaining 36% to semi-products and manufactures (Acoplásticos, 2020; Sáenz, 2018). According to the diagnosis of the Global Quality and Standards Program (GQSP, 2020), exports in the packaging category reached a value of USD 258.6 million in 2018. It should be added that the Cartagena cluster is the first producer and exporter of petrochemical-plastic products in Colombia (Invierta en Colombia, n.d.).

In 2019, the main imports were polymers of ethylene (53%) and polyethylene terephthalate (17%). The largest suppliers of plastic materials imported into the country are the United States (45%), Brazil (15%) and Mexico (10%). Among products imported more often are household applications (30%), construction materials (26%), articles for packaging or transport including lids (23%), footwear with its soles and heels (21%), films, sheets, and the like (19%), pipes and pipe fittings (12%) (Acoplásticos, 2020).

3.3.2. Consumption

The country consumes about 1.3 million tons of plastic resins each year, including raw materials and finished products, of which only 15-17% are recycled. Of this total, approximately 891 thousand tons of plastic consumed correspond to single-use products (55% for packaging), of which 93% is not recycled. The sectors that consume and distribute these plastic items are mainly the food industry (54%), followed by beverages (39%), cosmetics and hygiene (3%), household (3%) and others (7%) (Acoplásticos, 2018; 2020; DANE, 2020; Sáenz, 2018; Semana Sostenible, 2020a).

In 2018, the size of the fossil plastics market in Colombia was USD 7,302 million, with a local production of USD 5,564 million. The plastics market registers an annual historical growth of 10.1% and is expected to reach USD 10.649 billion by 2032, with a projected increase of 7.8% (Invierta en Colombia, n.d.; GQSP, 2020).

3.3.3. Plastic waste management

In Colombia the plastic waste management system is not efficient © Shutterstock

In 2019, Colombians produced approximately 11,787,310 tons of solid waste (Figure 16; SSPD, 2020), of which 40% have recycling potential and, of these, half are single-use plastics, such as plastic bags, packaging, PET, among others, which according to the Office of the Procurator-General of the Nation (PGN, for its acronyms in Spanish) would amount to USD 658 million in recyclable plastic, which now ends up in landfills or in nature (Acoplásticos, 2020; Cámara de Comercio de Bogotá, 2019).

In Colombia, only between 15 and 17% of plastic is recycled and the management system is inefficient for reasons such as: i) little formalization of the recycling sector (79% of people work under informal conditions), ii) no market for most of the recovered materials (e.g. only PET has potential buyers at very low price), iii) the obligatory recovery rate of waste leaves out 70% of the production and, iv) only 50% of recycling organizations are being supervised by the Superintendency of Residential Public Services (SSPD, by its acronym in Spanish) (Figure 16; SSPD, 2020). According to the Ministry of Environment and Sustainable Development (MADS, for its acronyms in Spanish), in Bogotá alone, 6,300 tons of garbage are produced per day and only between 14 and 15% are recovered, and according to the classification of the average composition, 11% are plastics (Figure 16; UAESP, 2021).

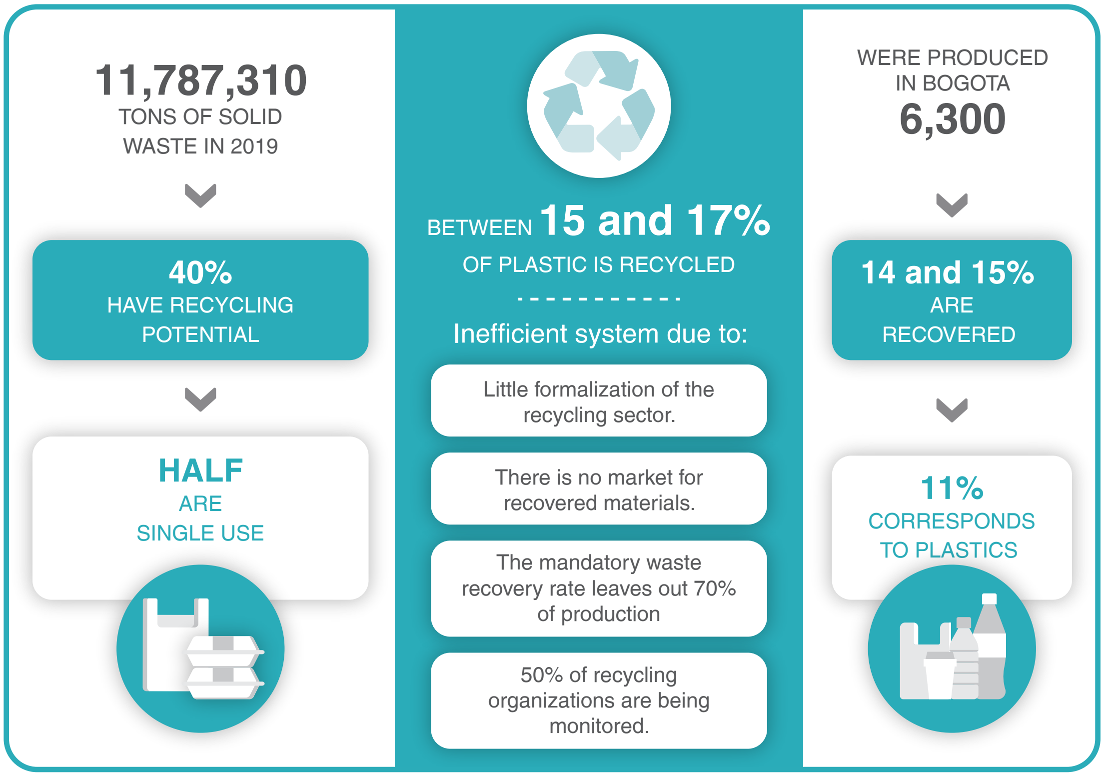


Figure 16 - Waste management in Colombia (Source: Cámara de Comercio de Bogotá, 2019; Acoplásticos, 2020; SSPD, 2020; UAESP, 2021)

In 2019, Doña Juana, the city's landfill, received 950 tons of potentially recyclable material, 45% (428 tons) corresponding to plastics, followed by 23% of paper and cardboard, 15% of textiles, 11% of glass and 6% of metals. Of the plastics that reach the landfill, most are HDPE (Ramos, 2020; Semana Sostenible, 2020b). However, general statistics on recycling programs from other parts of the country are limited by the informality of these activities Contraloría General de la República, 2018).

3.3.3.1. Landfills and dumps

The latest SSPD national solid waste disposal report indicates that sites authorized in Colombia for final solid waste disposal include 169 landfills, 17 dumps (contingency cells) and four treatment plants. Unauthorized sites include 99 dumps and 14 transient cells, which had to be closed when contingency cells were authorized in 2010, for a total of 303 sites (SSPD, 2020).

However, 12 of the 303 disposal sites reported are already outdated, 33 of them will complete their useful life in the next three years, 57 have an estimated durability of three to nine years, and 81 (27%) have a useful life of more than nine years. There is no information regarding the remaining 120 disposal sites (38%), most of which open-air dumps and unauthorized transient dumps. It is estimated that, under the current conditions, by 2030, 18.74 million tons of solid waste will end up in landfills without the capacity to receive them or will be disposed of in an uncontrolled manner in natural environments (CONPES 3874, 2016; SSPD, 2020).

A 74% of plastic packaging in Colombia ends up in landfills. The greatest deficiencies occur in coastal municipalities. Although 55% of them have adequate sites for final disposal, there are deficiencies in the design and implementation of the Comprehensive Solid Waste Management Plans (CSWMP) of the facilities, both on the coast and in the rest of the country, as well as irregularities in the allocation of resources for future closure and post-closure at the end of their useful life. Additionally, in 26% of coastal municipalities, citizens deposit their waste in open-air dumps and 8% directly in water bodies that transport them to the sea, exacerbating the problem of marine pollution in the country (Nieto and Lopez, 2017; Contraloría General de la República, 2018; Greenpeace, 2018).

According to the National Planning Department, the final waste disposal sites of 231 municipalities in Colombia are facing risk of collapse in 2021. In addition, because of inadequate management, there are toxic gases present such as esters, hydrogen sulfide, organosulfur compounds, alkylbenzenes and limonene[3] among others, which can have serious effects on human health (Contraloría General de la República, 2018).

3.3.3.2. Differentiated recovery of plastic waste

The free competition model in activities of waste separation and use, is a limitation both for monitoring and management control (Contraloría General de la República, 2018). In Colombia, only between 15 and 17% of the more than 11,787,310 tons of annual solid waste are recovered (CONPES 3874, 2016). It should be noted that, on average, a recycler can collect between 2.4 and 2.7 tons of reusable material per month (Semana sostenible, 2020c).

It is estimated that there are 60,000 recyclers who live mainly from PET collection, but who also recycle other materials such as paper, cardboard, and metal (ENKA and APROPET, mentioned in an interview with Semana on October 12, 2019). The 256 companies registered in Bogotá and Medellín dedicate to the transformation of post-consumer plastic, processing more than 160,000 t/year, processing between 81 and 100% of material, where 2.6% (4300 t/month) corresponds to PET and HDPE resins and 1.1% (1800 t/month) to LDPE and PP.

Of the 12 million PET bottles on the market every day, 25% are recycled. The raw material resulting from processing is used to produce returnable and non-returnable containers, such as those used by beverage factories, composed of 46% recycled PET resin, and the remaining 54% is virgin resin. The product of this transformation is also used to produce other thermoformed containers and PET resins used in other segments of the plastic industry, as well as fibers used in textile applications. In contrast, there are materials without demand such as amber plastic which for this reason are not being recycled (Cámara de Comercio de Bogotá, 2019; Acoplásticos, 2020).

3 Natural substance extracted from the oil in citrus fruit peel that gives them a characteristic scent.

As noted in the second paragraph of section 3.3.3., the Colombian recovery and recycling system suffers from various structural problems, including access to information by the SSPD, to actual solid waste recovery values, including plastics (SSPD, 2019). On the other hand, the Single Information System (SIS) of the SSPD, which contains information provided by the recyclers and operators of the sanitary landfills, presents many inconsistencies due to improper updating (Contraloría General de la República, 2018), a situation confirmed during the research phase of this analysis.

During the Covid-19 crisis, recycling has declined even further. Even though recyclers have continued to operate, the levels of separation at the source are even lower and a large amount of usable material has ended up in the landfills (Rodríguez, 2020). In summary, Figure 17 presents the life cycle of plastic in Colombia.

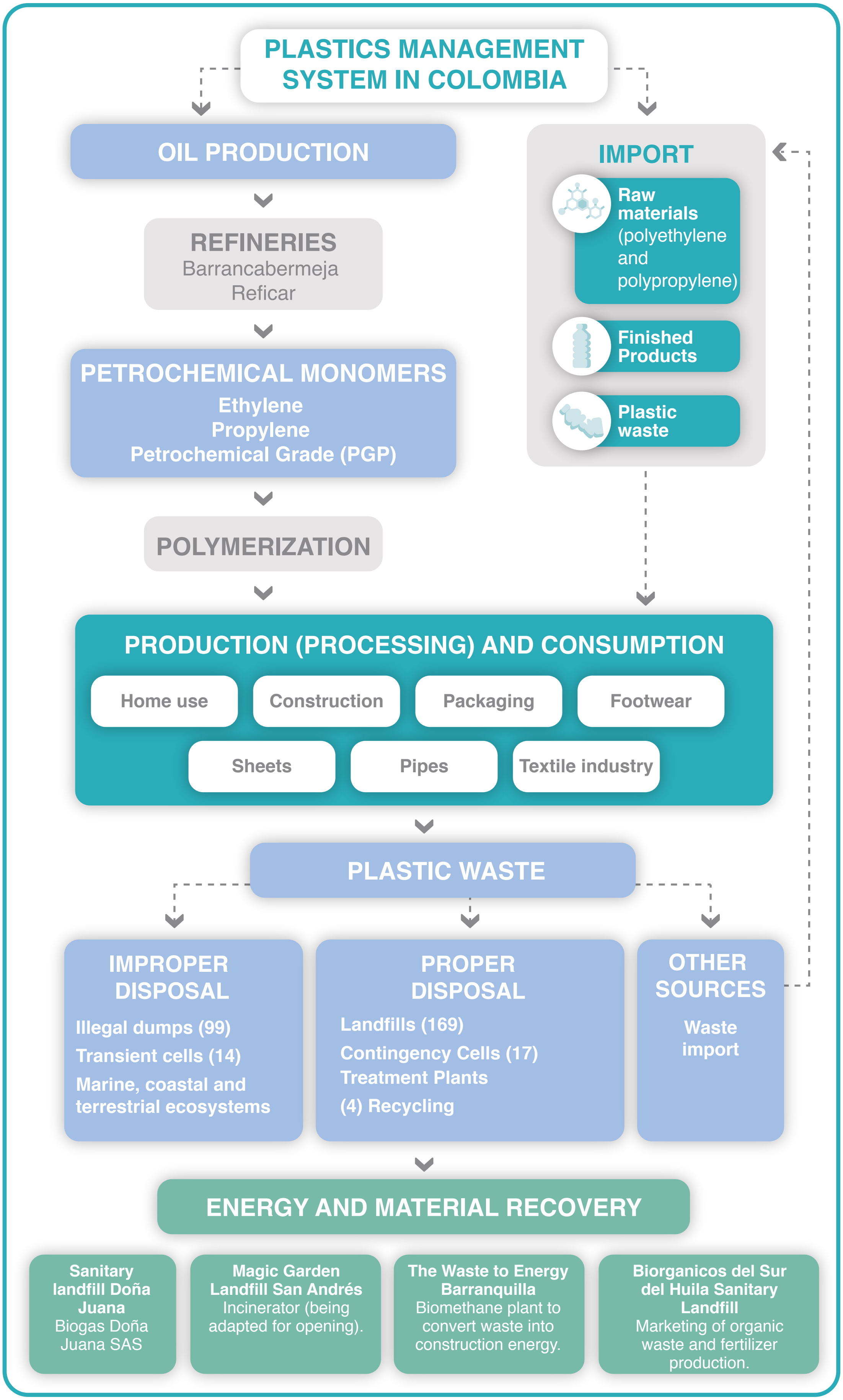


Figure 17 - Plastics management system in Colombia (Source: Prepared by the authors, from information obtained for this research)

3.3.4. Regional regulations and policies for the management of plastic waste

Over the past decade, Colombia has made progress on plastic and waste legislation. In different cities and departments, measures have been taken to manage pollution and prohibit the use of some single-use plastic products. In addition to legislative regulations, other public policy provisions have recently been issued, such as the link to the Global Plastics Agreement (2019) and the Presidential Statement on Sustainable Plastics Management (during the XIV Pacific Alliance Summit, in 2019).

Other management tools are the 2019 National Plan for the Sustainable Management of Single-Use Plastics, promoted by the Ministry of the Environment and the 2020 Methodological Guide on Waste Disposal in the Context of Coronavirus, in response to the increase in single-use plastics durn the pandemic.

In addition, in January 2021, Regulation 2184 (2019) came into force, which established the white, black and green color code for the separation of waste at the source. This is an important step to increase recycling rates and avoid the loss of valuable materials, in addition to dignifying the work of recyclers and contributing to a reduction in the waste that reaches the country's landfills, are already collapsed.

However, the current regulatory framework in Colombia shows that it is ineffective in managing single-use plastic pollution. Although different initiatives have been proposed to address this problem, no specific and systematic efforts have been adopted to provide comprehensive regulation. The legal framework has focused on public sanitation, solid waste management, disincentives to consumption and the local prohibition of EPS and other single-use plastics, as well as strengthening the circular economy and recycling schemes.

The result is a dispersed and disjointed legal-institutional mechanism. In addition, the government has not designed actions aimed at preventing the generation of waste. In short, the policies designed to protect marine-coastal spaces have been proposed independently of this regulatory framework and do not define actions to mitigate marine plastic pollution.

Even public policy instruments such as the National Plan for the Sustainable Management of Single-Use Plastics, promoted by the Ministry of the Environment, has limitations to address the problem. In a recommendations report, MarViva Foundation points out that the Plan focuses on promoting the recycling of plastic but does not prohibit highly disposable materials such as EPS; it promotes the substitution of single-use plastics for bio-based plastics (not compostable under natural conditions) and does not require an increase in the extended responsibility of the producer.

3.4. Transboundary movements of plastic waste in Costa Rica, Panama and Colombia

Costa Rica, Panama and Colombia export and import plastic waste. Data for tariff headline 3915, which includes waste, scrap, and plastic scrap, indicates that between 2015 and 2019, Colombia was the country that imported the most waste, followed in order by Costa Rica and Panama (Figure 18). In terms of exports, Costa Rica leads the list, followed by Colombia and then Panama (Figure 19).

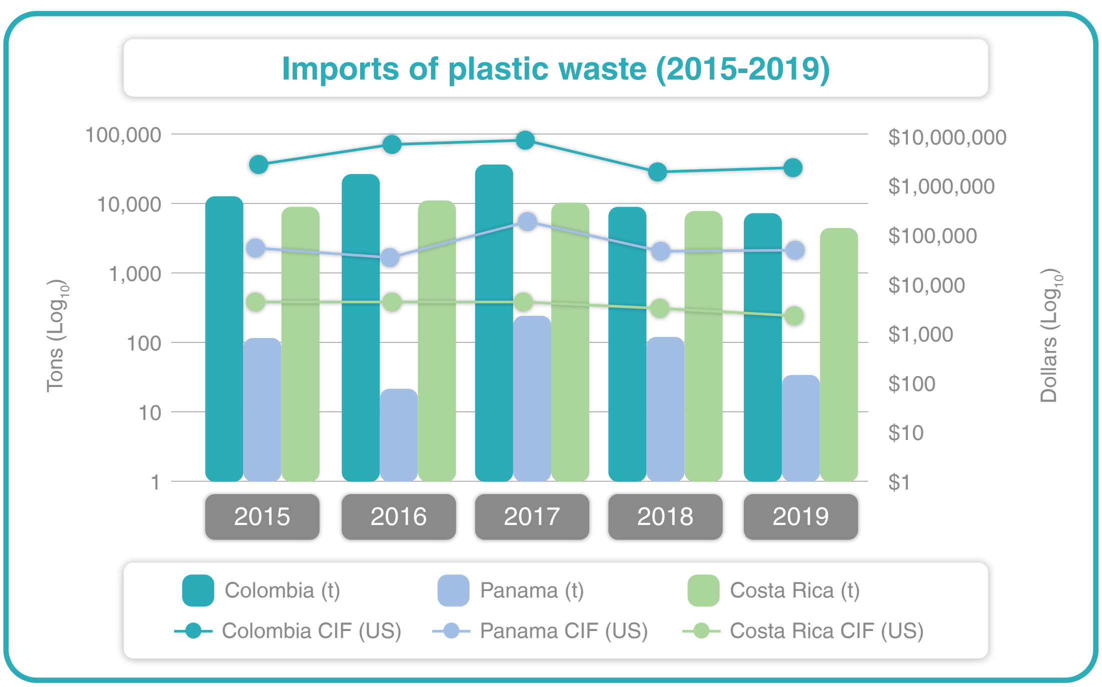


Figure 18 - Imports of plastic waste in Costa Rica (CR), Panama (PAN) and Colombia (COL) in tons (t) and their price in invoiced dollars (FOB), in decimal logarithmic scale (Log_{10}) (Source: PROCOMER, 2020; INEC, 2020 and DIAN, 2020).

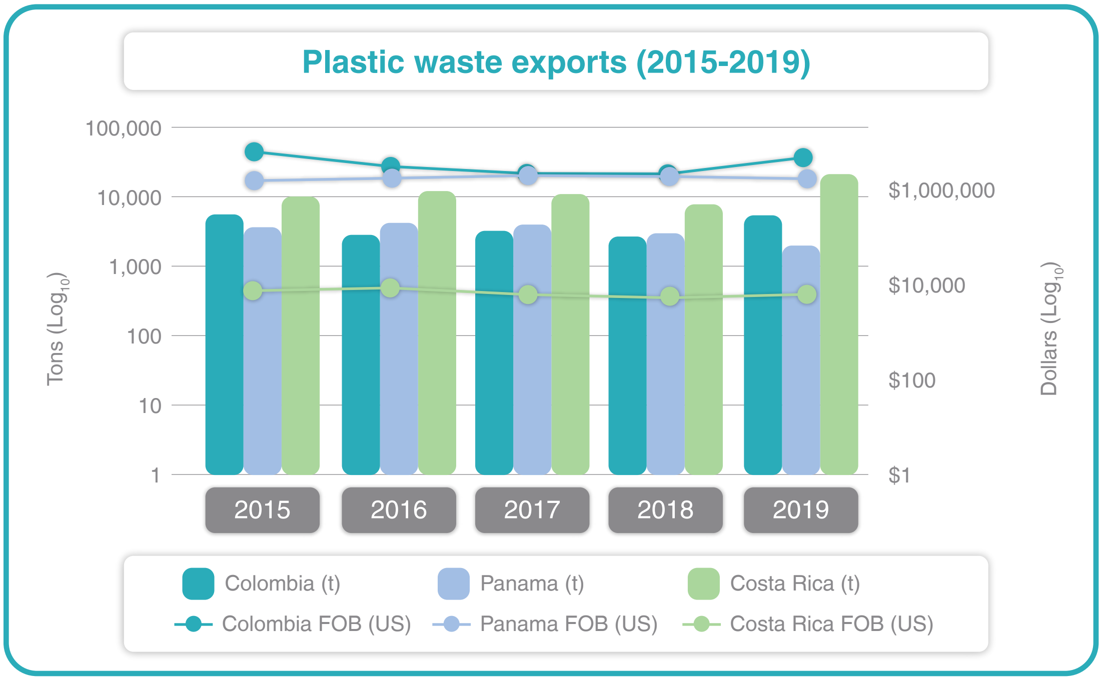


Figure 19 - Exports of plastic waste to Costa Rica (CR), Panama (PAN) and Colombia (COL) in tons (t) and their price in invoiced dollars (FOB), on the decimal logarithmic scale (Log_{10}) (Source: PROCOMER, 2020; INEC, 2020 and DIAN, 2020).

Tariff heading 3915 covers the following subheadings: 391510 for ethylene polymers, 391520 for styrene polymers, 391530 for vinyl chloride polymers and 391590 for other plastics (Table 3). Regarding the export and import of bio-based plastics in the countries under study, it is currently impossible to determine specific trade flows, because there is no particular tariff classification for these products. Therefore, transboundary movements of bio-based plastics and their wastes would be reported under headings and subheadings meant for petrochemical plastics.

In the case of Costa Rica, according to PROCOMER's Statistical Portal on Foreign Trade, the products classified as waste, cuttings and plastic waste imported between 2015 and 2019 (tariff item 3915), come mainly from Central American countries such as El Salvador, Guatemala, and Panama. Most of this waste was classified under subheadings that do not correspond to the classification of single-use plastic waste (391590) (Table 3).

As for waste that could be used in the production of single-use plastics, such as ethylene polymers (subheading 391520), these represented the largest imports, with much higher amounts than styrene polymers (Table 3).

Table 3 - Average quantity (t) and value (USD) of waste exported and imported by Costa Rica between 2019 and 2015, according to tariff subheading (type) (Source: PROCOMER, 2020)

SUBHEADING (N°)	DESECHOS, RECORTES Y DESPERDICIOS DE:	EXPORTACIÓN (t)	EXPORTACIÓN (FOB – USD)	IMPORTACIÓN (t)	IMPORTACIÓN (CIF – USD)
391510	Ethylene polymers	1,375.63	558.65	1,743.,55	807.90
391520*	Styrene polymers	20.30	1.26	376.89	346.32
391530	Vinyl chloride	449.87	354.83	1,395.59	889.71
391590	Other plastics	10,564.77	3,222.88	4,290.67	1,101.03

*Data were only reported in 2017.

In the case of Panama, according to the National Institute of Statistics and Census (INEC, for its acronyms in Spanish) in 2019 the plastic waste classified in subheading 391590 (other plastics) was exported to Belgium, Canada, Chile, Colombia, Costa Rica, Ecuador, the United States, Honduras, Nicaragua, Paraguay, Peru, and the Dominican Republic, for a total value of USD 427,831. Meanwhile, waste classified as ethylene polymers, used to make plastic bags and packaging, was exported to Belgium and Costa Rica, for a total of USD 359,226 (subheading 391510) (Table 4).

This information allows us to appreciate that Panama imports more plastic waste than it exports, and in each of the proportions, both in imports and exports, the most active are products other than ethylene, styrene, and vinyl chloride (Table 4).

Table 4 - Average amount (t) and value (USD) of waste exported to and from Panama between 2019 and 2015, according to tariff subheading (type) (Source: Recomex, 2020)

SUBHEADING (N°)	WASTE, PARINGS AND SCRAP FROM:	EXPORT (t)	EXPORT (FOB – USD)	IMPORT (t)	IMPORT (CIF -USD)
391510	Ethylene polymers	883.4	315,459	23.2	20,341.4
391530*	Vinyl chloride	10	3,959	37	106
391590	Other plastics	2,545.2	555,559	68.8	39,504

*Data were only reported in 2018.

In the case of Colombia, according to the tariff subheadings for plastic waste, the most imported waste between 2015 and 2019 was ethylene polymers, which it is assumed could be destined to produce single-use plastics, since Colombia has a resin-producing industry (Table 5).

In 2019, plastic waste imports in general came from 14 countries: Aruba, Australia, Chile, China, Honduras, Israel, Italy, Mexico, Panama, Portugal, Puerto Rico, United States, Uruguay and Venezuela (Table 5).

Table 5 - Average amount (t) and value (USD) of waste exported to and from Colombia between 2019 and 2015, according to tariff subheading (type) (Source: DIAN, 2020)

SUBHEADING (N°)	WASTE, PARINGS AND SCRAP FROM:	EXPORT (t)	EXPORT (FOB – USD)	IMPORT (t)	IMPORT (CIF -USD)
391510	Ethylene polymers	1,158.2	212,877.18	11,388.87	1,372,049.76
391520	Styrene polymers	77,923.20	201,556.99	1,296.81	1,202,184.6
391530	Vinyl chloride	156.77	186,787.21	1,312.08	224,904.12
391590	Other plastics	1,465.86	1,167,088.71	2,521.30	879,407.8

Although it is not possible to determine the destination and end use of these transboundary flows, it should be emphasized that plastic waste exports to countries without management capacity is increasingly common in the Latin American region. This has attracted the attention of international authorities and has supported the beginning of global regulations to prevent these situations, as is the case of changes approved in the Basel Convention in 2019.

In this context, the increase in the illegal trade in plastic waste is related to the limitations that certain countries have implemented, both within the framework of the changes imposed by the Basel Convention and prior to its entry into force. In particular, import restrictions from China, covered by new pollution rules for the import of 24 types of solid waste, which were extended to a total of 32 in January 2019. China has set much stricter pollution standards for plastic waste, going from a purity of 90 and 95% to 99.5%. These limits have meant that even small materials, such as water bottles, cannot be exported to that country (Interpol, 2020). For this reason, in the last two years, there has been a significant increase in illegal shipments of waste, mainly diverted to South-East Asia, through many transit countries to camouflage the origin of the shipment. This is a subject of study and analysis in the countries under study and should be subject to regulations (Interpol, 2020).

Plastic contamination is a problem in the region © Shutterstock

4 Plastic contamination in the region of Costa Rica, Panama and Colombia

4.1. Approximation of the impact of plastic on the environment in each stage of the cycle

Plastic impacts the environment throughout its entire life cycle, starting from the extraction of the raw material (hydrocarbons or biomass), through production, followed during consumption, poor disposal of post-consumer waste and its consequent effect on marine and terrestrial ecosystems (de Souza et al., 2018; The Pew Charitable Trust, 2020). The production and incineration of plastics alone can generate 850 million tons of greenhouse gases annually, including energy consumption to extract fossil fuels and emissions from deforestation in areas where exploration and exploitation take place (Kistler and Muffett, 2019).

Additionally, for plastics to maintain their characteristics of durability and flexibility, additives such as carbon, silica, thermal stabilizers, plasticizers, flame retardants, UV stabilizers, dyes, mattifying agents, opacifiers or gloss additives are included in their manufacturing process (Hahladakis et al., 2018; Landrigan et al., 2020), many considered dangerous to human health (HEAL, 2020) (Table 1). For example, synthetic dyes are classified as mutagens and carcinogens (Koch and Calafat, 2009; Turner, 2018; Landrigan et al., 2020). Of the 906 chemicals associated with plastic packaging, present in manufacture and/or final manufactures, 63 are classified as highly dangerous to human health and 68 as dangerous to the environment, according to the European Chemicals Agency. Meanwhile, the European Union classifies seven additives as persistent, bio-accumulative and toxic, and 15 as endocrine disrupting chemicals, which damage the hormonal function of organisms (Keswani et al., 2016; Wright and Kelly, 2017).

The UN Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) unifies the classification of polluting plastics and/or their fragments according to size (Table 6). Microplastics (< 5 mm) are recognized for their extensive presence in both marine and terrestrial ecosystems. These can come from direct sources, such as personal care articles and microfibers detached from textiles, or indirect sources, such as the fragmentation of larger plastics.

Table 6 - Plastic pollutants by size (Source: GESAMP, 2019)

CLASS	SIZE
Megaplastics	> 1 m
Macroplastics	25 – 1000 mm
Mesoplastics	5 – 25 mm
Microplastics	< 5 mm
Nanoplastics	< 1 μm

In the ocean, the three polymers found in largest quantities are the ones with the highest global production: PP, PE, EPS, distributed according to their density. For example, PP and PE microplastics float on the ocean surface, while EPS microplastics can be found at different depths, causing pollution throughout the water column, and accumulating mainly in marine sediment. It should be noted that these accumulations are not homogeneous and depend on the variations in salinity and temperature that determine the flow of currents (Kooi et al., 2016; Rochman, 2018; Guo and Wang, 2019; Thushari and Senevirathna, 2020).

Plastics remain intact in the environment, especially if they are on the seabed or buried in sediment. However, when exposed to environmental factors such as UV radiation, oxygen, and waves, microparticle fragmentation processes begin, which are only the beginning of a degradation that can take from hundreds to an undetermined number of years (Eriksen et al., 2014; GESAMP, 2019). Plastic additives are released into the environment (Walkinshaw et al., 2020), constituting a serious threat to aquatic life, since in addition to facilitating the absorption of other persistent organic pollutants (POPs), they can also release them, chemically altering ecosystems and even entering the food web by being ingested by fish and other organisms that, in turn, can transfer them to humans (Andrady, 2017; Hahladakis et al., 2018; Cox et al., 2019; Landrigan et al., 2020).

Although studies on plastics in terrestrial ecosystems are limited, microplastics are known to be present in soils, urban dust and even in the atmosphere, altering air quality. Macroplastics, on the other hand, affect birds, reptiles, and mammals which, like marine animals, can swallow them or get entangled in them. Observations on American crows showed that these birds use plastics to build their nests, and when the chicks try to start flying, they can become entangled and die (Craggs, 2018). On the other hand, in the United Arab Emirates, camel deaths have been recorded after they are attracted by the smell of food waste, they have ingested plastic bags and ropes that cause intestinal obstruction (Townsend and Barker, 2014; Hurley et al., 2020; Eriksen et al., 2021).

It is estimated that humans may be consuming the equivalent of a plastic credit card each week (5 grams), by means of the microplastics present in both bottled water, tap water, beer and salt (WWF, 2019b). Even since infancy, it has been established that babies are exposed to 16,200,000 plastic particles released from baby bottles per liter (Li et al., 2020). Likewise, children can inhale or eat plastics and their chemicals directly from toys, packaging, or the air, producing chronic intestinal inflammation, among other diseases (Newell et al., 2000; Waring et al., 2018; Aurisano et al., 2021). In addition to the chemicals transferred from these materials, evidence indicates that plastic microparticles are capable of crossing the intestinal walls and reaching organs such as the liver, lungs, spleen, kidneys, and even the placenta of pregnant women (Paul et al., 2020; Thompson, 2020; Ragusa et al., 2021).

Plastics deposited in landfills contribute to the accumulation of carcinogens and toxins produced there, with the potential to contaminate nearby sources of water and affect animals and people in nearby areas (Craggs, 2018). Experiments carried out in soils show that microplastics could alter physical properties, such as water retention, as well as cause changes in the functions of the microbiota[4] (de Souza et al., 2018). Some terrestrial arthropods, such as swallows, have been observed transporting plastic particles to lower layers of the soil, which could contribute to the accumulation of microplastics and their subsequent incorporation into the soil food web. Another factor that contributes to the direct transfer to terrestrial ecosystems results from the plastics used to cover crops to improve productivity, which is evidenced by the high concentrations of these particles in agricultural soils (Cajamar, n.d.; Maaß et al., 2017; Zhang and Liu, 2018).

It is then observed that, from production to post-consumer disposal, plastics significantly affect marine and terrestrial environments, putting at risk the health of animals and people who depend on the services (water, air, food, etc.) that these ecosystems provide. Additionally, polymers containing these additives directly affect consumers of plastics since these materials are in direct contact with food or the mouth (e.g. toys).

4 Set of microorganisms that are normally located in different sites of the body of multicellular living beings, such as the human body.

4.2. Plastic marine pollution: distribution and accumulation areas

Pollution affects beaches, Costa Rica © Shutterstock

Eight of the 122 rivers most polluted with plastics worldwide are located in the Central and South American region (Lebreton et al., 2017; USAID, 2019). These rivers flow into the Pacific Ocean and the Caribbean Sea, becoming a stressor on the coasts and islands of Central and South America. An example is the periodical accumulation of garbage in the Bay of Omoa, in the Caribbean waters shared by Honduras and Guatemala, producing artificial tides loaded with plastic garbage (e.g. toothbrushes, containers, syringes, action dolls, among others). The waste carried away by the Motagua River, one of the largest in Central America, which collects the waters of a tributary that comes from the municipal dump in Guatemala City. This accumulation of waste at sea has even caused conflicts between the two countries (Urry, 2019; USAID, 2019; Lima, 2020).

Plastics are the most common waste accumulated on beaches in the Pacific, the Caribbean and Isla del Coco, in Costa Rica (Blanco, 2010). A study by the Center for Research in Marine Sciences and Limnology (CIMAR, by its acronym in Spanish) of the UCR, showed the presence of microplastics on beaches in both the Pacific and the Costa Rican Caribbean, represented mainly by PE and EPS (El Mundo, 2019a), with greater polluting concentration in the Pacific (Teletica Radio, 2019).

In addition, Costa Rica is known for having the most polluted basin in all Central America, the Rio Grande de Tárcoles, in which several tons of waste are dumped daily from the Greater Metropolitan Area (GMA). The impact can be seen in beaches such as Guacalillo, Azul beach and Tárcoles beach, areas of influence of the mouth of the river where a large amount of solid waste is accumulated. On these beaches, 15 tons of waste are collected per week between tires, shoes, plastics, refrigerators, washing machines and even gas cylinders (Grajales, 2018). Contributing to this is the disorderly growth of the city, the destruction of mangroves and dumping garbage in ditches and areas connected to rivers, which transport domestic and industrial waste (Urriola, 2018).

In Panama, the impact of contamination by plastics and other waste is clearly visible in the Bay of Panama, where large quantities of bottles, cans and even mattresses are found piling up in sectors such as the East Coast (EFE, 2018b). This area is the outlet of four rivers that run through the entire city dragging all kinds of waste, such as the Curundú, Matasnillo, Juan Díaz and Tapia (EFE, 2018a). On the other hand, specific studies carried out in the Caribbean coast of Panama detected concentrations of up to 385 microplastics/square meter (m^2) of beach, in areas important for tourism (Feldberg, 2018; Delvalle et al., 2020; Ministerio de Ambiente de Panamá, 2020), among them were pellets, used by factories as a raw material to produce bottles and plastic bags using polypropylene or polyethylene. Meanwhile, in the Pacific, although there was homogeneity in shapes (pellets, fragments, foams), EPS was one of the plastics with the greatest physical presence (RFI, 2019; Delvalle et al., 2020).

The most important tributaries in Colombia are also two of the 20 rivers most contaminated with plastic on the planet: the Amazon River, in place seven, and the Magdalena River, the country's main river artery, which occupies the fifteenth place in pollution by plastic waste into the sea (Lebreton et al., 2017). In addition, tourism and poor waste management are associated with the large increase in plastic waste on beaches (Acosta and Olivero-Verbel, 2015; Acosta-Coley et al., 2019; Garcés-Ordóñez et al., 2019; 2020).

Plastic contamination has been studied in the country in sensitive ecosystems such as mangroves, lagoon complexes like Ciénaga Grande de Santa Marta (CGSM) and in most coastal areas (Ambientum, 2018; Garcés-Ordóñez et al., 2020). In the CGSM, plastic represents between 73 and 96% of solid waste, while the presence of microplastics in sediments associated with the mangrove swamp ranges between 31 and 2,863 particles/kg of waste (Garcés-Ordóñez et al., 2019). The highest concentrations of microplastics are found in the Caribbean, mainly in highly populated areas such as Cartagena and Santa Marta. On both the Caribbean and Pacific coasts of Colombia it is possible to find up to 8,000 microplastics/liter of water and 1,000 microplastics/m^2 of beach (Delvalle et al., 2020).

4.3. Biological impacts of plastic waste on the sea

The impacts caused by plastics on marine ecosystems are related to entanglement, intake, and suffocation events (Figure 20), reaching from microorganisms to large cetaceans, increasing the urgency to assume effective mitigation management measures. Plastic impacts have been documented in more than 800 species of marine animals, many of them unique or endemic to certain areas or listed as endangered species (Kühn et al., 2015; Steer and Thompson, 2020; The Pew Charitable Trust, 2020). Records range from strangulation of Antarctic fur seals that fail to free themselves after becoming entangled (Waluda and Staniland, 2013; Waring et al., 2018), to suffocation of corals by bags and plastic sheets that prevent light capture (Landrigan et al., 2020; Reichert et al., 2018).

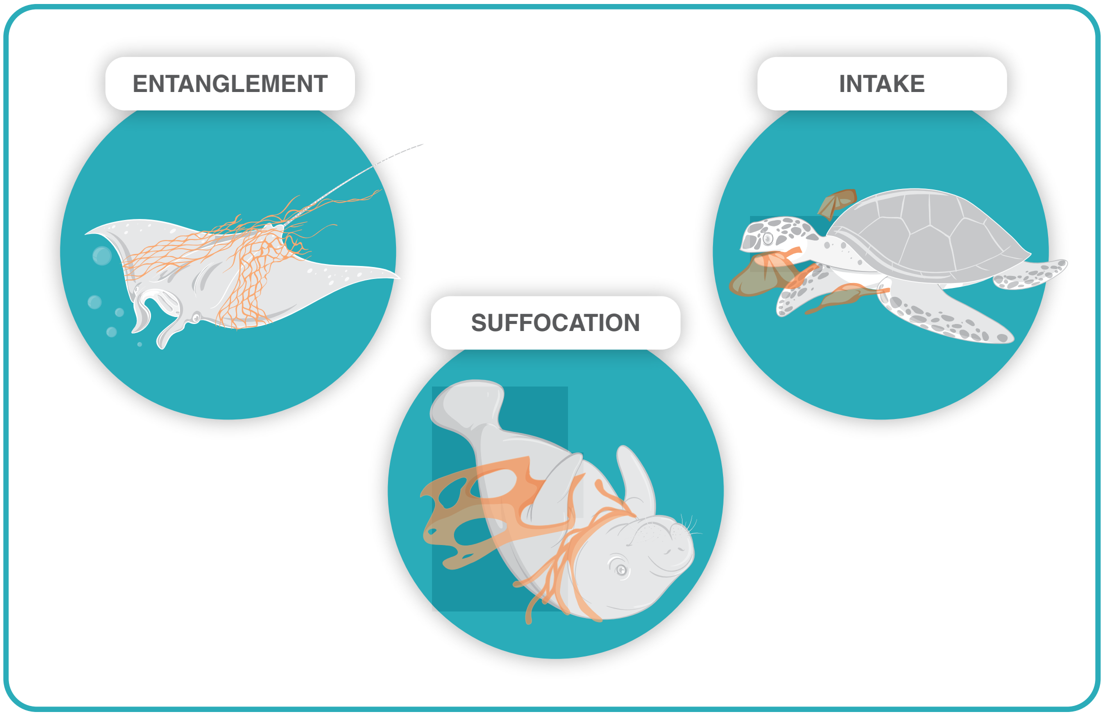


Figure 20 - Impacts caused by plastics on marine fauna (Source: Kühn et al., 2015; Steer and Thompson, 2020; The Pew Charitable Trust, 2020)

Cases of ingestion or entanglement are also known in 54% of the 120 species of marine mammals listed as threatened by the International Union for Conservation of Nature (IUCN). Likewise, plastic entanglements have been documented in all 350 existing species of seabirds, as well as in the seven species of sea turtles, 89 species of fish and 92 species of invertebrates (Kühn et al., 2015; Ryan, 2018; Steer and Thompson, 2020).

Regarding the intake of plastics, organisms can ingest them in two ways: when fed in the natural environment and consumed accidentally, or by trophic transfer, feeding on other animals that have ingested plastics.

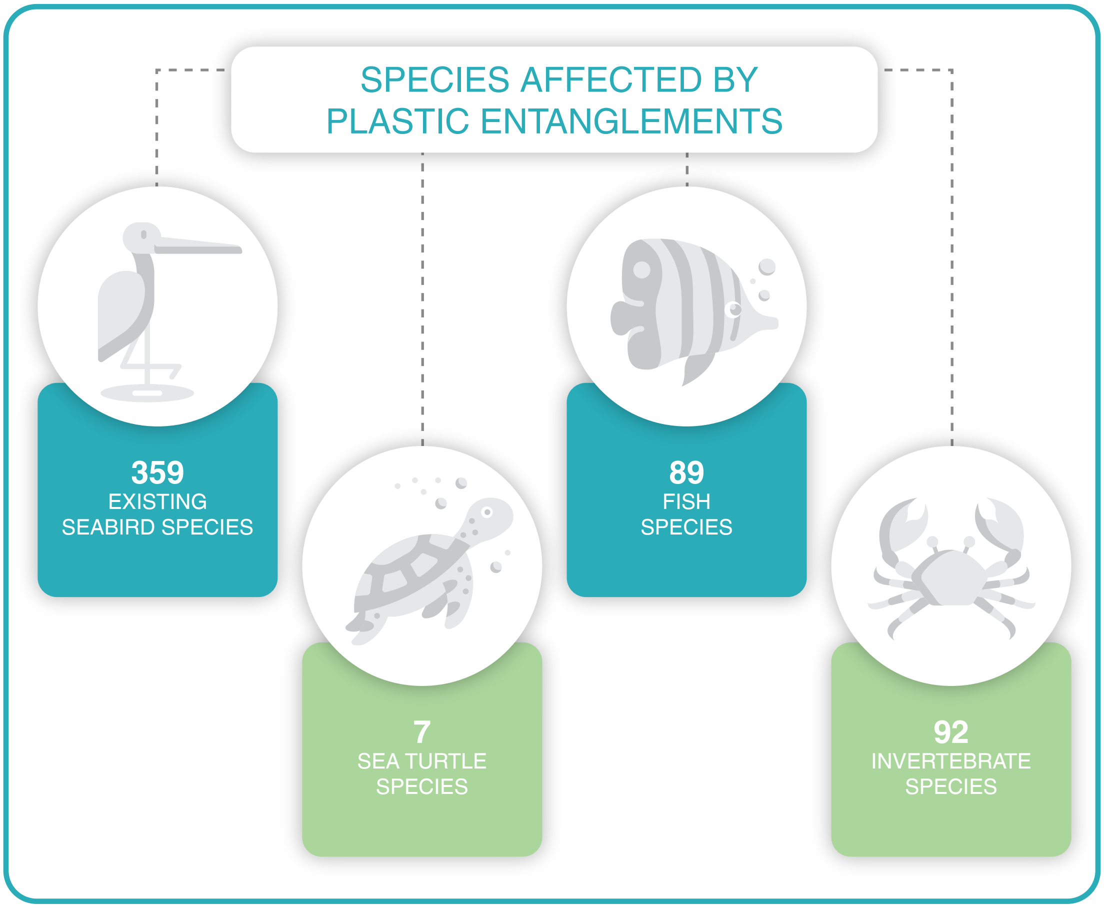


Figure 21 - Number of species affected by plastic entanglements (Source: Kühn et al., 2015; Ryan, 2018; Steer and Thompson, 2020)

Additionally, in the case of fish and crustaceans, microplastics can enter their body through the gills. The type and size of the polymer determine the depth at which they are found, facilitating the availability and selectivity for various organisms in the water column. For example, oysters can consume larger particles than mussels, which explains the different amounts of plastic accumulated internally in these species (Watts et al., 2014; Desforges et al., 2015; Carbery et al., 2018; Nelms et al., 2018; Welden et al., 2018; Karbalaei et al., 2019; Walkinshaw et al., 2020). Surface water organisms are likely to find plastics with a lower specific density than seawater, such as PS, PP and PE. In contrast, bottom or benthic organisms are more susceptible to ingesting denser or dirtier plastics, such as PET and PVC (Cole et al., 2013; Carbery et al., 2018).

Plastics can be accidentally ingested by large whales and even become entangled in their filtration structures or baleen (Alzugaray et al., 2020; Im et al., 2020). Plastics have also been found in the stomachs of blue sharks and other oceanic sharks, as well as sea turtles. Some species of the latter often confuse plastic bags with one of their prey, jellyfish. These intakes can cause a false sense of fullness, leading animals to a slow process that culminates in death by starvation (lack of food) or intestinal obstruction (Colmenero et al., 2017; Pham et al., 2017; Caron et al., 2018; Waring et al., 2018; Barreto et al., 2019; Mucientes and Queiroz, 2019).

Seabirds often confuse their food with plastic contaminants that take on the aroma of natural chemicals, such as dimethyl sulphide, when in contact with water, creating an olfactory trap for birds seeking food. A 44% of seabird species are considered to have ingested plastic particles (Savoca et al., 2016; Roman et al., 2019; The Pew Charitable Trust, 2020). Some large species, such as albatrosses, have ingested plastic items such as golf balls, lighters and even whole bottles (Cartraud et al., 2019; Roman et al., 2019; Petsko, 2020; Vale, 2020).

The ingestion of smaller particles (< 5 mm), such as micro and nanoplastics, is mostly documented in invertebrate organisms that are part of zooplankton, such as copepods, isopods, amphipods and polychaetes, as well as in sponges, pelagic insects, annelids and sand hoppers (Goldstein et al., 2012; von Moos et al., 2012; Cole et al., 2013; Hämer et al., 2014; Cole et al., 2015; Baird, 2016; Jemec et al., 2016; Bruck and Ford, 2017; Hurley et al., 2017; Jang et al., 2018; Reichert et al., 2018).

Trophic transfer (food chain) from one animal to another has been detected from mussels to fish and crabs (Farrell and Nelson, 2013; Watts et al., 2014; Santana et al., 2017; Carbery et al., 2018). It has been established that plastics can pass from fish such as Atlantic mackerel to grey seals (Nelms et al., 2018). Likewise, plastics pass from sea grasses and algae to shellfish, such as rock snails or snails of the genus *Littorina* (Gutow et al., 2015; Goss et al., 2018; Sundbæk et al., 2018; Walkinshaw et al., 2020) and to detritivores that consume the feces of other animals that have ingested plastic, such as copepods (Cole et al., 2015; Walkinshaw et al., 2020).

Carbery et al. (2018) developed a model of the marine food web, showing the amount, size, and shape of microplastics present in organisms found in nature, reflecting polymer intake at all trophic levels.

In all its forms and sizes, the ingestion of plastics has serious repercussions on aquatic organisms, affecting their biology (Arias-Andres et al., 2019; Franzellitti et al., 2019) and activating a set of reaction mechanisms that include: i) oxidative stress[5] (Jacobsen et al., 2010; Neves et al., 2015; Lu et al., 2016; Magara et al., 2018; Wang et al., 2019), ii) inflammation (Wright et al., 2013), iii) increase in immune activity (Browne et al., 2008), iv) reduction in feeding activity (Cole et al., 2013; Wright et al., 2013; Watts et al., 2014; Cole et al., 2015), v) depletion of energy reserves (Wright et al., 2013; Watts et al., 2014), vi) significant impacts on offspring (Sussarellu et al., 2016; Landrigan et al., 2020) and vii) mortality of exposed individuals (Oliveira et al., 2013; Landrigan et al., 2020) (Figure 22).

5 Excess of oxygen-free radicals in the body of a living being.

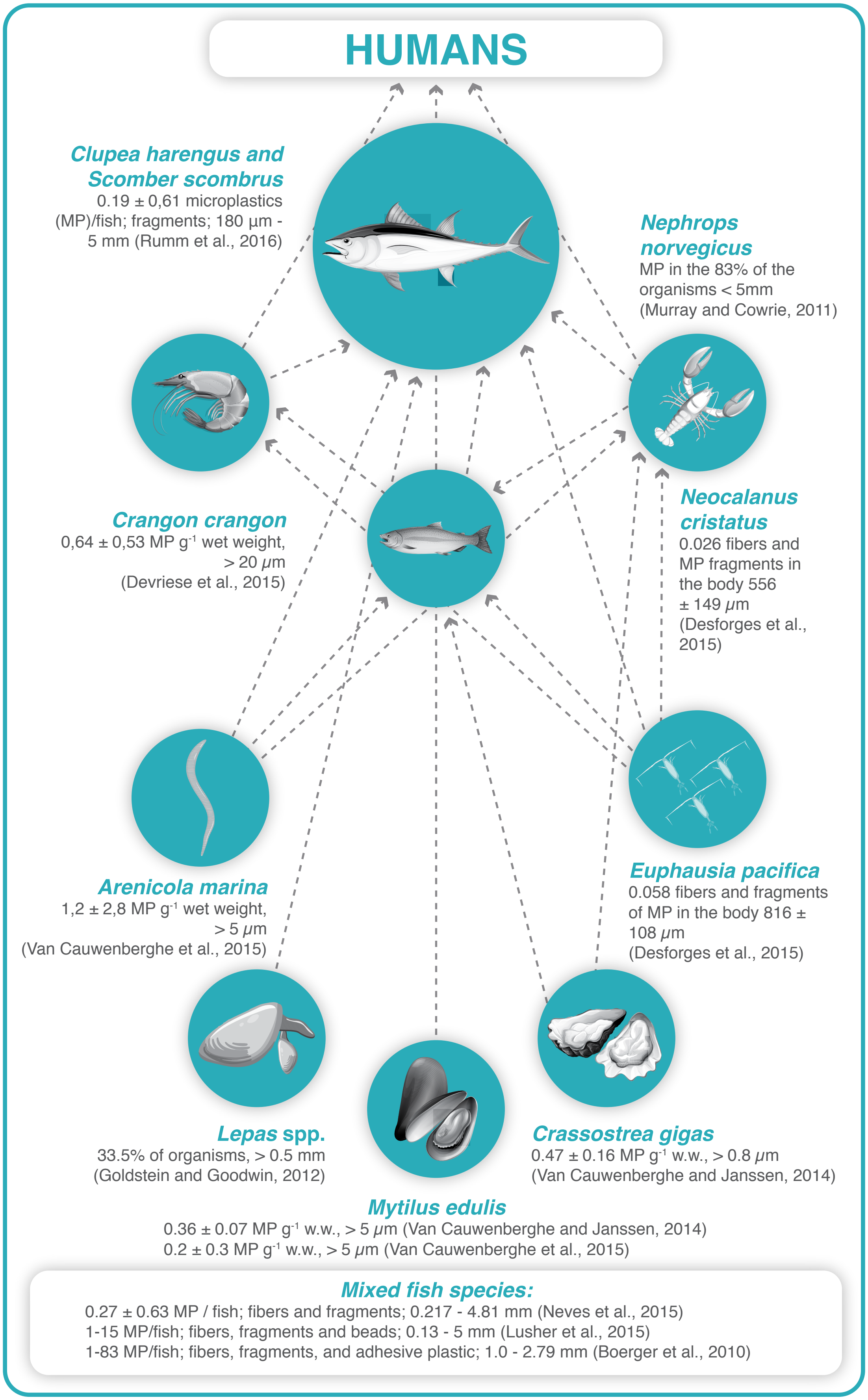


Figure 22 - Marine trophic network model, indicating the load, size and shape of microplastics present in organisms at different trophic levels present in the natural environment (Source: Carbery et al., 2018)

Likewise, nanoplastics (< 1 μm) are of particular concern, since their small size allows them to penetrate membranes. In the case of zebrafish larvae, these nanoparticles can cross the blood-brain barrier, which is a system that protects the brain from foreign substances (Rabanel et al., 2020). Likewise, it has been documented that, in several invertebrate species, ingested nanoplastics can be transferred to reproductive tissues and the brain (Crooks et al., 2019; Walkinshaw et al., 2020). However, these are more difficult to detect, as there are still limitations in terms of sampling and analysis equipment (da Costa et al., 2016; Carbery et al., 2018).

Another type of biological impact is generated from the chemicals released by plastics and their additives. They can cause deformations in organisms, as documented for sea urchin larvae (Rendell-Bhatti et al., 2020), which could mean a negative impact on this populations that play a very relevant role in the control of algae. Likewise, leachates[6] impair the growth and oxygen production of one of the most abundant and ecologically important photosynthetic bacteria in the ocean, belonging to the genus *Prochlorococcus* (Figure 23; Tetu et al., 2019).

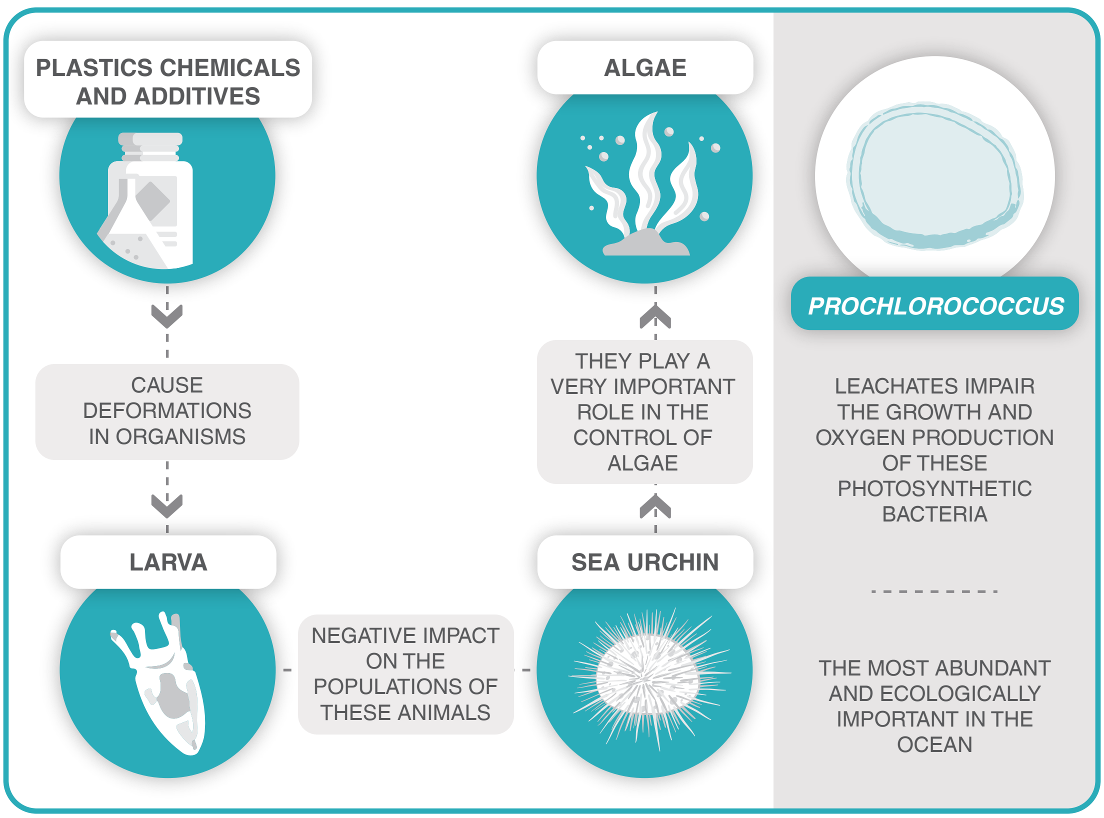


Figure 23 - Biological impact of chemicals and plastic additives (Source: Tetu et al., 2019)

Additionally, plastics at sea act as transport mechanisms for dangerous microorganisms, vectors of human diseases and invasive alien species, forming what has been called “Plastifera”, a kind of biological microsystem that moves on plastics to new areas, causing diseases and eliminating populations that have not previously been exposed to these organisms (Landrigan et al., 2020). Some of the pathogenic organisms they

6 Liquid resulting from a process of leaching a fluid through a solid.

carry include *Vibrio* spp. (Keswani et al., 2016; Kirstein et al., 2016), *Escherichia coli, Stenotrophomonas maltophilia, Bacillus cereus* (van der Meulen et al., 2015) and *Aeromonas salmonicida* (Viršek et al., 2017; Barboza et al., 2018). The high concentration of microplastic waste in the subtropical gyre of the North Pacific have caused an increase in egg densities of the pelagic insect *Halobates* sericeus, which could result in the disappearance of the plankton populations from which it feeds (Goldstein et al., 2012; Walkinshaw et al., 2020), causing severe imbalances in the ecosystem.

Another problem that could be exacerbated by the transport of microorganisms in marine plastics is that outcrops or red tides of toxic dinoflagellated algae, which commonly cause poisoning in organisms that encounter them, increase mortality in fish, mammals, seabirds and invertebrates. Red tide events have risen due to the increase in sea surface temperatures caused by climate change. Some of the dinoflagellates responsible for red tides are *Ostreopsis* spp., *Coolia* spp., *Alexandrium taylori*, *Alexandrium* spp. and *Alexandrium catanellaha* (Masó et al., 2003; Griffith and Gobler, 2020; Walkinshaw et al., 2020).

The study of the biological impacts of plastics in the region is still in its initial phase. However, in Costa Rica, fish intake has been evaluated, finding plastics in the digestive tract of black marlin (*Istiompax indica*), lancetfish (*Alepisaurus ferox*) and thread herring (*Opisthonema libertate*). In the latter, the ingestion of a total of 1,101 pieces of plastics was recorded in 30 samples examined (Blanco, 2010, 2019; Nuñez, 2019).

The first experiment on the formation of plastispheres in the Caribbean was carried out in Panama, verifying the potential of plastics as pathogenic microorganism transports (Dudek et al., 2020), but no further information was found on studies related to the biological impacts of plastic on that country.

In the Caribbean Sea of Colombia, the focus has been on the intake of plastics by marine fish, mainly in some crustaceans and invertebrates, such as nematodes and the queen conch (*Aliger gigas*) (Acosta-Coley et al., 2019; Hurtado et al., 2019; Garcés-Ordóñez, et al., 2020; El Tiempo, 2021). On the other hand, in a study carried out in the Rosario Islands, near Cartagena, it was found that fish associated with the mangrove ingest more plastic than those associated with coral reefs. The same differentiation was found between males and females, where the latter, due to having a higher energy expenditure, tend to ingest more plastics (Martínez, 2020). Likewise, the ingestion of plastics was detected in four carnivorous species of the CGSM, such as the Parassi mullet *Mugil incilis*, the crevalle jack *Caranx hippos*, the yellow mojarra *Caquetaia kraussii* and the striped mojarra *Eugerres plumieri* (Calderon et al., 2019), as well as the presence of microplastics in the gills of blue crabs (*Callinectes sapidus*) in this estuarine-lagoon system (Hurtado et al., 2019). In the Bay of Cispata, 22 species were analyzed, of which eight recorded ingestions of plastics classified as filaments (55%), fragments (23%), films (19%) and foams (3%) (Garcés-Ordóñez, et al., 2020).

It is important to mention that many of the species affected by plastics serve as food for humans or for other species that, in turn, are consumed by humans. Invertebrates such as copepods and krill are a source of nutrition for species of food importance for humans (Walkinshaw et al., 2020), such as crabs, prawns, shrimp and clams (Xu et al., 2016; Gray and Weinstein, 2017; Cau et al., 2020; Horn et al., 2019; Piarulli et al., 2019; Renzi et al., 2020;). Oysters, mussels, and fish consume microplastics

(Calderon et al., 2019; Cho et al., 2019; Li et al., 2019; Teng et al., 2019; Garcés-Ordóñez et al., 2020; Walkinshaw et al., 2020) directly showing an impact not only on the marine food web, but on the food security of consumers of fishery products.

According to what has been stated for the region under study, data seems to indicate that organisms associated with coastal zone ecosystems, such as mangroves, are facing a greater availability of plastics in their environments, which increases the possibility of consumption. It is also striking that females of certain fish consume more plastics than males, as it could have a negative impact on reproductive processes and on the ability of populations to maintain healthy numbers.

4.4. Potential effects of plastic waste on human health

The direct consumption of marine plastic by humans is immediately related to the intake of filter-feeding shellfish that consume the microplastics and nanoplastics present in the water when eating and breathing (Barboza et al., 2018; Smith et al., 2018). It has been concluded that the highest exposure occurs when eating complete animals such as oysters, mussels, or clams (Cole et al., 2013; Carbery et al., 2018). On the other hand, sea salt also facilitates the intake of microplastics. In Spain, 50 to 280 fibers can be found in a kilogram of salt, mainly of PET, PP and PE. And in China, 550 to 681 fibers per kilogram of salt have been found, mainly from EPS and PET (Iñiguez et al., 2017). Such concentrations can be used as indicators of the sources and levels of contamination of sea salt extraction areas.

According to WWF and a study conducted by the University of Newcastle (Australia), humans consume about 100,000 plastic micro-particles per year (Barboza et al., 2018; WWF, 2019b), of which we can excrete up to 90%. However, other studies confirm that smaller or nanoplastic particles, when ingested, can be transported by the lymphatic system and generalize their presence in other tissues of the human body (Barboza et al., 2018; Waring et al., 2018; Schwabl et al., 2019; Teles et al., 2020).

Remains of micro-plastics left in the gut can induce cell toxicity, stop cell cycles, and even alter immune system cells at the onset of inflammatory reactions (Teles et al., 2020). Likewise, chemical additives from plastics, such as bisphenol A (BPA), which is banned in most countries, but present in human tissues (American Chemical Society, 2020), and phthalates, can alter the function of the endocrine system imitating, blocking, or altering hormones and glands such as the thyroid (Smith et al., 2018). For their part, perfluorinated additives, widely used to make water-repellent plastics, can cause irreversible damage to the skin and adverse effects on the sexual function of adults, known as toxicity to human reproduction (Vilakati et al., 2020). Other plastic additives can reduce male fertility, cause problems in fetal development, damage the developing human brain many years after birth, and cause other damages to neurological development (Smith et al., 2018; Landrigan et al., 2020). Although long-term direct effects from microplastic ingestion remain unclear, it is suspected that they may be more severe than currently known (WWF, 2019b).

Models (*in vitro*) of human nanoparticle uptake indicate that the size and shape of nanoplastics are important variables in determining their involvement. Once the nanoplastics are in the intestinal epithelium[7] they can cross layers of tissue that cover the internal cavities, entering the systemic circulation and managing to reach important organs such as the liver, lungs, spleen, brain, heart, and kidney. In addition, they are likely able to cross the blood-brain barrier (a system that protects the brain from foreign substances) (Waring et al., 2018; Teles et al., 2020). On the other hand, local inflammation induced by nanoplastics can compromise the functionality of gastrointestinal processes and trigger alterations in microbiome communities, which lead to dysbiosis or abnormal reactivity of the intestinal microbiota (Teles et al., 2020). Another critical risk is that plastic nanoparticles can interact with proteins, lipids and carbohydrates, which translates into easy access to the exchange mechanisms that occur across the cell membrane and potential cell access (Teles et al., 2020).

Other types of direct external impacts have also been recorded. The presence of plastic garbage can entangle swimmers and divers, or injuries caused by sharp plastic fragments, and the presence of debris in the water interrupts rescue operations at sea, causing loss of human life (Abalansa et al. al., 2020).

In general, plastic waste at sea can increase the overall risk of human and animal diseases, becoming dispersers of pathogens and their vectors, causing contamination and infections (Barboza et al., 2018; Keswani et al., 2016).

4.5. Economic and social impact of marine plastic pollution

The presence of marine litter affects tourism, recreation, fishing, and industrial productivity by disrupting key ecosystem functions and services, even at points far from the source of contamination (Newman et al., 2015; Steer and Thompson, 2020). The most impacted ecosystem services are fishing and related to the disappearance of species and recreation (Beaumont et al., 2019).

The High-Level Panel for a Sustainable Ocean Economy, an initiative promoted by Norway since 2018, made up of a group of countries committed to developing, catalyzing and supporting solutions for ocean health and wealth in matters of policy, governance, technology and finance, estimates that the negative economic effects of microplastics in the oceans that reduce global marine ecosystem services are between USD 0.5 to 2.5 million per year (Ministerio de Ambiente de Panamá, 2020). The impact of ecosystem services is directly linked to the loss of millions of jobs based on maritime activities (Abalansa et al., 2020). In addition, they can mean losses of between USD 15 million and USD 17 million due to boat repairs and fishing time lost in the cleaning of gear (Steer and Thompson, 2020), as well as losses of economic income from tourism of between USD 29 million and USD 37 million, due to the presence of waste on beaches after rainfall (Jang et al., 2014).

7 Tissue consisting of cells closely linked, flat or prismatic, covering the external surface of the body and certain internal organs.

The economic losses from disposing of single-use plastics that could be reused are equivalent to between USD 80 billion and USD 120 billion per year (The Pew Charitable Trust, 2020). On the other hand, it is estimated that the impact of marine plastic pollution produces between 1 and 5% of loss of marine ecosystem services of between USD 500 million and USD 2,500 million, which are lost in natural capital each year, without counting other types of economic impacts and that, at current rates, are expected to increase (Beaumont et al., 2019). The global cost in plastic waste management for the States, between 2021 and 2040, is estimated at USD 670 billion (The Pew Charitable Trust, 2020).


Thousands of tourists visit the region every year. Rio Celeste, Costa Rica © Shutterstock

5 Current discussions

The obvious plastic pollution that currently impacts the environment is affecting economic sectors that depend on its services (e.g. tourism, maritime transport, fisheries). Along these lines, reports and complaints from the civil society support the severity of the problem and have prompted international treaties such as the Basel Convention on the control of transboundary movements of hazardous waste and their disposal, as well as the Convention of Stockholm on persistent organic pollutants, include the management of plastic and derived substances (Basel Convention, 2019; Stockholm Convention, 2021).

Promoted by Norway and supported by an alliance of global organizations #BreakFreeFromPlastics, of which MarViva Foundation is a part, has developed proposals to establish an international treaty, like the Paris agreement on Climate Change (WWF et al., 2020), but focused on plastic pollution. Recently, the United Nations Expert Group on Marine Litter presented a recommendation that emphasizes a proposal for new global regulation, which is expected to be discussed during the V session of the UN Assembly, in February 2022 (Ellen MacArthur Foundation, 2020; UNEP, 2020).

5.1. Regulations on single-use plastics

5.1.1. Treaties and international instruments

Although there are several international treaties and instruments that address the problem of marine litter (Table 7), an analysis of regulations in force until 2019 indicates that, despite providing guidelines to address the problem, many of the treaties are not legally binding, therefore they lack legal force for actions to be implemented in signatory countries (Karasik et al., 2020). This is evident in the case of the Aichi Targets and the Strategic Biodiversity Plan 2011-2020. For example, target eight was aimed at reducing pollution due to excess nutrients, pesticides, plastics, and other wastes by 2020, but to date, it has not been met and measures are required to prevent another "lost decade" for biodiversity and the planet (Berger, 2020).

Table 7 - International instruments and treaties to address marine litter pollution (Source: UNEP, 2019)

INSTRUMENT	YEAR	PURPOSE
Stockholm Convention on Persistent Organic Pollutants (COP)	2004	Take measures to eliminate or reduce the release of COPs into the environment.
Honolulu Strategy	2011	Global framework for the prevention and management of marine litter.
Declaration of the Global Plastics Associations for Solutions on Marine Litter	2011	Contribute with solutions, support research, promote the implementation of policies, increase recovery opportunities, and monitor the transport and distribution of pellets to prevent losses and marine pollution by plastics.
Rio Summit +20	2012	Within their common vision towards plastics: 1. Concern that the health of the biodiversity of the oceans and seas is negatively affected by marine pollution, including marine debris, especially plastics, COPs, heavy metals, and nitrogenous compounds. 2. Recognize the importance of adopting a lead-time approach and further develop and implement policies to achieve resource efficient and environmentally sound waste (electronic and plastic) management.

Regional Action Plan for Marine Litter Management in the Greater Caribbean	2014	Comprehensive tool to assist countries in the Region to incorporate components for the proper management of waste in all sectors.
Sustainable Development Goals (SDGs) – Goal 14	2015	Goal 14. Target 1. Prevent and significantly reduce marine pollution of all types, from land-based activities, including marine debris and nutrient pollution.
Regional Action Plan for Marine Litter in the Baltic Sea	2015	Reduction of the entry and presence of marine litter in the Baltic Sea.
United Nations Environment Assembly (UNEA) Resolution 3/7 Marine Litter and Microplastics	2017	Establishes guidelines to address the problem of marine litter and microplastics from all levels and at all levels of government.
Action Plan for the Conservation and Protection of the Environment and the Comprehensive Management of Natural Disaster Risks to strengthen efforts and make the region plastics free, of the Central American Integration System (SICA)	2018	Strengthen efforts to make Central America a plastics-free region.
Ocean Plastics Charter	2018	Statute to ensure that plastics are designed to be reused and recycled. Brings together governments, businesses and civil society organizations committed to a more efficient and sustainable approach to the use and management of plastics.
Modification of the Basel Convention	2019	Establishes procedures for transboundary transportation of plastic waste, lists toxic plastic waste which can be rejected by importing countries and must be declared by exporting countries.
G20 Osaka Blue Ocean Vision	2019	Reduce additional marine litter pollution to zero by 2050 with a comprehensive life cycle approach that includes reducing the dumping of poorly managed marine litter through improved waste management and innovative solutions, recognizing the important role of plastic in the society.
Regional Action Plan on Marine Litter of the Coordinating Body on the Seas of East Asia (COBSEA)	2019	It consolidates, coordinates and facilitates cooperation, and guides the implementation of policies, strategies and measures necessary for the integrated and sustainable management of marine litter in the East Asian Sea region.

In 2021, new legally binding guidelines to the Basel Convention entered into force, of which Costa Rica, Panama and Colombia are signatories. This Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal has included in its Annexes II (other wastes) and VIII (hazardous waste) plastics made with a combination of polymers or those that are not easily recyclable. This restriction is a great precedent to limit imports of plastic waste from highly polluting countries, such as the United States (Basel Convention, 2019).

Furthermore, on January 16, 2021, the XVI Meeting of the Persistent Organic Pollutants Review Committee of the Stockholm Convention, agreed to recommend to the countries party to the Convention to list the UV-328 plastic additive in Appendix A of the Convention, so that it can be eliminated from the market. This highly toxic stabilizer is used in personal care products and as a rubber cover. It has been found in such isolated environments as the Arctic and Pacific oceans, accumulating in the tissues of seabirds that feed on these areas and sticking to microplastics. It has also been detected in human breast milk (Stockholm Convention, 2021).

These type of decisions with global impact are paving the way for actions that will require greater commitment on the part of governments. Previous diagnoses conclude on the need to establish an international body with the capacity to coordinate and strengthen current efforts within the framework of Sustainable Development Goals (SDGs), a legally binding international instrument to combat marine plastic garbage and microplastics (UNEP, 2017).

At the Fourth Meeting of the United Nations Expert Group on Marine Litter (November 2020), the parties agreed that maintaining the status quo is not an option. Most countries agree that consideration should be given to creating a legally binding international agreement that would allow: i) setting global and national reduction targets, ii) designing standards, iii) eliminating unnecessary plastics, iv) facilitating national and international action plans, v) sharing knowledge in a scientific panel and using a harmonized global methodology, and vi) coordinating financial and technical resources at the international level (Figure 24; UNEP, 2020).

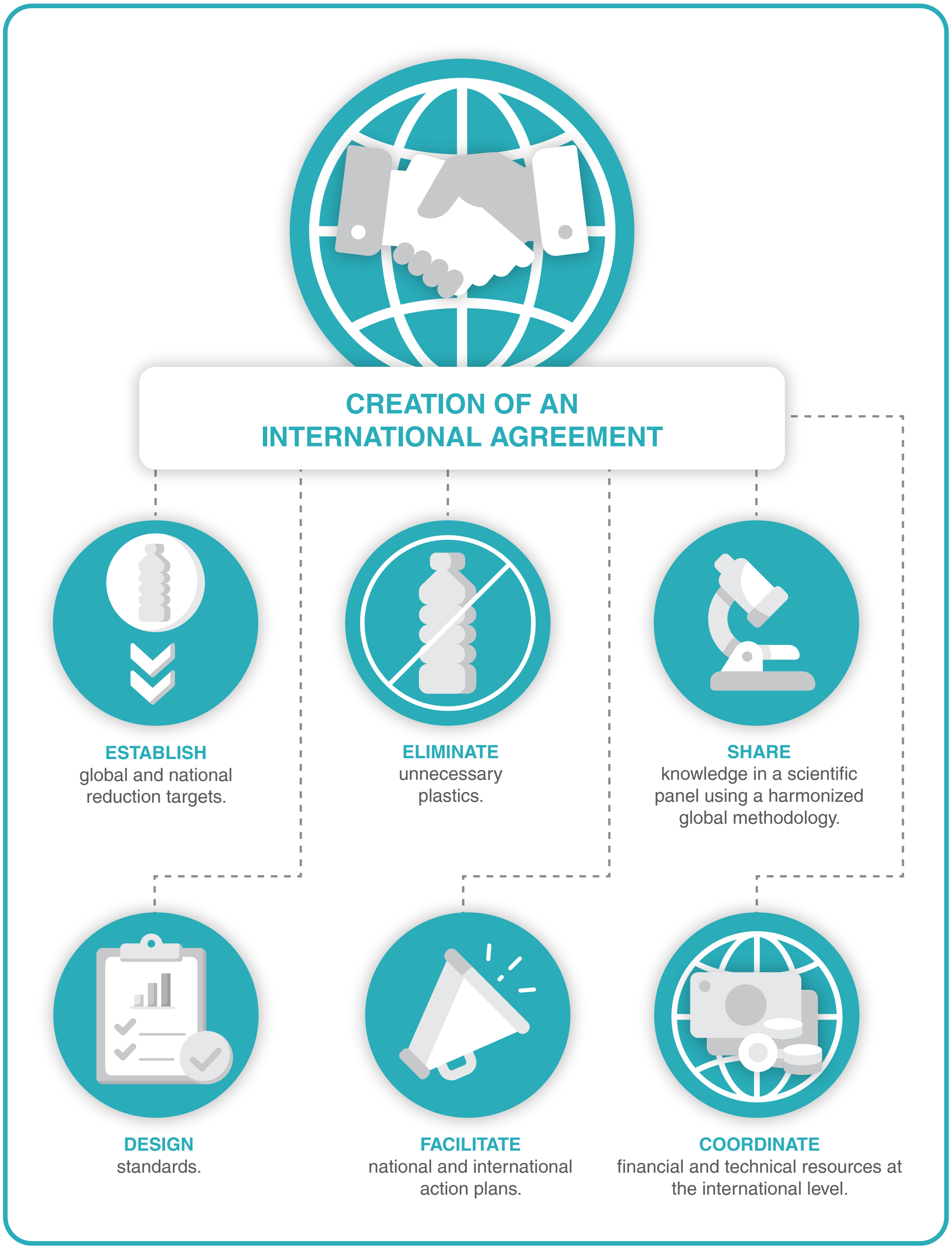


Figure 24 - Benefits of Creating an International Agreement (Source:UNEP, 2020)

Although countries such as the United States, the country that produces the most plastic waste in the world (Law et al., 2020), and the United Kingdom, have not committed to participate in the proposal for the international agreement. More than two-thirds of the UN member countries, including African, Baltic, Caribbean, Nordic, Pacific countries, as well as the European Union (Figure 25), have expressed their support through ministerial declarations warning about the negative consequences for the planet and humanity, if a treaty like the Paris Agreement is not implemented to address the issue of marine litter (McVeigh, 2020).

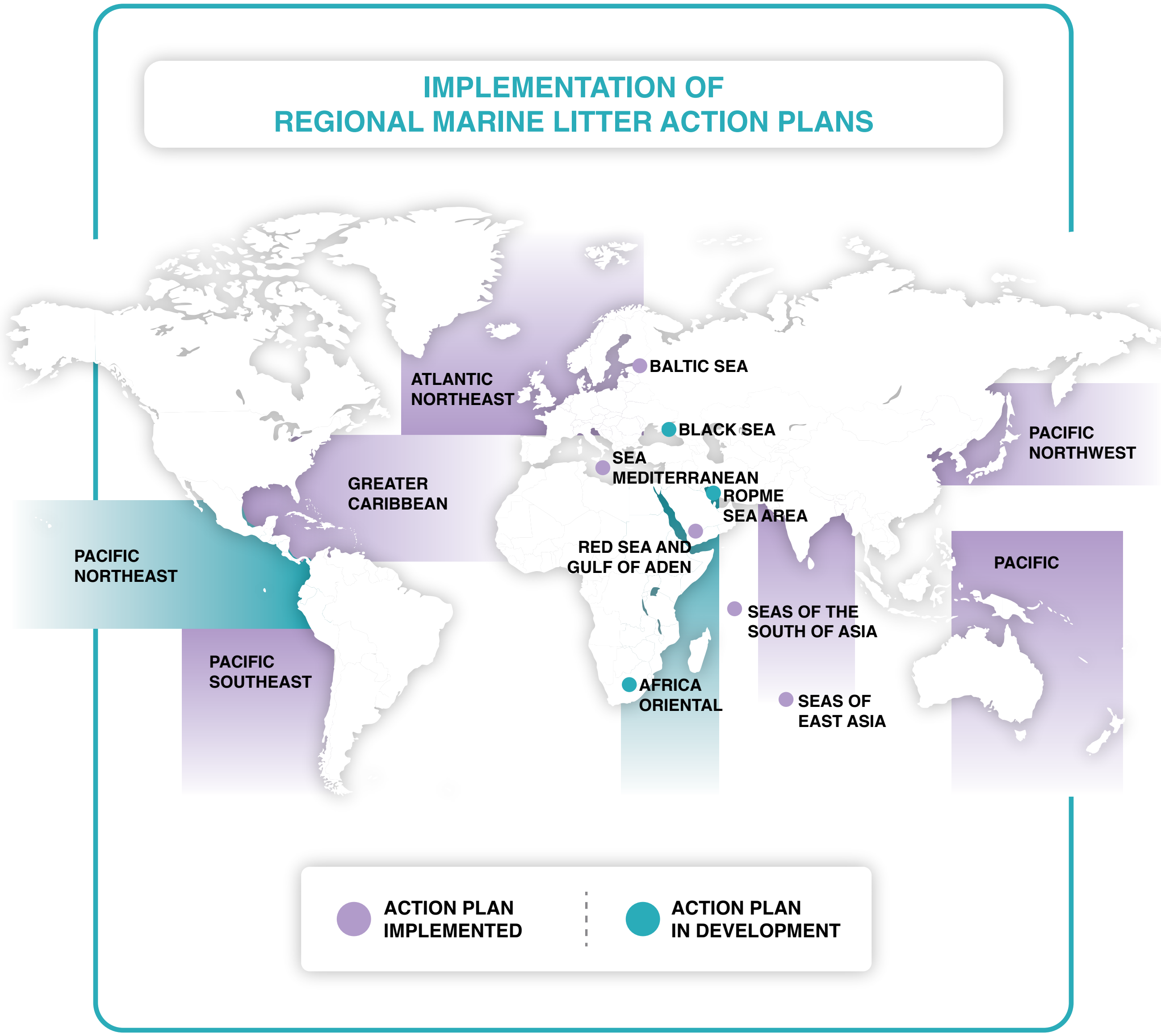


Figure 25 - Implementing Regional Marine Garbage Action Plans (Source: UNEP, Marine Plastic Debris and Microplastics, document in preparation)

5.1.2. National and local regulations on single-use plastics

In 2019, 170 countries signed the agreement to significantly reduce single-use plastics by 2030 (Noticias ONU, 2019), many of which have begun or continue to implement regulatory measures to meet this commitment. By mid-2019, at least 43 countries around the world had banned or imposed some tribute to the use of plastic bags. These regulations are established mainly in developing countries (33 countries), most of them in Africa, where the sanctions are severe and the industrial sector has been confronted, giving priority to the natural environment over economic interests. For example, in Rwanda, controls are strict and plastic has become part of the black market as the zero plastic tolerance policy includes penalties of up to a year in prison for entrepreneurs who decide to bring it to the market (de Freytas-Tamura, 2017).

Despite shortcomings in the implementation of regulations, it has been possible to establish a trend towards the reduction in the use of products, which indicates that this type of policy is efficient (Karasik et al., 2020).

However, because of the pandemic in 2020, some cities were pressured to suspend legislation for the first months of the year or delay the entry into force of regulations. This was the case in the United States, in cities such as California, Massachusetts, Connecticut, New York and Maine, as well as in Mexico (El Comercio, 2020).

In other cities and countries, regulations on single-use plastics were maintained despite the pandemic, due to the positive impacts they had generated during its implementation. Since 2008, a State Council Statement in China limited the production, sale, and use of plastic bags under 25 microns[8] thick for retail purchases. As a result, the generation of 40 trillion bags had been prevented after one year (UNEP, 2018b). Likewise, in New York, Local Law 142 of 2013 prohibited the sale and use of EPS containers for food service. The measure came into effect in 2017 and has been maintained because the city's Sanitation Department found that EPS packaging cannot be recycled in an economically feasible or environmentally effective manner (Departamento de Saneamiento de Nueva York, 2017).

Adding to this global trend, in Chile, through Law 21100 (2018), it was prohibited to deliver plastic bags in commercial establishments throughout the national territory. It is estimated that in the first six months of this law, the delivery of almost 1,000 million plastic bags was avoided (Ministerio de Ambiente de Chile, 2019). In the same country, pioneering legislation is being discussed that will regulate the use of single-use plastic products, prohibiting their use, both within shops and for delivery services. This law will also oblige supermarkets, convenience stores and warehouses to always offer returnable beverage options and will be obliged to receive consumer packaging (Ministerio de Ambiente de Chile, 2019).

Figures 26 to 32 present a list of countries that have implemented regulations focused not only on the immediate or progressive elimination of plastic bags, but also of other types of single-use plastics, from 2019 to the beginning of 2023. The progressive ban on these plastics in the European Union is highlighted, starting in 2021, and the positive influence it could have on other countries with which the bloc has strong political and economic ties, including Costa Rica, Panama, and Colombia.

8 Millionth part of a meter.

NORTH AMERICA (MEXICO, CANADA & USA)

Mexico (2019 - 2021)

PROHIBITED PLASTICS:
Plastic bags, tableware and straws.

LEGISLATION:
State - Mexico City

REFERENCE:
Decree 1054 of 2019

Canada (2021)

PROHIBITED PLASTICS:

Bolsas plásticas, pajillas, mezcladores, anillos para six packs, cubiertos y loza de plástico difícil de reciclar. Proceso por finalizar en diciembre del 2021.

LEGISLATION:
National

REFERENCE:
Law 33/1999

EE.UU. (2020 - 2021)

PROHIBITED PLASTICS:
Plastic tableware and straws, plates, cups and EPS containers.

LEGISLATION:
Municipal – Honolulu

REFERENCE:
Ordinance 30-40/2019

Figure 26 - National and local regulations on single-use plastics in North America (Source: Prepared by the authors)

CENTRAL AMERICA AND THE CARIBBEAN

Belize
(2020)

PROHIBITED PLASTICS:
Single-use EPS products, plastic tableware, bags and straws.

LEGISLATION:
National

REFERENCE:
Law 8/2020.

Bahamas
(2020)

PROHIBITED PLASTICS:
Plastic bags, straws, tableware, cups and EPS food containers.

LEGISLATION:
National

REFERENCE:
Law 38/2019

Barbados
(2020)

PROHIBITED PLASTICS:
Plastic tableware, straws and egg trays and EPS containers used in the retail culinary industry.

LEGISLATION:
National

REFERENCE:
Law 11/2019

Grenada
(2020 - 2021)

PROHIBITED PLASTICS:
Plastic tableware, utensils and containers.

LEGISLATION:
National

REFERENCE:
Law 8/2018

Panamá
(2020)

PROHIBITED PLASTICS:
Plastic swabs, plastic bags for dry cleaning, plastic trays for eggs, plastic stirrers, plastic rods to hold balloons, plastic toothpicks, plastic straws, plastic cocktail sticks, plastic sticks for candy, six-pack rings, disposable tableware.

LEGISLATION:
National

REFERENCE:
Law 187/2020.

Costa Rica
(2019)

PROHIBITED PLASTICS:
EPS packaging (import and production), straws and single-use plastic bags.

LEGISLATION:
National

REFERENCE:
Law 9703/2019 and Law 9786/2019

Figure 27 - National and local regulations on single-use plastics in Central America and the Caribbean (Source: Prepared by the authors)

SOUTH AMERICA

Peru (2018)

PROHIBITED PLASTICS:
Plastic bags, straws, containers and tableware made of polyethylene and EPS.

LEGISLATION:
National

REFERENCE:
Law 30884/2018

Chile (2018)

PROHIBITED PLASTICS:
Plastic bags for retail. Excludes plastic bags for food packaging or used for hygienic reasons.

LEGISLATION:
National

REFERENCE:
Law 21100/2018

Uruguay (2019)

PROHIBITED PLASTICS:
All plastic bags used to contain and transport products and goods. Excludes plastic bags for food packaging or used for hygienic reasons.

LEGISLATION:
National

REFERENCE:
Law 19655/2018

Ecuador (2020 - 2021)

PROHIBITED PLASTICS:
Bags or covers made of plastic material, disposable containers, EPS extruded or in foam, straws, stirrers, cutlery, bowls, cups, lids and disposable and plastic plates, in addition to PET plastic bottles.

LEGISLATION:
National

REFERENCE:
Law SN/2020a

Figure 28 - National and local regulations on single-use plastics in South America (Source: Prepared by the authors)

EUROPE

United Kingdom (2018)

PROHIBITED PLASTICS:
Microperlas en la fabricación de cosméticos – Sancionado entre el 2017 y el 2019 en los diferentes países del Reino Unido.

LEGISLATION:
Regional

REFERENCE:
Law 18/2019, Law 760/2018, Law 162/2018 and Law 1312/2017

Inglaterra (2020)

PROHIBITED PLASTICS:
Straws, stirrers and cotton swabs.

LEGISLATION:
National

REFERENCIA:
Law 971/2010

España (2020)

PROHIBITED PLASTICS:
Marketing of non-reusable plastic utensils, plates, cups, cutlery and straws.

LEGISLATION:
National

REFERENCIA:
Law 161/2722/2018

Alemania (2021)

PROHIBITED PLASTICS:
Cutlery, plastic plates and straws.

LEGISLATION:
National

REFERENCE:
Law 5/2021

Francia (2020 - 2022)

PROHIBITED PLASTICS:
2020: Plates, cups and swabs
2021: Straws, disposable cutlery, stirrers, lids for disposable cups, confetti, EPS containers, plastic packaging for fruits and vegetables. Penalty for excessive plastic wrapping.
2022: Tea bags, free toys at fast food stores, free plastic bottles at businesses.
Disposable plastics served at the table in fast-food restaurants.

LEGISLATION:
Nacional

REFERENCE:
Law 1451/2019

Unión Europea (2021)

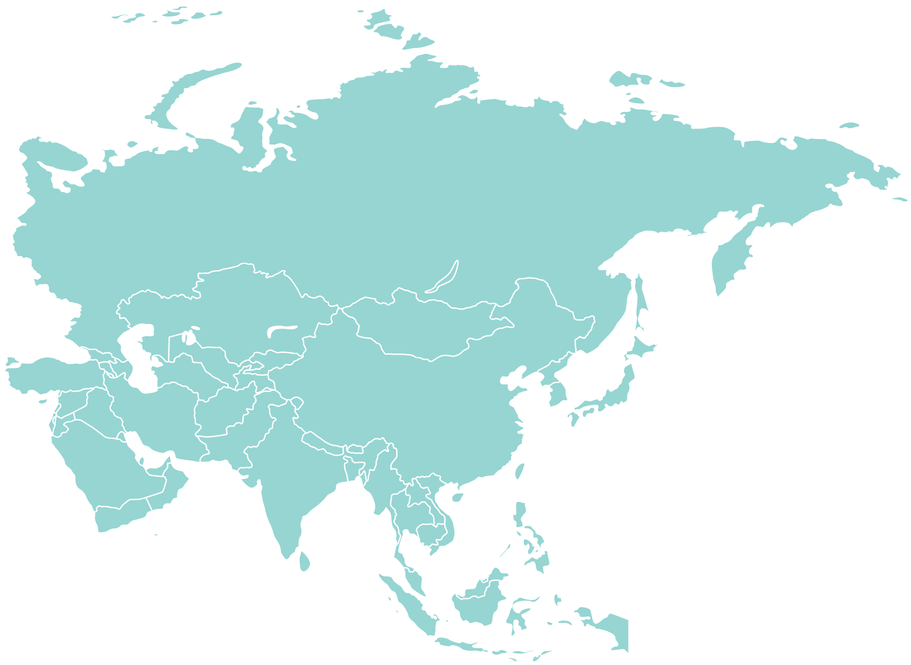
PROHIBITED PLASTICS:
Cotton swabs, cutlery, chopsticks and plastic plates, straws.

LEGISLATION:
National

REFERENCE:
Directive 904/2019.

Figure 29 - National and local regulations on single-use plastics in Europe (Source: Prepared by the authors)

ASIA



China (2020)

PROHIBITED PLASTICS:

Non-degradable bags and straws.

LEGISLATION:
Municipal – Major Cities

REFERENCE:
Five-Year Plan/2020

Tailandia (2020)

PROHIBITED PLASTICS:

Bolsas plásticas de un solo uso.

LEGISLATION:
National

REFERENCE:
Roadmap/2020

China (2022)

PROHIBITED PLASTICS:
Prohibición de bolsas no biodegradables para 2022.

LEGISLATION:
National

REFERENCE:
Five-Year Plan/2020

Figure 30 - National and local regulations on single-use plastics in Asia (Source: Prepared by the authors)

AFRICA

Tanzania (2019)

PROHIBITED PLASTICS:
Plastic bags.

LEGISLATION:
National

REFERENCE:
Law 394/2019

Ruanda (2019)

PROHIBITED PLASTICS:
All types of single-use plastics except compostable plastics.

LEGISLATION:
National

REFERENCE:
Law 17/2019

Kenia (2020)

PROHIBITED PLASTICS:
Plastic bottles, polypropylene and polyethylene plastic bags, food wrappers, bags, straws and lids, in protected areas.

LEGISLATION:
National

REFERENCE:
Law 47/2019

Figure 31 - National and local regulations on single-use plastics in Africa (Source: Prepared by the authors)

OCEANIA

New Zealand (2019)

PROHIBITED PLASTICS:
Lightweight boutique-style and "emergency" plastic bags offered by some supermarkets as an alternative to a plastic bag. It also includes bags made of degradable plastic.

LEGISLATION:
National

REFERENCE:
Law 270/2019

Australia (2020)

PROHIBITED PLASTICS:
Plastic straws, cutlery and stirrers and EPS cups and containers.

LEGISLATION:
State – South Australia

REFERENCE:
Law SN/2020b.

Figure 32 - National and local regulations on single-use plastics in Oceania (Source: Prepared by the authors)

It is noted that several Caribbean countries have used the same three-phase strategy, which first bans imports, followed by restricting wholesale and completely banning consumption of products. In Mexico City, the ban on plastic bags makes an exception if they are compostable. One of the clearest strategies is the one established by France, which will progressively prohibit from disposable tableware to plastic toys given free of charge in fast food stores.

5.1.3. Initiatives of the Civil Society

In the last 20 years, different initiatives have been promoted from civil society and private companies aimed at the prevention of marine pollution by plastics. These efforts are framed in different stages of the life cycle of plastic, some seek to reduce consumption and others promote more and better recycling. Some examples are given in Table 8.

Table 8 - Some initiatives of civil society organizations worldwide (Source: Prepared by the authors)

INITIATIVE	YEAR	PLACE OF ACTION	PURPOSE	WEBSITE
Zero Waste International Alliance	2002	International	Promote alternatives to landfill and incineration and raise awareness about the social and economic benefits of waste as a resource.	http://zwia.org/
Take 3 for the sea	2010	International	Global movement seeking action against plastic pollution. Their slogan is "Take 3 pieces of rubbish with you when you leave the beach, the canal or… any other place, and you will have made a difference".	https://www.take3.org/
The Ocean Cleanup	2013	Ocean gyres	Design and develop cleaning systems for what is already polluting the oceans and intercept plastic on its way to the ocean through rivers.	https://theoceancleanup.com/
Plastic Oceans	2015	United States, Canada, Chile (Oceana), Europe and Mexico	End plastic pollution by strengthening communities around the world, under the principles of education, activism, advocacy and science.	https://plasticoceans.org/who-we-are/

INITIATIVE	YEAR	PLACE OF ACTION	PURPOSE	WEBSITE
Break free from plastic	2016	International	It is a movement of more than 11,000 organizations and individuals that demand the reduction of single-use plastics and press for definitive solutions to the plastic pollution crisis, with values of environmental protection and social justice.	https://www.breakfreefromplastic.org/about/#
Clean Seas Campaign - (UN)	2017	International	Urges governments to pass policies to reduce plastic; calls on the industry to minimize plastic packaging and redesign products; and calls on consumers to change their disposal habits before irreversible damage is done to our seas.	https://www.cleanseas.org/?_ga=2.95853599.2096681259.1611700592-66120374.1611117448
New Plastics Economy (Ellen Macarthur Foundation)	2018	International	It is an initiative to generate momentum towards a working plastics system. Applying the principles of the circular economy, it brings together key stakeholders to rethink and redesign the future of plastics, starting with packaging.	https://www.newplasticseconomy.org/
Ocean Plastics Leadership Network	2019	United States of America	Network to mobilize brands, materials scientists, innovative technologies and NGOs/Activists within the plastic value chain.	https://oceanplasticsleadershipnetwork.com/
#OceánosSinPlásticos (Oceana)	2019	Chile	It seeks to focus on prevention and reuse as effective tools in reducing plastic pollution, through a bill that regulates waste and single-use plastics.	https://chile.oceana.org/our-campaigns/plastica/campaign

5.1.4. Awareness-raising campaigns and regional and local education

The MarViva Foundation concentrates its actions in Costa Rica, Panama and Colombia with the #ChaoPlásticoDesechable (#ByeByeDisponsablePlastic campaign). In Panama, after the adoption of the national law that prohibits the use of polyethylene bags for the transport of goods, the same communication proposal of #ChaoPlásticoDescechable has been used to increase awareness using the hashtags #SinCarrizoPorFavor (#WithoutStrawPlease), #AdiósCarrizo (#ByeByeStraw) and #MenosPlástico (#LessPlastic), among others, discouraging the use of these materials. Even the National Police of Panama created a campaign called "For a Planet without Plastic Pollution" (Por un Planeta sin Contaminación por Plástico) which motivates every officer to change their plastic bags for reusable bags (ANCON, 2017).

In Colombia, the Greenpeace campaign "better without plastics" (mejor sin plásticos) invites companies that pollute, among other actors, to become aware of the impact they cause. One example was the campaign "Success: free the fruit" (Éxito: libera la fruta), specifically aimed at businesses that sell this type of product to eliminate unnecessary wrapping of fruits (Greenpeace, n.d.). The most prominent of these are listed below, while acknowledging the efforts of other organizations (Table 9).

Table 9 - Regional and local initiatives to mitigate plastic pollution (Source: Prepared by the authors)

INITIATIVE	YEAR	PLACE OF ACTION	PURPOSE	WEBSITE
Campaign #ChaoPlásticoDesechable (Fundación MarViva)	2015	Regional (Costa Rica, Panama, Colombia)	Change consumption habits; reduce the use and consumption of single-use plastic bottles, inform and raise awareness about the impact of disposable plastic in marine and coastal environments, as well as debunk myths and misperceptions about waste treatment and recycling.	https://www.marviva.net/es/chaoplasticodesechable
La Verdad Sobre el Plástico (citizens) (The Truth About Plastics)	2015	Costa Rica	Citizen initiative to spark a necessary conversation: The Truth About Plastics	https://www.facebook.com/laverdadsobreelplastico/
Basura Cero (Zero Trash) (Mayor's Office)	2015	Panama City	Reduce waste disposal through the implementation of the 3Rs (reduce, reuse and recycle) through awareness programs, regulations and institutional strengthening, as well as through a market economy in order to contribute to the quality of life of the inhabitants.	https://basuracero.mupa.gob.pa/#:~:text=El%20Programa%20Basura%20Cero%202015,fortalecimiento%20institucional%2C%20as%C3%AD%20como%20a

INITIATIVE	YEAR	PLACE OF ACTION	PURPOSE	WEBSITE
National Single-Use Plastic Replacement Strategy for Renewable and Compostable Alternatives (Government)	2017	Costa Rica	Reduce the presence of single-use plastics in rivers and beaches in Costa Rica and in final disposal sites in the country. In addition, to allow the economic growth of the industry of renewable and compostable alternatives.	http://estrategia.zonalibredeplastico.org/
Desplastifica tu ciudad (Desplastify your city) (DADSA)	2018	Santa Marta – Colombia	It seeks to reduce the high rates of plastic contamination that affect the entire world and the city of Santa Marta. Preserving water sources, mainly marine fauna and flora that are affected with straws, bottles, bags and all kinds of single-use plastics.	https://dadsa.gov.co/index.php/project/desplastifica-tu-ciudad/
Campaña major sin plásticos (Campaign better without plastics) (Greenpeace)	2018	Colombia	Consider plastic pollution as one of the most serious environmental problems in the country and urge the Ministry of Environment and Sustainable Development to comply with the National Policy of Waste Management Solids and remove single-use plastics.	https://www.greenpeace.org/colombia/noticia/issues/contaminacion/greenpeace-anuncia-campana-para-frenar-el-avance-del-plastico-en-colombia/
Switch your bag (UNDP)	2019	Panama	Provide relevant information on the implementation of the prohibition law in Panama and alternative measures for people to become “agents of change”. It recommends carrying reusable bags and educating family members and acquaintances about the law, with the aim of avoiding the use of plastic.	https://www.pa.undp.org/content/panama/es/home/presscenter/articles/2019/cuenta-atras-para-decir-adios-a-las-bolsas-plasticas-en-panama.html

5.2. Circular economy: limitations of plastic recycling and alternatives

Biodegradable plastics do not exist, plastic waste contaminates for years © Shutterstock

5.2.1. Circular economy of plastic

A "Circular Economy" is defined as one that looks for materials and products that will continue to be used indefinitely in the same production cycle, allowing natural systems to regenerate, and reducing the consumption of natural resources, preventing the generation of waste and pollution. As waste, emissions and energy loss are minimized, one-way consumption becomes a closed and regenerative cycle (Figure 33) (Ellen MacArthur Foundation, 2019; UNCRD, 2020).

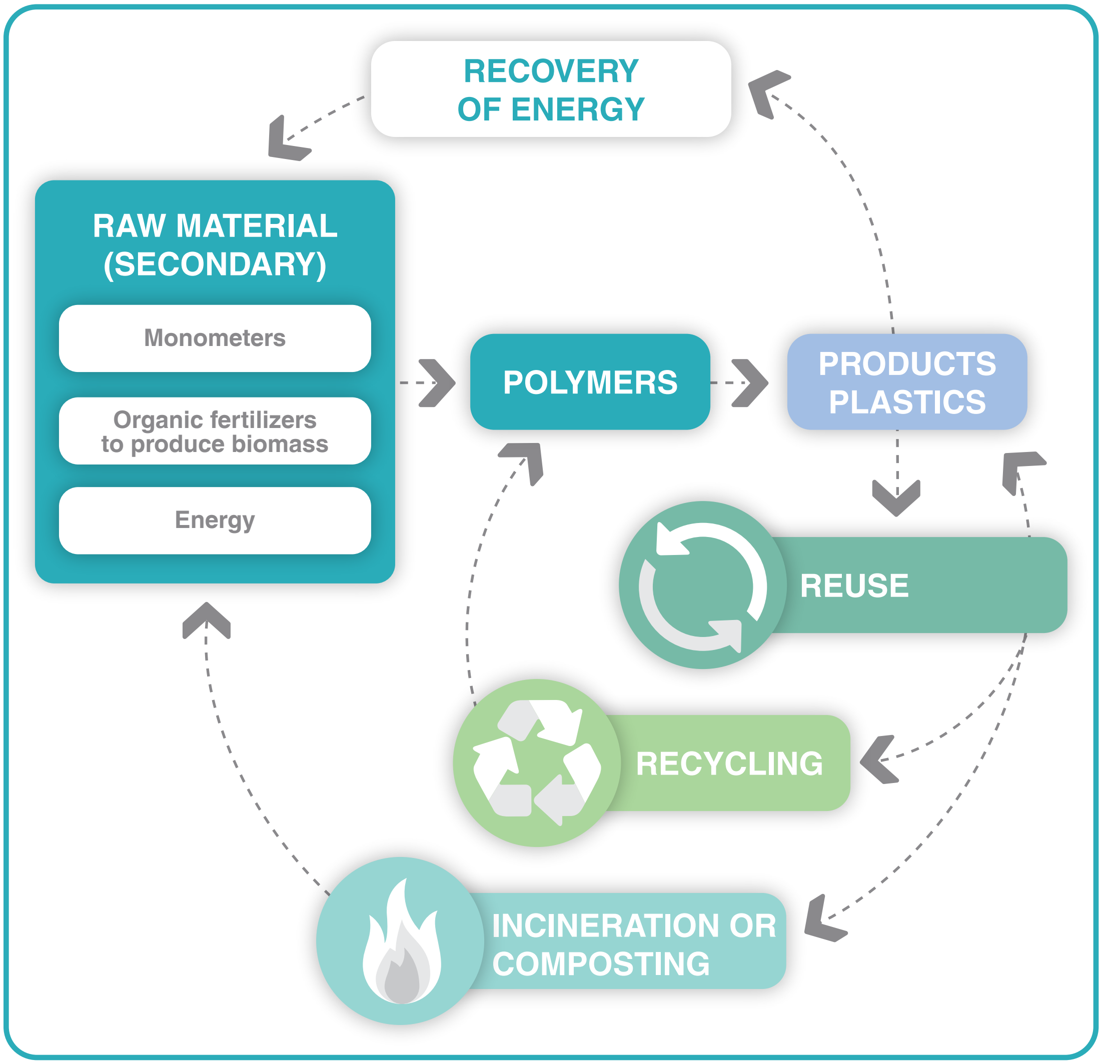


Figure 33 - “Ideal” scheme of the circular economy of plastics, provided that certain conditions of recyclability, biodegradability or composting are met (Source: modified from Bromine and the Circular Economy - https://www.bsef.com/sustainability/bromine-the-circular-economy/)

Proposals for the circular economy of plastics seek to keep the value of plastic as high as possible for as long as possible, preventing environmental impact, which is a concept that goes far beyond recycling. In 2016, the World Economic Forum proposed the creation of an effective post-consumer plastics economy as a strategy for transitioning to the circular plastics economy. Its goals included achieving effective recycling, reuse, and controlled biodegradation for specific applications, reducing the leaching of plastics into natural systems (particularly the ocean), and decoupling plastic from fossil fuels. In addition, it was proposed to reduce material losses by adapting to renewable raw materials (World Economic Forum, 2016; Bucknall, 2020).

However, the challenges and structural problems to achieve this vary, since the criteria of the circular economy require that the materials be based on renewable sources, that they can be reused, repaired or remanufactured, or that they break down easily and without polluting the environment, something that does not happen with plastics as explained below.

5.2.2. Challenges of the plastic recycling process

Mechanical pile for manual collection of mixed waste © Shutterstock

Recycling is the essential element of the circular economy, and, in the case of plastics, it constitutes the main proposal to reduce environmental pollution by this type of waste which has the greatest application throughout the world. However, plastic recycling continues to be an open loop. This means that the product, such as a plastic bottle, is transformed into other products different from the original, which after use can no longer be recycled; in short: *plastic is not infinitely recyclable*. On the contrary, in closed loop systems such as that of aluminum cans or glass, these are converted back into aluminum cans or glass containers, something that cannot be replicated with plastics (Davis, 2019; Bucknall, 2020).

The two main methods for recycling plastic are mechanical and chemical. Mechanical recycling consists of collecting, selecting, and washing the plastic waste, then melting it and converting it back into pellets, without losing the properties of the polymers. However, not all plastics can be processed in this way and those that can, such as PET, lose quality when subjected to high temperatures.

On the other hand, chemical recycling consists of reducing plastic (polymer) to its simplest forms (monomers), through chemical processes to, in theory, reuse them in the creation of new plastics, chemicals or fuels (Pahl, 2020).

Depending on the level of reduction of plastics, chemical recycling technologies have been divided into: i) solvent purification, which reduces plastic to the polymer level only, but works just with one type of plastic at a time, ii) chemical depolymerization, which reduces plastics to monomers (the base molecule) which, like solvents, requires the material to be of a single type of polymer and, iii) thermal depolymerization and fragmentation, which are the most used technologies, since they can reduce plastics to their simplest particles, regardless of whether the materials are of different types. One of the by-products of this type of chemical recycling is fuels (e.g. hydrocarbons) (Zero Waste Europe, 2019).

Thermal depolymerization and fragmentation are promoted as the alternative to recycle everything that cannot be treated with mechanical recycling. However, these technologies are mainly based on pyrolysis and gasification techniques, which consist of subjecting plastic to high temperatures with zero or little oxygen, respectively (Zero Waste Europe, 2019; CNBC, 2020). These technologies require large amounts of energy throughout the material treatment and production cycle (Pahl, 2020). In addition, the products of the physical, chemical, and thermal reactions that occur in the process (gas and fuel), require the addition of other chemical components (Rollinson and Olajedo, 2020).

On the other hand, in addition to the additives used to improve the properties of plastics, such as phthalates, BPA, polycyclic aromatic hydrocarbons, among other carcinogenic chemicals (see 2.1.1.1), plastic waste is contaminated with toxic compounds that are transformed into dioxins during the depolymerization process. According to the World Health Organization (WHO, 2016), dioxins are highly toxic, can affect the immune system and alter hormones causing cancer in humans. Dioxins remain in several of the by-products of pyrolysis, including toxic gases containing hydrogen cyanide (HCN) and carbon monoxide (CO) (Rollinson and Olajedo, 2020). Gasification also results in the emission of these and other polluting gases such as nitrogen oxide (NxOy), which causes acid rain, toxic particles, heavy metals, and greenhouse gases, resulting from the mixture of different types of polymers (Tangri and Wilson, 2017).

In the case of chemical recycling, the picture is not very clear. There is great disappointment in wanting to present the transformation of plastic into fuel as a sustainable and circular alternative, when the final product will emit toxic gases and, contrary to what is desired, will encourage the use of plastics. However, chemical recycling is receiving more funding than mechanical recycling (Pahl, 2020). Regarding the conversion of plastic waste into new plastic, the industry does not appear to be transparent as to the actual environmental impacts of the processes, which, in a way, allows them to evade the permitted limits of air pollution. The information on the impacts available to date has been obtained from independent studies related to the by-products of pyrolysis and gasification in general (Tangri and Wilson, 2017; Rollinson and Olajedo, 2020).

In conclusion, although chemical recycling is more versatile in terms of the types of recyclable polymers, it is more expensive, requires more energy and could be much more polluting, emitting through pyrolysis, up to 77% more greenhouse gases than the production of hydrocarbons such as naphtha (Tabrizi et al., 2020). In addition, the limitations regarding the quality and volume of raw material required are the same as those of mechanical recycling (Pahl, 2020;). Although both types of recycling could be complementary, the challenge of processing capacity versus virgin plastic production speed remains (Hundertmark et al., 2018; Tullo, 2020), while the ideal goal of reducing the production of plastics is left aside.

As for the plastic found in the sea, it has been shown that, although it requires a good cleaning process due to the amount of salt, sand, algae, and seagrass it accumulates, it can be subjected to recycling and reuse processes, taking into account that due to exposure to UV rays, in the case of floating plastic, it loses color and may be less resistant. However, there is concern about the toxicity of the by-products of this plastic, not only because of the toxicities inherent to the plastic, but also because of other contaminants that can be absorbed at sea (Myers, 2020; Ronkay et al., 2021).

On the other hand, mechanical recycling being the most used and least expensive method, is still more expensive than the production of virgin plastic (Bucknall, 2020; Walker et al., 2020). The process requires classification to the most specific scale possible including polymer types and colors. As a result, up to 30% of the plastic cannot be sorted or is too contaminated for recycling. This incompatibility is very present in bio-based plastics which, in the case of PLA, significantly affects the quality of recycled products if it is combined with fossil-based plastics in the recycling process (Alaerts et al., 2018; Franklin- Wallis, 2019; Bucknall, 2020).

All this discarded material ends up in incinerators, also presented as a sustainable option when producing energy from waste. However, they generate polluting gases, ash, water, sewage sludge and heat. It is estimated that the incineration of one ton of plastic generates the equivalent of 2,894 kg of CO_2 of greenhouse effect (Kistler and Muffett, 2019). Given these conditions, it is estimated that the incineration of plastic waste in the short term will become almost equivalent in carbon emissions to gas and coal, emitting more toxins and pollutants into the air without contributing to the reduction in the use of plastics and negatively impacting the environment and the health of the communities near the incineration plants (Client Earth, 2021).

Garbage incineration plant pollutes the environment © Shutterstock

Finally, the plastics industry operates in line with market dynamics and economic incentives. Thus, in 2018, the market was valued at USD 41.7 million, with an expected growth of 6.6% between 2019 and 2027 (Research and Markets, 2020). However, China's 2018 ban on receiving waste from other countries contributed to the drop in the prices of virgin plastic, added to the Covid-19 pandemic crisis, which has produced a drop in the price of hydrocarbons, resulting in production costs of recycled resins being even higher than potential revenues. Therefore, there is a greater economic incentive to purchase virgin plastic resins than recycled resins.

5.2.3. International standards commonly used in bio-based plastics

Worldwide, there are international standards, established by private organizations, to guarantee that the information on product labels complies with some particular characteristic. Among the most widely used standards are those of the International Organization for Standardization (ISO), the European Committee for Standardization (CEN, for its acronym in Spanish), those of the ASTM of the United States and the Australian Standards (AS). Based on these, other organizations, research centers and laboratories are dedicated to recreating and certifying the conditions that are specified in the product, carrying out the tests detailed in the norm or standard and providing the right to use the seals that communicate the endorsement and type of certification for end users.

Campaign on "biodegradable plastics" launched by Fundación MarViva. Costa Rica, 2021 © Fundación MarViva

If any product or material is likely to biodegrade under certain very specific environmental conditions (e.g. seawater, soil or air; with a certain level of humidity and certain microorganisms present), a laboratory recreates those conditions and certifies and endorses the result for that specific environment and for such a specific result. For example, in the case of plastics of biological origin, there is no certification that establishes their ability to biodegrade and compost in natural environments or home composting, and the existing certifications authenticate compostability in different types of industrial facilities (European Commission, 2019). In no case, the certifications related to plastics of biological origin legitimize that such materials are biodegradable in all possible environments existing in the world, including sanitary landfills, seabed, soil, home gardens and an endless number of possible environmental conditions present.

Campaign on "biodegradable plastics" launched by Fundación MarViva. Costa Rica, 2021
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To refresh the information on biodegradability and bio-based plastics, you can return to section 2.1.2.1.).

In Latin America, the use of ASTM and EN standards has been identified. ASTMs include the technical standard D6866 for certifying plastics as bio-based (e.g. containing some raw material of biological or renewable origin), the D6400 which indicates that the plastic is designed to be industrially compostable and the D6868 which incorporates paper and other substrates, facilitating this same type of composting. Also, the EN13432 standard is used to characterize products for recoverable packaging through industrial composting.

In the case of plastics, when the purchaser or user consumes products that have been certified, they find printed symbols such as those of the TUV AUSTRIA certifier (Figure 34), which are assumed to clearly inform whether the plastic is bio-based, industrial compostable or compostable at home. However, this does not seem to be the reality, since on the contrary, it tends to create confusion. For example, in observations made in the United Kingdom, it was determined that there are up to seven different symbols, in which legible stamps indicate: (i) whether the plastic is extensively recyclable, (ii) whether it should be checked with the local recycling center or (iii) whether it should not yet be recycled. In other cases, products have symbols that the consumer may not be familiar with and that do not necessarily mean that the product is recyclable or compostable, leading to wrong disposal (Bucknall, 2020; Franklin-Wallis, 2019). All current certificates fail to explain clearly and in detail the specific environmental conditions, all industrial, in which plastic waste can be composted or treated in such a way that it does not negatively affect the environment, an element that undoubtedly confuses the consumer.

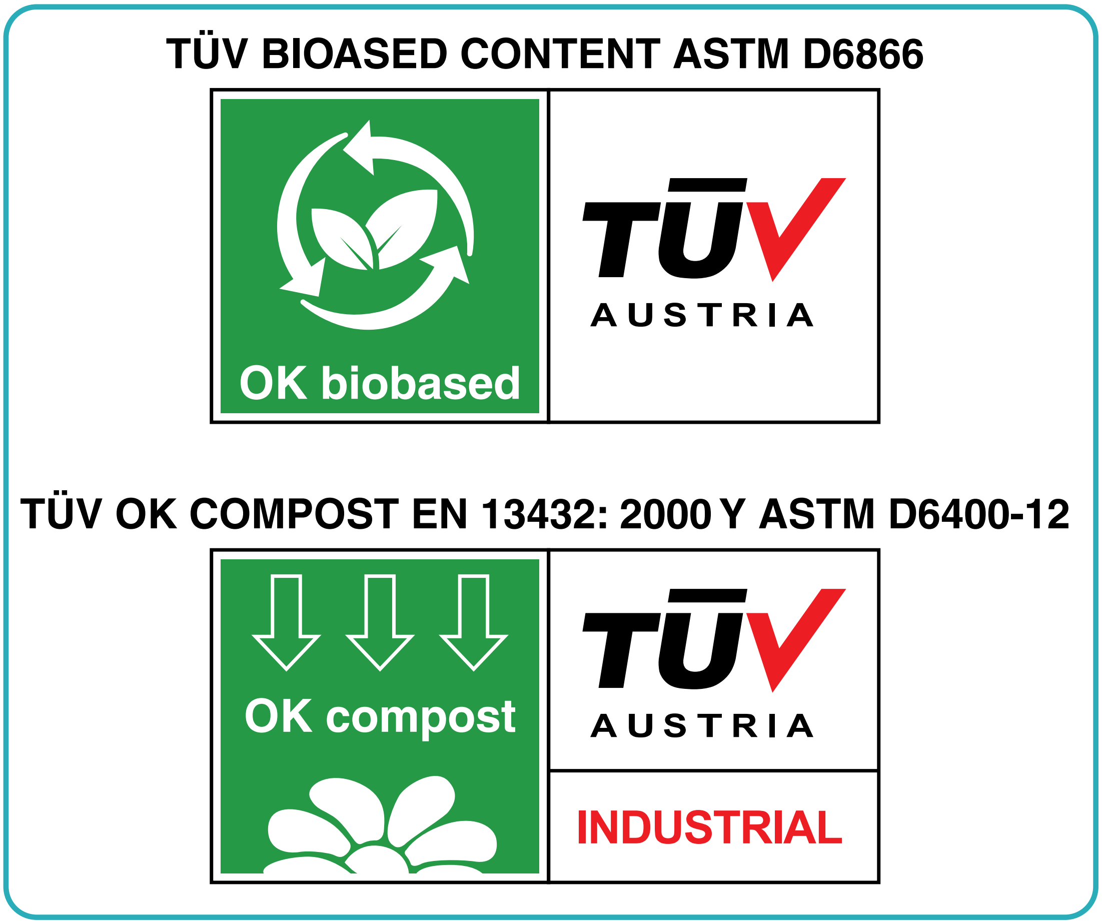

Figure 34 - Example of packaging seals (Source: https://www.interplasticoscolombia.com/)

Different standards (ISO, EN, ASTM) are comparable (Table 10) and their corresponding certifications can be used simultaneously to identify the products, generating misinterpretations even for country regulations. This is the case in Costa Rica, where the National Strategy to Replace Single-Use Plastics with Renewable and Compostable Alternatives aims to implement an RCM classification scheme, based on international standards (ASTM 6400, 6488, 7081-5 and EN13432).

However, the ASTM 6488 and ASTM D7081-5 standards are not applicable. In the case of ASTM 6488, it is a standard that does not correspond to plastic management and yet it is mentioned on pages 13 and 44 of the Strategy. Likewise, ASTM D7081-5, which certified non-floating plastics as biodegradable in the marine environment, was withdrawn in 2014, probably because it did not have a description of the biodegradability performance of the material (Sai Global, 2005). In the case of Costa Rica, it is important to review the suggested standards.

Given the constant confusion, it is very important that producers and countries improve the analysis of the type of standards they want to adopt, especially if they are going to be linked to national legislation. On the other hand, it must be ensured that the seals or symbols used are very clear to consumers, ensuring a correct management from the source. Therefore, if the consumer is not educated about the different symbols and their meaning, it can lead to a blind trust in products that will generate more waste.

Table 10 - Examples of some international standards for renewable and compostable plastics (Source: Adapted from Oceana, 2019)

ASTM	EUROPEAN STANDARD EN	ISO
6400	13432	
Standard specification for marking plastics designed to be compostable in a aerobic in municipal facilities or industrial.	Packaging requirements recoverable through the composting and biodegradation industrial.	
6868		17088
Standard specification for marking final products incorporating plastics and polymers such as coating or additives with paper or other substrates designed to be compostable aerobically in municipal facilities or industrial.		Specifications for plastics compostable industrially.
7081		
Standard specifications for biodegradable plastics that do not float in the marine environment (Discontinued).		
6866	16785	
Standard test method for determining the bio-based content of solid, liquid and gaseous samples using a radiocarbon analysis.	Determination of the bio-based content of solid, liquid or gaseous products, raw materials, final or intermediate products.	

Consumers have the right to clarity regarding certification seals, to understand the conditions under which a product is biodegraded or composted. Otherwise, using this type of certification will be invalid and will continue to negatively affect recycling systems, the problem of overflowing sanitary landfills, and the environment directly.

The individual seal is insufficient, as it does not describe all the conditions that users must consider for the final disposal of waste (Figure 35). This can be counterproductive, because, unintentionally, the consumer can mix industrial compostable products, with compostable products at home, or with recyclables, without being aware that, in each case, different temperature conditions are required, as well as the type of microorganisms capable of degrading the material in the shortest possible time (ASTM, 2019).

Figure 35 - Simple seals, without specific indications on the conditions of compostability or biodegradability. (Source https://www.interplasticoscolombia.com/)

Accumulation of plastic bottles © Shutterstock

Conclusions and recommendations

The contribution of plastic products to the current economic development of all countries in the world is undeniable. However, there is also global consensus on the negative impacts of plastic waste on marine and coastal environments. As evidenced in this publication, in the last 10 years a series of public and private actions have been carried out to reduce and prevent this impact. Today, there is more scientific information on the potential negative impacts of plastic throughout its life cycle: production, consumption, use and waste management, making the economic cost of plastic pollution increasingly evident.

The main challenge of plastic pollution, and of single-use plastic waste, lies in the approach given to the problem, which is limited or narrow and currently the proposed solutions focus only on one stage of the cycle. An approach based entirely on recycling or only on prohibitions will have a limited scope in a context in which the problem responds to structural dynamics linked to forms of global production and consumption. Therefore, the solutions to the crisis of marine pollution by plastic waste and, in general, to pollution by plastics and single-use plastics, will have to be comprehensive and systematic.

To date, countless private and government actions have been implemented to mitigate plastic pollution. However, these have emerged disjointedly and focused on specific stages of the plastic life cycle. In the region under study, standards have been issued with different levels of scope (local, national, or regional), some aimed at promoting recycling, others at promoting widely questioned alternatives such as plastics of biological origin, and some focused on the prohibition of very specific single-use plastic applications, all of them without connection to each other. Another problem has been the implementation of measures aimed at cleaning up the "public image" of plastic, ignoring an environmental, economic, and social problem that can no longer remain hidden.

There is a common weakness regarding the outdated information systems available in Costa Rica, Panama and Colombia, preventing efficient management in the face of real knowledge of the problem and inhibiting informed and timely decisions. In addition, it causes a waste of resources by duplicating efforts, which can be seen in studies carried out more than once and on the same basis. The entire process may even resemble a strategy to delay early decision making.

The construction of public policies is based on the strategic approach to identify the problem through: i) the construction of baselines and status reports, ii) the definition of the object and objective of intervention, ii) the analysis of possible response options (e.g. potential alternatives according to the problem to be solved and the objective set), iv) the formulation of indicators to allow measurement and v) the financial analysis to provide sustainability and scalability to the proposed policies. All the above should be done for each specific case and regulatory scenario, considering the existing legal framework at all levels, and applying public policy evaluations with updated methodologies that include social, economic and environmental benefits as criteria.

It is recommended as a first step to implement harmonized and more efficient control and measurement mechanisms, linked to information systems updated in real time on import, export, production, consumption, and generation of plastic waste. This should be the first step to produce more efficient state and business sector actions.

Although the concept of circular economy is being widely used, it is critical to note that there is still no consensus and clarity regarding the practices and strategies to which it refers. It has even been understood as synonymous with recycling. Therefore, it is key that both consumers and producers recognize that to effectively incorporate plastics into this type of model, it must meet certain characteristics in terms of degradability and compostability or, failing that, have the capacity to preserve its quality at the time recycling. This loss of quality in the process is the reason why recycling, as currently implemented, continues to use a linear scheme. In addition, scientific research on the potential toxic effects of recycling should be intensified, as well as te recognition of the chemical nature of plastic, produced from and with chemicals, many of which are considered potentially toxic to humans.

The promotion of recycling must make clear that most plastics are not recyclable and be transparent about their financial and technical limitations. These are huge barriers that need to be resolved before communicating and inviting consumers to trust recycling as the optimal solution.

Users, consumers, and the public, without distinction of educational level, economic situation or place of residence, have the right to truthful, clear and timely information. One of the most obvious weaknesses is the lack of clarity regarding the seals or certifications used in plastic products. It is essential that producers label the packaging and report the necessary conditions for recycling, biodegradability or compostability (e.g. temperature, humidity, time) of the products they sell.

Likewise, these seals should also warn about the potential risks of plastic for human health. For this reason, clear and direct information must be given about the presence of chemical additives used to provide certain qualities to plastics, as well as the impact these may have on humans, especially on the endocrine system and through prolonged exposure.

On the other hand, it is important to involve citizens in data collection as part of awareness strategies. For example, generating information on the quantity, type and origin of the plastics collected during beach cleanups. Despite demonstrating that these initiatives do not contribute substantially to the coastal marine pollution crisis, they have the potential to generate data that can be incorporated into diagnoses for the development of public policies. It also encourages the participation of citizens in the construction of solutions. For citizens far from coastal areas, it is recommended to develop online or face-to-face activities that include information on the life cycle of plastics and the impact of each part of the cycle. In addition, it is recommended to generate interactive activities to ensure understanding of the seals and all the existing alternatives to reduce the consumption of single-use plastics, especially in the post-Covid-19 era.

Regarding environmental problems, it is advisable to establish traceability strategies to improve source management (e.g. barriers in rivers and other bodies of water) and to pay attention to the behavior of ecosystems that interact with plastics. For example, a recent discovery indicates that plastic can be trapped in what scientists have called "Neptune spheres", formed by fragments of seagrasses expelled onto beaches by tide action (Agence France-Presse, 2021), considered as a new service provided by this ecosystem.

Similarly, it is necessary to investigate the social uses of plastic, particularly on consumption habits in the region to determine the differentiated impact of the measures and regulations implemented so far, as well as the type of incentives that could generate behavioral changes to avoid the unnecessary use of plastic products. Also, it is key to produce scientific research on the connection between plastic pollution and the policies implemented to date to find a solution, as well as information on the general production and consumption systems in the region. In addition, it is essential to analyze how these relate to global political and economic relations. Other research to be carried out in the region relates to the climate crisis and the life cycle of plastic. Resources should be invested to study the trade in plastic waste in the PTO region, especially the illegal trade already alerted by international authorities.

On the other hand, given the environmental threat posed by the presence of plastics, microplastics and nanoplastics in the region's bodies of water, it is vital to obtain information on their concentrations in territorial rivers and seas, in the marine food web and in fishery products, in order to establish the routes of exposure and bioavailability that involve both marine ecosystems and organisms as well as humans (Andrady, 2017; Li et al., 2015; Rochman et al., 2015; Van Cauwenberghe and Janssen, 2014; Barboza et al., 2018). The results of this type of research should be used to generate regulations regarding concentrations that affect human health and appropriate pollution prevention strategies in Costa Rica, Panama, and Colombia.

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