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Review

Plastic Pollution, Waste Management Issues, and Circular Economy Opportunities in Rural Communities

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Citation: Mihai, F.-C.; Gündoğdu, S.; Markley, L.A.; Olivelli, A.; Khan, F.R.; Gwinnett, C.; Gutberlet, J.; Reyna-Bensusan, N.; Llanquileo-Melgarejo, P.; Meidiana, C.; et al. Plastic Pollution, Waste Management Issues, and Circular Economy Opportunities in Rural Communities. *Sustainability* **2022**, *14*, 20. https://doi.org/10.3390/su14010020

Academic Editor: Elena Cristina Rada

Received: 24 September 2021
Accepted: 15 December 2021
Published: 21 December 2021

Abstract: Rural areas are exposed to severe environmental pollution issues fed by industrial and agricultural activities combined with poor waste and sanitation management practices, struggling to achieve the United Nations' Sustainable Development Goals (SDGs) in line with Agenda 2030. Rural communities are examined through a "dual approach" as both contributors and receivers of plastic pollution leakage into the natural environment (through the air–water–soil–biota nexus). Despite the emerging trend of plastic pollution research, in this paper, we identify few studies investigating rural communities. Therefore, proxy analysis of peer-reviewed literature is required to outline the significant gaps related to plastic pollution and plastic waste management issues in rural regions. This work focuses on key stages such as (i) plastic pollution effects on rural communities, (ii) plastic pollution generated by rural communities, (iii) the development of a rural waste management sector in low- and middle-income countries in line with the SDGs, and (iv) circular economy opportunities to reduce plastic pollution in rural areas. We conclude that rural communities must be involved in both future plastic pollution and circular economy research to help decision makers reduce environmental and public health threats, and to catalyze circular initiatives in rural areas around the world, including less developed communities.

Keywords: plastic pollution; waste management; circular economy; rural areas; Sustainable Development Goals (SDGs); microplastics; macroplastics; open burning; illegal dumping

1. Introduction

Rural lands and rural populations are the main providers of food and resources for the ever-expanding urban areas. At the same time, rural communities around the world are facing serious environmental challenges related to climate change, biodiversity loss, and plastic pollution of the natural environment. Plastic pollution is less studied and there has been limited focus on this issue in rural communities compared to urban areas. Degradation of the rural environment through linear economy mechanisms (fossil fuels industry, resource depletion, intensive agriculture, waste pollution) combined with climate change effects (natural hazards) leads to poverty, depopulation, and marginalization of rural areas around the world [1]. These areas are also vulnerable to critical threats such as famine, water crises, illnesses, land degradation, or conflicts. Rural areas must cope with such cascading events in the context of climate change [2] and unequal access to services and development opportunities [3]. The United Nations' Sustainable Development Goals (SDGs) aim to reduce such threats by 2030 [4]. However, rural communities are often lacking basic services such as waste and sanitation management services, particularly in low- and middle-income countries [5,6]. At the global level, 1.9 billion people lack access to regular waste collection schemes in rural areas [7] and waste management infrastructure is underdeveloped [8], resulting in domestic plastic pollution leakage into the natural environment.

Cheap plastic packaging materials are accessible to rural communities and even to remote villages [9]. Plastic pollution covers a wide spectrum of natural and semi-natural habitats that are found in rural areas, including coastal and island communities, threatening SDGs #14 (Life Below Water) and #15 (Life on Land). Key economic sectors such as agriculture and rural tourism are already affected by plastic pollution. An efficient rural waste management sector needs to be developed in order to reduce the increasing plastic inputs from surrounding urban areas and curb mismanagement of rural waste in line with SDG #12 (Sustainable Production and Consumption).

At the global scale, estimates of inadequately managed plastic waste range from 90 to 95 million metric tons (MT) [10] to 60 to 99 MT [11]. According to the authors, the more recent estimate by Cordier et al. [10] is likely conservative, given the large amount of plastic waste produced and potentially leaked into the natural environment. A recent global model argues that more than 1000 rivers account for 80% of global annual plastic emissions, ranging between 0.8 million and 2.7 million MT per year [12]. Rural areas' contributions to global plastic pollution are still unknown and difficult to assess in the context of limited rural waste statistics at national and subnational levels.

Plastic pollution generated by large cities affects nearby rural communities through the air–water–soil nexus [13]. Rural domestic inputs consist of uncontrolled landfills and wild dumps [14], illegal dumping on lands [15], or open burning practices [16]. Domestic, agricultural, and industrial activities feed macro- and microplastic (<5 mm in size) pollution of freshwater bodies in both urban and rural areas, in addition to regular organic contaminants loads. However, data availability on plastic pollution is scarce for rural lakes and rivers [17] and also for agricultural soils. The illegal trade of plastic waste is an additional threat to the environment and rural communities due to limited plastic waste processing facilities of importing countries from Eastern Europe, Turkey, South-East Asia, or African destinations following the Chinese ban on plastic waste imports [18]. Therefore, with this review paper, we aim to provide a holistic analysis of the plastic pollution dimension in rural communities based on key stages such as (i) plastic pollution effects on rural communities, (ii) plastic pollution generated by rural communities, (iii) the development of the rural waste management sector in low- and middle-income countries in line with the SDGs, and (iv) circular economy opportunities to reduce plastic pollution in rural areas. This paper also reveals the current knowledge gaps related to rural plastic pollution, rural waste management, and circular economy opportunities relevant to rural communities.

2. Materials and Methods

This review examines rural plastic pollution issues around the world using a "dual approach" considering rural communities both as *plastic pollution destination sites* with associated public health threats and as *contributors* to plastic pollution leakage into the natural environment (through the water–air–soil pollution nexus), as shown in Figure 1. Plastic pollution of the natural environment is gaining attention through multi- and inter-disciplinary approaches and perspectives. Our work highlights the significant knowledge gaps regarding rural communities' challenges in managing this environmental threat. Despite the fact that plastic pollution is an emerging research field, few studies concerning plastic pollution and plastic waste management involve rural communities (i.e., [19,20]). Therefore, proxy analysis of peer-reviewed literature related to macro- and microplastic (MPs) pollution and rural waste management deficiencies in different geographical areas is required in this paper to provide a comprehensive analysis of current knowledge gaps at the global scale and outline future research perspectives with a focus on rural communities. Figure 1 reveals the stages (Sections 3–5) of this new "dual approach" analysis with associated subsections related to plastic pollution and rural waste management challenges around the globe. The role of a circular economy paradigm is highlighted to divert rural plastic waste from natural environments fed by current linear economy mechanisms and poor rural waste management facilities.

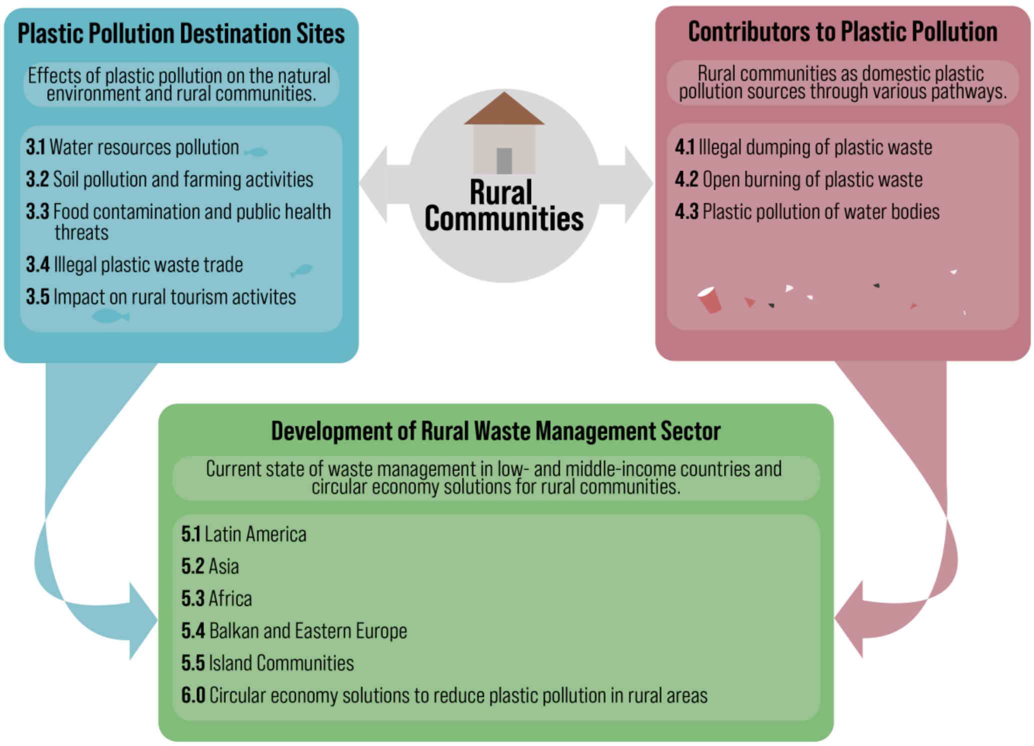

Figure 1. Plastic pollution and conceptual framework of rural environment and communities examined through a dual approach. This paper considers rural communities and environments as both plastic pollution destination sites (Section 3) and contributors to plastic pollution (Section 4). Based on this dual approach review, we provide further information on the rural waste management sector in various parts of the world (Section 5) and potential circular economy solutions to reduce rural plastic pollution (Section 6).

In Section 3, the effects of plastic pollution on the natural environment and rural communities are broken down into five critical environmental and socio-economic subtopics such as water source pollution with micro- and macroplastics (Section 3.1), soil pollution and farming activities threatened by microplastics (Section 3.2), food contamination and public health (Section 3.3), the illegal trade of plastic waste feeding pollution in rural communities (Section 3.4), and the impact of plastic pollution on rural tourism activities (Section 3.5).

In Section 4, rural communities are examined as domestic plastic pollution sources associated with the lack of waste management practices around the world, resulting in illegal dumping of plastic waste (Section 4.1), open burning of plastics (Section 4.2), and plastic pollution of freshwater and marine environments (coastal communities) fed from domestic and agricultural sources (Section 4.3). Figure 2 provides the main plastic pollution contamination routes fed by domestic waste, tourism, agricultural application, fishing, and waste imports. These routes are associated with uncontrolled disposal options in the context of underdeveloped rural waste management infrastructure (open burning, burying, open dumps) that pollute the soil–air–water nexus. Future studies need to better identify the magnitude of plastic waste flows in rural communities and to investigate the interactions between terrestrial, atmospheric, freshwater, and marine contamination in rural regions.

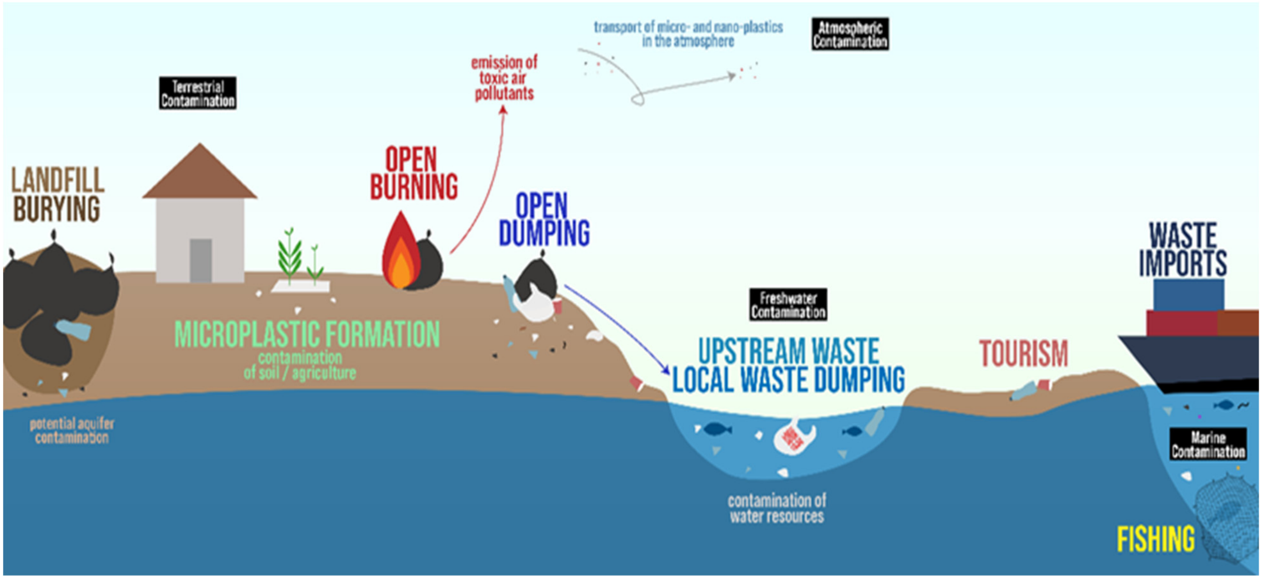

Figure 2. Overview of rural plastic pollution contamination in the terrestrial, atmospheric, freshwater, and marine environments. Sources of plastic pollution in rural environments include landfilling, burying, open burning, open dumping, local waste dumping, waste imports, tourism, agricultural application, and fishing. Additional pathways for the distribution of plastics in the environment include upstream waste and transport in water and air from nearby areas.

In Section 5, the role of rural waste management sector is highlighted as a key factor to reduce domestic plastic pollution sources at the downstream level. This stage includes major geographical areas with a particular focus on low- and middle-income countries from Latin America, Africa, Asia, Balkan and Eastern Europe, and island communities. In such regions, rural populations are not fully covered by waste collection services and/or waste management infrastructures are poor, and the collection capture of domestic plastic waste flow is low. Additionally, these regions are exposed to illegal traffic of hazardous waste, including plastic materials from high-income countries. However, even rural communities of high-income countries are facing fly-tipping or illegal dumping of plastic waste due to gaps in law enforcement, collection efficiency, and irresponsible behavior of residents or economic agents. The need for a global alliance on waste management is argued for island communities due to their particular geographical and socio-economic challenges associated with their isolation. Such an alliance could bring all island communities under the same agenda to promote sound waste management practices and to combat the plastic waste crisis.

In Section 6, circular economy opportunities for rural communities are highlighted based on literature review and supported by organizations with global expertise in this sector (i.e., WasteAid UK). Lessons learned from projects implemented by such organizations in less developed rural communities need to be further developed and adjusted around the world. Therefore, the dual approach of this review paper provides new insights into rural waste management challenges and circular economy opportunities under the emerging plastic pollution crisis.

3. Plastic Pollution Effects on Rural Communities

3.1. Water Resources Pollution

Plastic pollution in rural water resources is understudied and often overlooked. Despite a lower population density, macroplastic (>5 mm) and microplastic (<5 mm) pollution is a common problem in rural areas owing to a lack of formal or informal waste infrastructure [21,22]. This often results in solid waste dumping on land and in water bodies, which is a common source of microplastics into the environment, as well as the open burning of plastic waste [14]. Plastic waste can, directly and indirectly, impact the quality and stability of water resources. Plastic pollution in macro- and microplastic forms may transport endogenous [23] and exogenously associated chemicals (i.e., HOCs and metals) [24,25] and serve as surfaces for the development of the microbial "Plastisphere" [26,27]. Floatable plastics can also influence the quality of water resources by increasing the likelihood of regional flooding. Flume experiments and observations of urban plastic waste found that blockage of trash racks occurs at higher rates with plastic pollution than organic material [28]. The Rwanda Environment Management Authority cited plastic bags as contributors to regional flooding and decreased agricultural productivity [29]. Flooding is associated with increased incidences of water contamination, which can impact water resource quality [30].

Rural water resources may vary regionally and include surface and groundwater, in addition to processed water in tanks or bottles. The storage, acquisition, and quality of water resources will likely have an impact on the prevalence of plastic contaminants. As of 2017, 2.2 billion people worldwide were reliant on unsafely managed water resources, which includes improved sources off-premises, unprotected wells and springs, and untreated surface water from lakes, ponds, rivers, and streams [31] which may be susceptible to plastic pollution dumping. At least 15% of the United States population is reliant on untested water systems, such as shallow wells, that are more susceptible to contamination from outside sources [32] and potential infiltration of nano- or microplastics. Diverse and variable sources of water are used globally. The population in the rural Bukhar-Zhyrau district in central Kazakhstan primarily obtains drinking water from groundwater through both centralized sources, such as tap water and standpipes, and decentralized sources, such as boreholes and wells. Additional sources include tankered water and open source water from springs, rivers, or lakes, in addition to occasional bottled water usage during water shortages [33]. The consumption of plastic bottled water is expected to increase in rural areas where tap water resources are limited under rising temperature conditions [34]. The vulnerability of water resources to plastic pollution varies based on local conditions, particularly the influence of water treatment.

The prevalence of plastics in drinking water is largely dependent on the degree of water treatment. Research conducted on the presence and characterization of microplastics in raw and treated drinking water from treatment plants within the Czech Republic found that whilst treatment removed microplastics >100 µm, they were inefficient at removing the smaller size ranges, particularly <10 µm [35]. Similarly, although the treatment of river water reduced the average microplastic concentration from 330.2 particles L^{-1} to 105.8 particles L^{-1}, a significant number of microplastics remained in the drinking water of the Sinos River in Southern Brazil [36]. The high proportion of fibers suggests that washing machine effluent may be a significant source of microplastics in the water source. However, formal water treatment is less common in rural areas [31]. Thus far, identified sources of plastic in drinking water include macroplastic pollution in freshwater resources, the release of microplastics from product packaging, such as polyethylene terephthalate bottles, and sources along the water supply chain [37–40]. A study investigating the presence of microplastics >100 μm in globally sourced bottled water found an average of 10.4 microplastics L^{-1}, with fragment (66%) being the most common morphology [41]. However, the majority of studies conducted on drinking water focus on treated sources of water [42] rather than untreated water sources, such as private wells.

Open source water is more susceptible to plastic contamination from upstream urban sources, inadequate waste management in nearby rural areas, and disposal of sanitary waste. For example, Treilles et al. [43] estimated that separate sewer systems of Greater Paris may discharge 8–33 tons of plastic per year. Only 33% of the population in low- and middle-income countries have sewer connections that would partially remove macro- and microplastics from treated effluent before releasing it into the environment [44]. Instances of flash flooding associated with extreme hydrologic events increase the likelihood of floatable plastic contamination, as seen in rural mountain rivers discharging into the Izvoru Muntelui lake in the Eastern Carpathians [19].

Water resources used for irrigation can become contaminated with plastics (micro and macro) and other mismanaged waste. Sulaeman et al. [45] performed a survey of trash in irrigation canals and rice fields in urban Indonesia. This research was based on farmers' observations of trash near their farmland using the Irrigation Rapid Trash Assessment (IRTA) method. Observed trash in the irrigation network was predominantly plastic items (52%), mainly plastic bags. Plastic trash in the irrigation system increases the time needed for operation and maintenance of irrigation waters and adversely impacts the quality of water used for irrigation, and social conditions between farmers and irrigation officers [45]. Water resources surrounding agriculture and farmland can become further contaminated with plastic waste from the use and improper disposal of plastic materials used in agricultural practices [46–48]. Microplastic particles have been found variously detected in irrigation networks alongside other contaminants including pesticides and pharmaceuticals [49] and via such networks have been spread across agricultural lands [50]. Although irrigation wastewater cannot account for all the microplastic spread into agricultural soils, with mulching also a significant factor [51], the spatial correlations between microplastic pollution and wastewater treatment and effluent have been reported globally [52].

Though urban areas are a focus for plastic pollution research, downstream rural areas and the scarcity of rural waste management programs makes these areas a potential hot spot for plastic pollution. It is essential that further research characterizes the impacts of rural plastic pollution on potable and irrigation water resources.

3.2. Soil Pollution and Farming Activities

Rural land, particularly agricultural soil, is highly susceptible to microplastic pollution. Agroecosystems are imperative for food security and biodiversity [53] and have progressively suffered stress due to climate change and increased populations. The potential additional stress caused by the presence of microplastics in soils requires understanding to assess its impact on rural communities, global food production and the environment. With rural communities and agricultural areas, in particular, being dependent on the land, the presence of pollutants, such as microplastics, has the potential to negatively impact those living and working in rural environments.

The FAO [54] outlines the importance of healthy soils and how pollution can lead to high economic costs due to a decrease in crop yields and crop quality. The transfer of pollutants to groundwater, flora and fauna, and ultimately to the food chain will also affect the welfare of those living in these areas [54]. Currently, there is limited research on the actual impact of plastic pollution on rural communities, but studies on terrestrial microplastics provide us some insight as to the possible effects. This section will outline the current knowledge in microplastic soil pollution and identify gaps in knowledge which should be focused on to better understand and mitigate the effects of this pollutant on rural communities.

Current knowledge of sources of microplastic pollution in agricultural soils indicate they are abundant, varied, and are influenced by land use and farming activities. It is possible to categorize the sources of microplastic to rural soils into the following:

(i) Application of microplastics through farming activities, including the use of sewage sludge [55,56], compost products [57], and irrigation with wastewater [58], all of which contain microplastics;
(ii) Degradation of macroplastic items into microplastics from farming activities, such as plastic mulching films and greenhouse coverings/polytunnels used for crops [59,60];
(iii) Indirect application of microplastics via other activities such as open burning of plastic waste [16] and washing of clothes [61]; and
(iv) Microplastic transfer from other environmental compartments and locations, such as freshwater bodies when flooded, and tire/brake and paint particulates from roads [62,63].

In agroecosystems, farming activities such as application of sewage sludge and use of mulching film and irrigation water have been found to be linked to microplastic abundance. Widespread application of sewage sludge from wastewater treatment plants as fertilizer is seen as advantageous to crop growth and economically viable in many developed countries. It has been estimated by Nizzetto et al. [64] that 63,000–430,000 (Europe) and 44,000–300,000 (North America) tons of microplastics are added to farmlands every year. In countries where sludge application is higher, for example, in the U.K., the accumulated microplastic pollution would also be elevated. Later estimates of microplastic amounts being applied to German agricultural land via organic fertilizers from biowaste plants are between 35 billion and 2.2 trillion microplastic particulates per year [57]. This is likely to be a significant underestimate as it only accounts for particles >1 mm in size. In Eastern Romania, the application of treated sewage sludge or compost obtained from urban biowaste treatment plants on agricultural lands is not widespread, but the problem of microplastic presence in rural soils is not yet investigated despite the deficiencies of waste and wastewater management practices in smaller urban areas and rural regions [65].

The use of plastic films (mulching) and plastic sheeting in polytunnels and greenhouses can improve crop production and quality, yet the large amounts of plastic film, which are difficult to remove, may be left to degrade after harvesting, forming a significant proportion of microplastic pollution in soils. This could be another key plastic pollution source in case of rural regions in addition to household waste and wastewater flows. Around 54% of farmers from rural China think that plastic film could pollute the environment based on a survey of 2025 households in five provinces [66]. Specific environmental regulations are necessary at the village level to stimulate local mulch recycling systems [67]. Agricultural waste management practices, including pesticide packaging, coupled with environmental awareness of farmers must be improved in rural regions.

Microplastics may be retained in soil for a long time; for example, Ohtake et al. [68] estimated it would take 300 years for complete degradation of a 60 μm thin LDPE layer. This is likely to have long-term effects such as promoting soil degradation and water repelling. It can be argued that such a reduction in soil quality is likely to impact rural communities economically due to crop yield reduction and lower quality crops. This is well understood for other soil pollutants but currently not quantifiable for microplastic pollution [69].

It can be argued that reduction in soil quality in this manner is likely to directly impact rural communities economically due to crop yield reduction and lower quality crops. This is well understood for other soil pollutants, but currently not quantifiable for microplastic pollution. Other sources of microplastics in rural soils are dependent on local cultures and activities, water supplies, and waste management status in urban and rural municipalities. Areas where illegal dumping/burning of waste are more prolific are likely to lead to increased microplastic pollution in soils (further described in Section 4.1). In rural regions, such as farming areas of southwestern China, village wastewater from clothes washing may be discharged directly into small ponds and then used as a water source for irrigation [61]; although this wastewater will not contain as many microplastics as that from municipal wastewater treatment plants, it will still be a continual contribution to the pollution levels.

Microplastic pollution within soils is dynamic, with the pollutant moving between environments readily. As described in Section 3.1, microplastics can enter waterways from soils and vice versa. Soil erosion of arable land has been shown to readily transport MPs from soil to water [70], and it is sensible to assume that this is a two-way transfer. Scheurer and Bigalke [71] propose that diffuse aeolian transport is also a likely mechanism for the wide distribution of microplastics in soils, including those in remote locations. Vertical transport in soil is also an area of interest. The presence of microplastics in topsoil vs lower layers of soil may differ due to farming practices [61] and harvesting [72]. Zhang and Liu [61] found no difference in the abundance of microplastics in surface layers (0–5 cm) and the lower layer (5–10 cm) likely due to tillage practices under the intensive cropping system used in the sampling area. In contrast, Weber and Opp [73] found greater abundance of microplastics in topsoil than layers deeper than 30 cm. The deepest layer in which MPs were found in this study was 75–100 cm. Vertical distribution of microplastics to these lower layers has been suggested as being due to preferential flow paths bioturbation [73] and earthworms as transport agents [72]. This dynamic movement within soil and between soil and other environmental compartments is still relatively unknown and further research is needed in this area. Therefore, the role of agricultural practices in spreading microplastics in rural lands must be further investigated.

Although estimates of microplastic additions to soil from various sources help to understand the amount that may be present, there have been limited studies actually sampling and quantifying this pollutant to understand its geospatial distribution. The potential risks to rural communities associated with microplastics in soils cannot be sufficiently assessed unless actual concentrations of this pollutant are known. Previous soil studies include floodplains in Switzerland [71] and Germany [73], Chinese soils including coastal [74], vegetable farmland [75], rice–fish co-culture farmland [76], cropped areas and an established riparian forest buffer zone at Dian Lake [61], agricultural soils in Chile [77] and Tunisia [78], soils from industrial areas in Sydney, Australia [79], and soils from fields in Spain [55]. These studies found microplastics in all recovered samples, with fibers being the predominant morphology. Associations such as greater microplastic abundance being linked with the presence of higher concentrations of mesoplastic waste (5 mm–2.5 cm size), increased local population [71], the application of soil amendments such as sewage sludge [77], and irrigation with wastewater [61,78] have been found. These studies suggest that rural lands around the world are exposed to microplastic pollution and that the impact on rural communities should not be ignored.

Since 2016, there has been an increase in studies investigating the impact of microplastics on terrestrial flora and fauna and soil properties.

Studies on the impact of microplastic exposure have focused primarily on detritus feeders such as earthworms [80–82]. These studies indicated that mortality rate was higher and growth rate lower in worms exposed to higher concentrations of microplastic [80] and that microplastics can cause gut damage [81]. Other biota investigated include springtails [83], snails [84], and soil nematodes [85], all of which indicate negative effects from being exposed to microplastics.

Studies on the effect of microplastics on plants are even rarer, with only wheat [86,87], spring onions [88], tomato plants [89], broad bean [90], and maize [91] being studied. These studies reported delayed and diminished fruit production [89], reduced shoot and root biomass [91], alterations in total plant biomass and root traits, and reduced plant growth [87] at both vegetative and reproductive stages [86]. For people living in rural communities who are reliant on crops for their income, these studies highlight how microplastics may negatively affect their livelihoods by reducing crop production. It is believed that the presence of microplastics alters soil characteristics such as its structure, water holding capacity, and microbial communities, and that microplastics are, in part, responsible for crop-reducing effects [87,88]. Moving forward, there is a need for further research in all aspects of microplastics in soils. Figure 3 outlines these requirements and how they link to improved knowledge and other benefits such as improved design of ecotoxicological studies, better quantification of MPs, and better quality risk assessments.

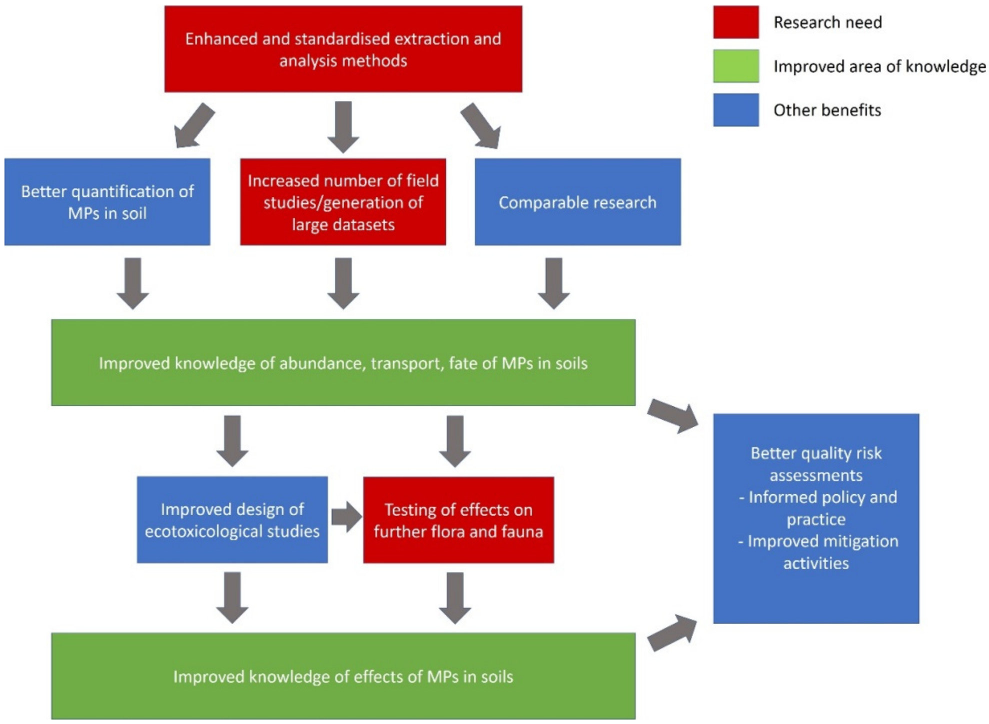

Figure 3. Future research needs in microplastic pollution in soils and their subsequent benefits.

The need to increase research in the quantification and source of microplastics via widespread sampling of agricultural and other rural soils has been expressed in multiple studies [82] and would better inform ecotoxicological studies. Currently, microplastic concentrations used in these studies can vary, for example, 7%, 28%, 45%, and 60% dry weight of polyethylene [80] and 62.5, 125, 250, 500, and 1000 mg/kg soil dry weight of polyethylene [81], and are not likely to reflect actual amounts in the environment. A better understanding of the characteristics of microplastics found in agricultural soils would also be beneficial for these ecotoxicological studies.

For example, some studies solely used plastic pellets as the source of pollutants [81], but they have been found from the limited field sampling studies conducted to not be a common form of microplastics in soils, particularly where irrigation water and sewage sludge have been applied. It is understood that waste water treatment plants' outputs contain predominantly fibers [56,92] and as such should be the main form used in ecotoxicological-based studies.

The limited studies sampling soils in rural environments may be due to the difficulty in extracting microplastics from this complex matrix, which is rich with soil organic material [58].

It is only recently that extraction protocols specifically for soils have been developed and tested [93], but these are still not standardized, and many are expensive and time consuming. More recently, emerging technologies such as hyperspectral imaging of microplastics in soils [94] and the development of Easylift® tape for recovery and sequential analysis of microplastics which could be used in soil sampling [95] may lead to improved detection and standardization of approaches. The need for improved data on terrestrial microplastics, particularly in soils in rural locations, is imperative for creating accurate risk assessments and improved mitigation activities. Such data need to be collected from a range of agricultural activities and to cover different rural regions around the world. Circular mechanisms such as wastewater reuse, sewage sludge, and compost application on agricultural lands need to be further investigated and adjusted in terms of microplastic pollution sources for rural soils.

Therefore, a wider impact analysis of terrestrial microplastics on rural regions needs to be addressed in order to reveal the potential threats related to soil, water, the agri-food sector, and human health at both the local and regional levels.

3.3. Food Contamination and Public Health Threats

In 2020, food packaging was the most prominent plastic usage area, comprising 39.6% of total plastic production in Europe [96]. Food packaging consists of plastics and combinations of material, e.g., other plastics, metals, paper and board, glass, adhesives, and coatings. In addition, plastic packages may contain residues of solvents used during their manufacture and unintentional substances, such as impurities, oligomers, or degradation products.

Development of retail industries in most urban areas increased the accessibility of surrounding rural communities to plastic-packed food items. The shift of rural residents' behavior to a plastic consumption culture raises environmental and public health concerns. However, such concerns are more applicable in metropolitan areas or peri-urban regions. These rural municipalities have more urban characteristics in terms of infrastructure and functionality compared to distant and remote communities, and they may be more reliant on subsistence agriculture.

Therefore, rural–urban interactions must the further studied in terms of plastic waste flow related to agri-food industries and domestic use of food plastic packaging materials to reveal the impact of plastic pollution on public health in various community types (urban, peri-urban, rural, touristic resorts, remote communities).

Groh et al. [23] stated that there are 906 chemicals likely associated with plastic packaging and 3377 substances that are possibly associated. Among the 906 chemicals associated with plastic packaging, 63 chemicals are considered hazardous for human health and 68 chemicals for the environment according to the harmonized hazard classifications assigned by the European Chemicals Agency (ECA) under the Classification, Labelling, and Packaging (CLP) regulation implementing the United Nations' Globally Harmonized System (GHS) [23]. Moreover, seven are classified as toxic and fifteen as endocrine-disrupting by the European Union [23]. The use of composite materials, including plastic, as food contact materials may cause risks. The risk posed by packaging is mainly associated with the chemicals used to make plastics and the additives that give them desirable qualities, including highly hazardous compounds. These hazardous chemicals in plastic packages can enter products such as food, cosmetics, or the environment after reuse, disposal, and recycling.

All types of plastic polymers can contain additives and different kinds of hazardous chemicals. These chemicals and additives can be listed as agents (antifogging, reinforcing and antistatic, blowing, nucleating, dehydrating), colorants/pigments, fillers, lubricants, optical brighteners, stabilizers, antiacids, antimicrobials, antioxidants, chain-breaking, light screening, heavy metals, and UV absorbers. All of these chemicals create the migration risk to food [97,98]. For instance, bisphenol-A (BPA) and its analogues are used as heat stabilizers and antioxidants to improve the effectiveness of metal stabilizers in plastics such as polyvinyl chloride and polycarbonate. Wang et al. [99] reported that BPA used in polyvinyl chloride could migrate in food with higher concentrations than the European Union specific migration limit [100].

Rural inhabitants from coastal rural communities could also be susceptible to plastic pollution through fishing and aquaculture industries. Alp and Yerlikaya [101] investigated seafood samples packed in plastics (polypropylene and polyvinyl chloride), cans, and glass bottles to determine the time-dependent migration of phthalate esters which are used to improve the flexibility, durability, and elasticity properties of plastics. They reported that all packaging materials have an active role in the migration of phthalate esters into seafood [101].

The risks posed by using plastic in food packaging are not limited to the migration of associated chemicals to food. Food packaging can also play a significant role in the contamination of food by micro- and nano-plastics. Microplastic could have different sizes ranging from 1–5000 μm [102]. According to the current definitions, the smaller particles can be specified as nano-plastics that range from 1–100 nm in size [103]. Several studies mention that newly manufactured plastic food containers and plastic packages can also play a significant role in human exposure to unintentionally produced microplastics [104,105].

Micro- and nano-plastics in food can also result from extensive plastic pollution in the environment. A significant proportion of the available data on microplastic pollution in the environment is on the marine environment, but freshwater and terrestrial ecosystems and the atmosphere are also contaminated. For example, there are 46 Brazilian freshwater fish species known to have ingested plastic [106]. Microplastics transfer through all trophic levels of the marine ecosystem, starting from plankton [107] to fish [108], bivalves [109], and crustaceans [110], hampering health, feeding, growth, and survival of the marine organism.

Due to their resemblance to a natural food source or filter-feeding, it can be said that the ingestion of microplastics is intentional or non-selective [111]. Consuming seafood contaminated with microplastics subsequently passes the accumulated pollutant through trophic transfer, which may cause adverse health effects among consumers, especially in children and pregnant women [112]. The effects of microplastics on the global ecosystem, human health, and wildlife may occur in any way. Although the amount of microplastic pollution in the environment is predicted to increase dramatically shortly, the adverse effects or toxicity of this pollution on human health and the ecosystem are still not fully understood [113]. In this regard, rural communities must not be excluded from future studies. Subsistence agriculture prevails in many rural regions of the world, and therefore, food resource contamination with microplastic from marine and terrestrial environments could pose serious threats to rural populations.

In low-income developing countries, the marketing and distribution rate of foods individually packaged with plastic and suitable for fast consumption are increasing. In Asia and Africa, where low-income countries are concentrated, the plastic waste generated with this increasing trend is exacerbated by the distribution of products in disposable plastic packaging for low-income families who buy most of their food in small, daily portions. Thus, low production standards cause these foods to be contaminated with associated chemicals or micro- and nano-plastics.

In addition, plastic wastes pollute the environment due to insufficient waste management infrastructure, which creates the risk of increasing plastic-related health problems. Although there is some attention given to improving waste management in densely populated urban centers of Asian and African countries, much less is known about the risk posed by plastic contamination in food resulting from both plastic packaging usage and plastic pollution in the environment.

In former soviet-countries, glass recycling facilities declined since the 1990s. This encouraged the use of plastic packaging materials as replacements for glass packaging in the agri-food sector. The agri-food sector's reliance on plastic packaging materials combined with easier access of rural population to plastic goods has fed rural plastic contamination. There are significant knowledge gaps in how rural communities are affected by the plastic pollution problem and the potential risks posed by the massive usage of plastic in food packaging.

3.4. Illegal Plastic Waste Trade

With their unique properties, plastics have become an essential global commodity and are now used in almost all compartments of life. This makes it easier for plastic to become waste and causes the generation of large amounts of waste, including in rural communities around the world. However, despite the limitations due to its content, recycling has been proposed as an alternative for the disposal of plastic waste.

Implementing policies that encourage recycling plastic waste has also led to the formation of a large and continuously expanding business sector subject to international trade globally. By 2018, China imported a cumulative 45% of the world's plastic waste, making the global plastic waste market heavily dependent on the Chinese recycling industry. However, in January 2018, when China introduced new import restrictions (national sword) on 24 types of solid waste, including plastic waste, the direction of the global waste trade suddenly turned to many different countries [114,115]. As a result, a high volume of plastic waste exports has been observed since January 2018, especially to countries such as Malaysia, Indonesia, Turkey, Hong Kong, and the Philippines, as shown in Figure 4 [116]. Malaysia started to take actions to reduce the import of plastic waste from developed countries [117]. As a result, rural regions, including touristic resorts, are affected by a surplus of unmanaged plastic waste in addition to domestic sources.

Figure 4. Leading exporters and the destination of the exported plastic waste (kg) in 2020 (Source: [116]).

Shipments of plastic waste in the intra-European market have also increased, especially towards Central and Eastern Europe. For example, rural regions of Romania are predisposed to illegal dumping practices of poor-quality recyclable plastic waste received from abroad that cannot be processed in recycling facilities. In fact, environmental authorities from Romania were facing serious challenges in recent years regarding the illegal plastic waste trade via the Constanta-Agigea port or from terrestrial borders [118].

Overall, the increasing volume of imported plastic waste will likely affect the recycling rates of household waste and create a waste surplus region. This surplus could be disposed of on rural lands if existing waste management facilities are overwhelmed and/or law enforcement and monitoring is neglected.

Although the global plastic waste trade volume has shown an increasing trend over the historical period, it has shown a fluctuating course in general.

Accordingly, the international trade of plastic waste has increased rapidly since 1990, experiencing a period of rapid development from 2006 to 2016, and a decline after 2016 [114]. Global imports and exports fell sharply after China announced that it would ban plastic waste imports after 2017. On the one hand, countries are looking for new solutions to overcome this situation. It has been reported that illegal activities also occurred during the process. Interpol [119] reported that the difficulties in monitoring the processing of plastic waste in both exporting and importing countries open the door to the emergence of criminal activities in the plastic waste sector in terms of both illegal trade and illegal waste processing. Indeed, an indicator of these illegal activities can be shown that the requests from South and Southeast Asian countries to return illegally shipped plastic waste containers to origin countries have increased since 2018. Similarly, an increasing number of media reports showed that plastic waste exported to Turkey, Malaysia, Indonesia, and the Philippines is illegally dumped and burned in open areas [120–123]. Illegal activities in the plastic waste trade mainly happen in the form of mixing plastic wastes with different types of waste on the black market, labeling hazardous plastic waste as non-hazardous, or classifying plastic waste as second-hand products. When plastic waste is classified with labels that do not reflect its actual content, it is no longer subject to international waste regulations. It can be sent to developing countries, although the scale of this remains unknown. This key issue must be further investigated because non-recyclable plastics feed illegal dumping or open burning practices in peri-urban and rural communities of destination countries.

Illegal activities are not necessarily associated with waste management regulations. It is also reported that serious illicit activities such as tax fraud or money laundering can occur in the plastic waste trade [119,124].

Illegal dumping of plastic waste that has been displaced between countries, both legally and illegally, is a common problem. Dumping and burning plastic at unregulated sites pose a chemical threat to human health and the environment.

Rural regions are prone to such uncontrolled disposal practices due to a lack of or poor waste management infrastructure. Waste disposal practices common in rural communities, such as illegal dumping and burning of plastic waste, can have negative consequences on human health. Toxic chemicals such as dioxin, polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs), perfluorooctane sulfonate (PFOS), and short-chain chlorinated paraffins (SCCPs) can be released from illegally dumped and burned plastic waste. Most of these toxic chemicals in plastics are regulated by the Stockholm Convention and are known to accumulate in the environment, food, and animals [125]. Once toxic chemicals are released from plastics, they can easily enter the food chain. These chemicals expose the people residing in the vicinity of illegal plastic dumpsites. Previous studies show that most of illegal dumping sites in rural communities are relatively close to residential buildings [19,126].

Petrlik et al. [127] reported an extremely high level of dioxins in eggs collected near a tofu factory in Tropodo/Indonesia that burns mostly imported plastic wastes for fuel. Greenpeace Malaysia [120] also reported that illegally disposed shredded plastic and plastic waste (mostly imported) at various landfills in Malaysia contain a range of metals, metalloids, and organic chemicals, including persistent organic pollutants (POPs). These toxic chemicals pose a potential risk of contaminating the environment with hazardous chemicals from plastic storage, processing, or recycling [120].

After China's plastic import ban, the effect reaches far beyond the importers. Now, countries that have insufficient environmental standards will continue to carry the burden of imported plastic waste. Most of these imported plastics are being dumped in the environment inhabited by rural communities. Although a few reports show the adverse effects of illegal waste trade on rural communities, much less is known about the risk posed by burning and dumping plastic in the environment. Moreover, there are significant knowledge gaps in how rural communities are affected by the toxic chemicals that enter the food chain by burning plastics.

3.5. Impact on Rural Tourism Activities

Rural tourism encompasses all tourism-related activities taking place in rural areas, both on the coast or inland. Among the most common types of rural tourism are ecotourism, agritourism, and cultural tourism. From an economic point of view, rural tourism represents an important source of income for the local population, as well as an opportunity to further develop the often-lacking infrastructure that characterizes rural areas concerning their urban counterparts [128]. From an environmental and social perspective, rural tourism has the power to increase environmental conservation efforts and is a way to expand the awareness of local religious beliefs, as well as cultural traditions [129,130]. According to the United Nations World Tourism Organization [131], rural tourism plays a key role in promoting the sustainable development of the local community and will be vital to meet the Sustainable Development Goals (SDGs). In particular, it is most important for SDGs #1 (No Poverty), #5 (Gender Equality), #8 (Decent Work and Economic Growth), #9 (Industry, Innovation, and Infrastructure), #10 (Reduced Inequalities), #11 (Sustainable Cities and Communities), #12 (Responsible Consumption and Production), #14 (Life Below Water), #15 (Life on Land), and #17 (Partnerships for the Goals).

Rural areas often lack proper waste management services and separate collections of dry recyclables from organic and inorganic waste.

Reliable data on rural solid waste generation are often missing, posing an additional challenge to the scientific community and decision makers on how to best manage the waste produced in rural areas [132,133]. While life in rural areas had always been characterized by a lower waste generation due to less financial availability, further distance from many stores, and more in-house reuse and recycle [134,135] and references therein), the increase in purchasing power and the widespread availability of pre-packaged goods, even far away from urban centers, has resulted in an increase in waste generation by rural communities [8]. Therefore, rural communities in areas where waste management practices are improper and insufficient contribute significantly to the pollution of the environment and nearby water bodies [19].

In this context, where and when proper tourism planning and management does not take place, tourists' waste becomes an additional burden to the environment [136,137], without any intention by the tourists themselves, who are often not aware of the improper waste management practices in rural areas [138]. Rural tourists expect to visit pristine natural areas, with particular environmental or cultural characteristics, as these are preconceived in the collective imaginary [139,140]. Finding waste scattered on the ground or piled up on roadsides, which pollutes the pristine, natural environment tourists expect to spend their time in, will have a negative impact on their visit and potentially dissuade them from returning or encouraging others to visit [141]. The scientific literature on tourists' reactions to polluted locations has mainly focused on coastal and small island destinations, likely due to the much larger attention on plastic pollution drawn by marine environments. However, locals' and tourists' reactions are expected to be similar in the countryside and mountainous regions, where waste mismanagement and plastic pollution ruin the pristineness of the landscape.

Many studies undertaken in different locations around the world have found that tourists are less likely to visit beaches where plastic pollution is visible, resulting in significant revenue losses for tourism [141–143]. To alleviate these consequences, in some more developed tourist destinations where high-level accommodations are present, a dualism between the conditions shown in resorts and touristic areas on one hand, and those in which the local population lives, has become apparent [144]. The former category comprises thoroughly cleaned beaches and natural areas that are privately owned by the accommodations or that are visited mainly by wealthy, often international tourists. The latter, on the other hand, includes all those more highly littered areas where waste is visibly polluting the environment. A drastically different level of beach cleanliness has been observed between resort or touristic beaches cleaned by the local government and more remote, uncared for ones [144,145].

As much as the authorities and the stakeholders in the tourism sector try to keep a separation between the more thoroughly cleaned areas that attract tourists and the areas where the locals live, this separation poses difficult challenges that require investments in spatial planning. As the number of tourists increases, so does the number of accommodations needed to host them; without proper planning and the implementation of strong waste management services, these new accommodations for tourists might show them the pollution present in the surroundings, as it happened on the Vietnamese island of Phu Quoc [144].

As rural tourism represents an incredible resource for rural communities to develop further and increase their economic well-being by providing a variety of jobs to their inhabitants, particular attention must be paid to spatial planning and sustainability [131,146]. This will ensure that rural tourism provides advantages and development for the entire community, without any potential negative side effects.

4. Plastic Pollution Generated by and Discarded in Rural Communities

4.1. Illegal Dumping of Plastic Waste in Rural Areas

Worldwide, 33% of all generated waste is not collected and ends up in the environment, including rivers, lakes, and oceans [5] (. In addition, waste dumping can also affect local economies by lowering real estate values, reducing tourism, and incurring high costs with remediation activities [147,148]. One of the challenges of illegal dumping is that although it is a visible issue, the volumes and hotspots of informal dumps often remain unknown, making it difficult to mitigate, particularly in rural and peri-urban areas [149]. Plastic made of non-biodegradable organic polymers is among the most common materials found at illegal dumpsites [126,150,151]. Concerns are growing about the toxic composition and the effects of plastic pollution on the environment, wildlife, and human health. Annual global plastic production is roughly 300 million tonnes, of which less than 10% is recycled [152]. The presence of plastic in disposed waste materials has continuously increased globally over the past several decades as production and use of plastics have risen significantly [153].

Rural areas are an important contributor to plastic waste. Some 45%, or 3.4 billion people, of the world's population live in rural areas, 1.9 billion of whom lack waste collection services [7]. Illegal dumping has thus become a major challenge in the countryside. This problem is particularly prevalent in rural areas in low- and middle-income countries, where governments tend to neglect the provision of waste management services and where poor and illegal waste disposal practices become dominant [20]. Many authors have identified illegal dumping in rural environments in Central and Eastern Europe, due to lower population density, sparser road networks, and hillier topography [126,148], as well as poorer socioeconomic conditions, long distances from urban areas, and higher transportation costs, among other factors [14]. Floodplains and riverbeds, in particular, often turn into common areas for illegal dumping. Plastic pollution is a widespread environmental threat to water bodies near rural settlements, particularly those situated in mountainous regions [19]. The geography in these communities makes the waste collection, recovery, and transportation particularly challenging [154], in addition to frequent flash floods that cause waste to be carried downstream into lakes and the ocean. Similarly, island communities also face specific additional waste management challenges. Plastic waste carried by wind and rain easily ends up in rivers, creeks, and at the beach, ultimately adding to the issue of marine littering [155,156]. Even rural communities with full waste collection programs experience illegal dumping practices, due to improper behavior of residents, poor collection frequency, inadequate collection infrastructure, and sanitation fees. Some countries have a proper plastic waste collection, but no capacity to process the materials [5], in which case open burning and dumping has become an additional common practice of disposing of plastic waste.

The reasons for illegal dumping are numerous. One of the more significant factors is the shortage of funding to acquire proper equipment or employ waste workers to properly manage the increasing amount of waste, particularly in poor and rural communities with difficult access [157]. In low-income countries, widespread poverty decreases the willingness of communities to pay for domestic waste removal [158]. In addition, existing collection stations or community bins may be too far away for community members to use, causing them to dispose of their waste illegally [159]. Furthermore, lack of legislation and law enforcement can be a driver for dumping and open burning, especially if residents are aware that their actions will bear no consequences [160].

Weak public awareness about the health impacts and environmental risks associated with illegal dumping is another major issue [158]. Additionally, a lack of technical knowledge of how to implement more sustainable waste management methods can lead to illegal dumping being practiced instead [159].

The global extent of illegal dumping highlights the need to find effective and sustainable methods of waste management. Some countries, such as Australia, have been successful in adopting strategies to combat illegal dumping, including community education, clean-ups, and regulatory enforcement [161]. In other cases, rural communities, such as the Valladolid Province in Spain, had a more difficult time with legislation measures, and as soon as one illegal dump was closed, another appeared almost immediately [161].

In low- and middle-income countries, the prospect of recovering plastic materials from waste with the service of thousands of organized waste pickers is gaining momentum as an inclusive and more sustainable waste management option, also in small rural towns and peri-urban areas, which will help reduce illegal dumping [162,163]. The workforce of waste pickers could be better employed to help reduce plastic waste littering and burning in the countryside, given their knowledge and skills in resource recovery. Inclusive waste management, recognizing waste pickers as important allies in helping achieve the goals of waste reduction and recovery in locations with no environmental control, could become a key solution to the problem.

Until now, the provisional, isolated solutions implemented by countries around the world have achieved little in reducing the scale of illegal dumping [160]. Developing credible, compliance-enhancing policies to prevent illegal dumping is necessary to tackle the problem at its roots. These policies, in addition to more participatory waste governance, could also include informal approaches that focus on creating awareness and activating social norms through education and grassroots movements also reaching the countryside. There is still a significant knowledge gap in terms of best practices and successful initiatives that have proven to effectively, systemically, and sustainably curb illegal dumping of plastic. The mapping and context-specific analysis of these experiences can provide the necessary clues on what works best under specific cultural, social, and economic settings in a given environment.

4.2. Open Burning of Plastics

Open burning of solid waste is a significant source of air pollution and a common practice in many economically developing regions of the world, as well as in rural areas in both high-income and low-income countries [164]. Globally, around two billion people lack access to efficient municipal solid waste collection services and dispose of household waste typically by open burning [165]. Uncontrolled waste combustion releases emissions of black carbon (BC), commonly known as soot, which has harmful effects on air quality, health, ecosystems, and agricultural productivity. Black carbon is also an extremely powerful climate pollutant with a global heating potential up to 5000 times greater than carbon dioxide (CO_2) [166]. Similar to methane (CH_4), BC is a short-lived climate pollutant, which means that it remains in the atmosphere for a much shorter period of time than CO_2. Therefore, action to control emissions, by stopping the practice of open burning of waste, would have a significant and immediate benefit in the fight against climate change [165].

Community size is an important factor to consider when assessing waste burning patterns, as larger communities tend to have access to better waste collection services and are therefore less likely to burn waste in uncontrolled fires compared to smaller populations [167]. For example, approximately 38% of the population in Mexico live in small communities (<15,000), usually with limited or no access to waste collection services (only 55% of this fraction have access to waste collection), and rates of open burning are higher (38% dispose of their waste by burning) compared to larger communities. In contrast, 48% of the population live in cities with populations of >100,000, and in this case, at least 88% have access to waste collection and the rate of uncontrolled burning of waste is 1%. Consequently, small communities and rural areas generate a relatively modest fraction of the total solids waste in Mexico, equivalent to 12%; however, they are responsible for 79% of the waste that is disposed of by uncontrolled burning [168]. In China, Wang et al. [169] reported that much of the rural solid waste that is collected is still being dumped, buried in a ditch, or burnt illegally. Additionally, 43% of villages represented in the study reported open burning of their waste.

The amount of plastics present in rural waste streams tends to be lower compared to urban areas. However, even the presence of small amounts of these materials in waste disposed of by open burning generates very large emissions of BC. Research has been carried out to develop emission factors (EFs) indicating the grams of BC emitted per mass of waste burned for different waste fractions disposed by open burning [170] (Reyna et al. 2019). The results have shown that plastics have the highest BC EFs compared to other waste materials disposed by burning. Specifically, the highest EFs corresponded to polystyrene (53.1 g BC kg^{-1}), polyethylene terephthalate (PET) (45.7 g BC kg^{-1}), and textiles containing synthetic fibers (9.1 g BC kg^{-1}). These materials represented only a small fraction of the waste, 5–10%, but contributed up to approximately 90% of BC emissions [167]. As a comparison, the EFs for garden waste and paper and cardboard were 0.5 and 0.02 BC kg^{-1}, respectively. Data reported by Reyna et al. (2018) [170] for case study areas in Mexico using health databases provided by the authorities showed that respiratory diseases were increased in rural areas, corresponding with the increased exposure of the population to emissions from open burning of waste. This suggests a possible link between the uncontrolled combustion of waste and respiratory health. This is an interesting trend, since the incidence of respiratory diseases is typically reported to be higher in urban areas due to the increased exposure to air pollution from transport [171,172].

Access to an efficient, sustainable waste management system will probably not be achievable in the short term in many developing regions of the world, especially in rural areas. However, extending waste collection to everyone and eliminating open dumping and uncontrolled waste burning would bring immediate benefits to the local environment and the health of the population of the region, as well as to global climate change mitigation. Unless addressed, this problem is set to worsen as the disposal of waste is expected to increase by 70% by 2050. Eliminating or at least significantly decreasing waste disposal by uncontrolled burning would provide a relatively "quick win" in tackling the global climate emergency. Indeed, a dramatic reduction in BC emissions from the open burning of waste could be achieved by ending the uncontrolled burning of plastics, particularly polystyrene (PS), polyethylene terephthalate (PET), and synthetic fibers. This is true in developing countries where most uncontrolled waste burning currently takes place, but also in developed countries such as the U.K., where plastics are commonly burnt in household and public bonfires [173].

4.3. Plastic Pollution of Water Bodies

4.3.1. Microplastic Pollution of Freshwater Environments

A growing body of evidence has shown microplastics to be a significant concern in freshwaters [174,175]. However, there remains a disparity between marine and freshwater microplastic research, with the production of scientific publications relating to marine microplastics five times higher than for microplastics in freshwater ecosystems [176]. Moreover, freshwater microplastics literature is often presented as fragmentary across locations, habitats, and species [91,177].

The importance of freshwaters is well established and from the standpoint of ecosystem services, freshwaters provide a great deal of ecological, provisioning, and cultural services for local populations, particularly rural communities. From the viewpoint of plastic pollution, freshwater research has been able to add direct links from population centers to the marine environment via the transport of microplastics by freshwater rivers [178,179]. Freshwater research has also provided some alarming headlines, such as those from the Austrian Danube, in which the mass and abundance of drifting plastic items were found to be higher than those of larval fish [180]. The frequency of such headlines highlights the urgency of the microplastic topic and the need to act.

A common theme to emerge within this research area relates to the diversity of microplastic prevalence and forms which can be attributed to human activities and sources of plastic pollution within the local vicinity. For instance, spheres ("microbeads") that are typically used in scrubbing and exfoliating products were commonly sampled from the waters of the North American Laurentian Great Lakes [181], while in Lake Hogsval, a remote mountain lake in Mongolia, common microplastics types (fragments and fibers/lines) were attributed to discarded and degraded recreational and fishing products [182]. The same theme continues within freshwater rivers with predominant types and sources of microplastics linked to the specifics of human inputs, and the characteristics of the found microplastics reflect upon the local human population. In Paris, the prevalence of fibers was related to both atmospheric fallout and wastewater [183], whilst in the Thames, a significant portion of plastic debris was directly linked to discarded sanitary products [184]. Similarly, documenting the presence of microplastics in fish often reveals local sources of plastic pollution. Fibers, fragments, and films were found within the gastrointestinal tracts of Nile perch (Lates niloticus) and Nile tilapia (Oreochromis niloticus). Lake Victoria and fishing and tourism activities were speculated to be likely sources [185]. However, the ubiquity of some microplastics morphologies, such as fibers, and some polymer types, such as polyethylene and/or polypropylene, makes pinpointing plastic sources difficult.

Despite linking microplastic pollution to human activity, one area that has yet to receive much attention is the contribution of rural communities. This is because the majority of freshwaters that have been studied are large, urbanized lakes or rivers, or when more remote locales are selected, it is due to their commercial or recreational reputation, e.g., Lake Hogsval [182]. A study from Izvoru Muntelui lake in Romania found that almost 300 tonnes of plastic bottles were dumped into the lake because of seasonal flooding [19]. Rural municipalities were shown to be directly responsible for 85.51% of the total plastic bottles. Although the study did not look to quantify microplastics in the lake, the degradation and fragmentation of those bottles into microplastics would be a logical outcome. This was the case for the surface waters of northern Lake Victoria, where all detected microplastics resulted from the breakdown of large plastic materials [186]. This study specifically addressed the comparison of urban and rural contributions to plastic pollution from a set of three grouped sites: Group A, fishing and recreational beaches located within urban or semi-urban settings; Group B, fish landing beaches with trading centers within a rural setting; and Group C, riverine areas of the lake. Microplastic abundance followed the gradient of intensive human activities A > B > C and thus, as expected, the urban population created more microplastics, but rural areas were not without pollution. The two groups had similar microplastic morphology profiles (fragment > flake > filament > film > foam), suggesting perhaps the use of similar types and proportions of plastic products adjusted for population density [186].

4.3.2. Macroplastic Pollution of Freshwater Environments

Domestic sources of macroplastic pollution of freshwater environments (rivers, streams, lakes, ponds) must be further investigated in different geographical areas around the globe taking into consideration the impact on rural communities. Generally, macroplastic pollution of water bodies refers to plastic items larger than 5 mm in diameter or length. However, rural communities are facing massive plastic pollution issues or "rivers of plastics" following floods or rainy periods in upper sectors of catchments. These massive plastic pollution events, where water bodies are covered by plastic bottles and other plastic items (much larger than the 5 mm threshold for macroplastic), are caused by the lack of waste management services in rural areas or nearby cities, particularly in low- and middle-income countries.

Dams and lakes are hotspots of plastic accumulation and reveal to us the magnitude of plastic pollution in the upstream sector. For example, in the Eastern Carpathians, 290 tons of plastic bottles were collected through sanitation activities during 2005–2012 [19]. However, the magnitude of plastic pollution could be worse since not all plastics collected in the Bistrita catchment area (upstream to Lake Izvoru Muntelui) are reflected in the statistics.

Plastic pieces (2.5–50 cm, >50 cm) and plastic bottles account for 38.59% and 9.55% of macro litter items transported by rivers to European seas, respectively [187]. Plastic bottles are also found as the most identifiable plastic litter in European freshwater environments [188], as shown in Figure 5 in accordance with rural plastic pollution investigation in Eastern Carpathians [19].

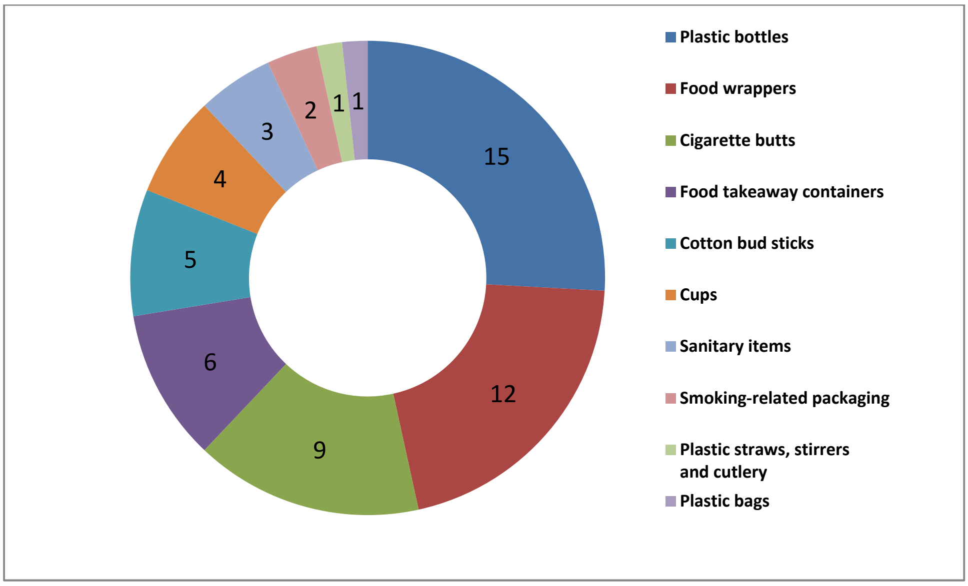

Figure 5. Top ten identifiable plastic litter items (%) found in European freshwater environments. Data source: Earthwatch Institute [188].

Food wrappers, cigarette butts, and cups are important plastic litter items that could contaminate rural environments. Most villages in low- and middle-income countries do not meet environmental regulations, and plastic pollution leakage into the natural environment is quite common [189]. Plastic wastes in rural areas have various sources such as household waste, agricultural plastic mulch, pesticide, and chemical fertilizer packaging polluting freshwater bodies [190].

Macroplastic pollution of water bodies is common in accessible mountain areas (e.g., moderate altitudes below 2000 m), where the development of human settlement networks on river and tributary valleys occurs, but with limited waste management services. Geographical barriers from mountain and hilly regions lead to improper plastic waste disposal practices in river/stream banks or floodplains prone to flash floods. In such regions, source-separated waste collection schemes must be adapted to particular features of villages. Door-to-door collection seems to be a wiser option compared to waste collection points to prevent illegal disposal activities. Alternatively, waste collection points must be sufficient to cover all villages and to avoid long distances for residents to dispose of their plastic waste into bins. Such measures must be coupled with strong awareness campaigns supported by a wide range of stakeholders (local municipalities, environmental authorities, waste service providers, NGOs, etc.). Additionally, the location of recycling and waste disposal facilities is a key issue for transportation reasons, as rural regions are prone to higher costs [191]. An additional burden is the annual and seasonal fluctuation of rural waste generation rates, reflected in plastic waste flows from one municipality to another due to various socio-economic and geographical conditions [192]. Local-scale factors are crucial in determining the extent of microplastic pollution in small streams [193] but are also important for macroplastic pollution of freshwater bodies in rural areas. Both urban and rural communities are developed along major river valleys around the world. Urban landfills and rural dumps are located in low-lying areas and flat terrains (e.g., floodplains), and represent potential plastic pollution sources of freshwater bodies. Along the Yangtze River economic belt, the ratios of waste dumping in urban, suburban, and rural areas were 5%, 10%, and 85%, respectively [194]. This river system exports the largest amount of plastic waste in the world with a median value of around 17,000 MT yr^{-1} [195]; therefore, the contribution of rural communities could be significant in the context of poor waste management infrastructure.

The proximity of the built environment to freshwater bodies (less than 1–2 km) increases the risk of pollution if there are no reliable waste management services [19]. In Poland, most illegal dumping sites are found near buildings (250–500 m and 500–1000 m), and plastics packaging materials, such as polyethylene terephthalate (PET) bottles, are one of the main waste fractions [196]. Large amounts of waste could be disposed of in or near water bodies, such as creeks near households, which are predisposed to illegal waste dumping practices [14]. Therefore, waste management facilities should be placed outside floodplain, or buffer areas between the river and floodplain must be present to better manage waste mobilization during flood events [197]. Modeling scenarios for integrated rural waste management systems are required to select a centralized, cluster, or decentralized approach [198].

The Bay of Bengal receives most plastic waste from rivers, with the Brahmaputra, Ganges, Vaippar, Vaigai, and Irrawaddy among the top 10 rivers with the highest annual riverine plastic outflows to oceans [195]. Besides domestic plastic waste, fishing gear is an important source of large river systems such as the Ganges River system [199]. Villages reliant on fishing activities must be further examined as macroplastic pollution sources for nearby river systems and to examine the impact on freshwater biodiversity [200].

To prevent and reduce plastic pollution of freshwater bodies from domestic sources, rural communities must take into consideration the following progressive steps:

(i) Provision of basic waste collection services (at least regular mixed collection system) and transport towards sanitary (at least conventional) landfills, with priority given to villages closer to freshwater bodies;
(ii) Closure of wild dumps, increased law enforcement to prevent illegal disposal of waste, and environmental awareness campaigns to educate localities;
(iii) Implementation of a centralized or decentralized regional waste management system (urban and rural municipalities) with cost-efficient operations and connection to wastewater treatment facilities;
(iv) Source-separation of dry recyclables (plastic, metal/cans, paper-cardboard, glass) in collection schemes, including by waste workers belonging to the informal sector;
(v) Access to recycling centers or seasonal collection campaigns for special waste streams which also include plastic items (e-waste, bulky waste, construction, and demolition waste, etc.);
(vi) Training for "zero-waste" activities involving local population; and
(vii) Access to deposit-refund schemes and refilling systems (e.g., plastic bottles) promoted by extended producer responsibility (EPR) framework.

Plastic pollution assessment at catchment levels must take into consideration both urban and rural localities as domestic sources [201]. Imported plastic waste from legal or illegal activities must be supervised by authorities since freshwater bodies on rural lands are exposed to dumping practices of non-recyclable or low-quality plastics.

Domestic macroplastic pollution of freshwater ecosystems by rural communities must be investigated in future studies in different geographical conditions: (i) mountain, hilly, plain, deltas, and estuaries around the world; (ii) various climate-related conditions (temperate, tropical, high altitude, etc.); and (iii) locations relative to urban areas (villages included under urban administrative area, peri-urban, metropolitan area, rural municipality, peripheral, or isolated communities). The role of tourism-related activities and agro-food industries must be further investigated as plastic pollution sources of rural environments. These approaches must be correlated with reliable regional waste management statistics (including rural waste indicators) to improve the current models and to make better predictions about the macroplastic pollution magnitude of freshwater ecosystems in certain rural regions at administrative and catchment levels.

4.3.3. Marine Plastic Pollution by Coastal Communities

Coastal communities, due to their proximity to the ocean, are inevitably a large source of plastic pollution to the ocean, especially where solid waste management services, such as the collection of household waste, presence of bins in touristic beaches, and separate collection of dry recyclables, are not available [202]. Additionally, as coastal communities rely on fishing for a large share of their diet [203], small-scale fishing businesses are inevitably contributing to marine plastic pollution with both accidental losses and intentional discarding of ropes and nets into the marine environment.

In isolated coastal communities, and even more so in remote inhabited islands, solid waste management represents one of the biggest challenges for the local population [138,204]. Packaged goods are often imported and available to the local population, but a system able to properly manage this type of waste is often not in place. Recycling and composting facilities, if present, are generally located far away [205]. This leaves communities to deal with their waste locally [202,206], most often resulting in the pollution of the surrounding coastal and marine environments. In addition to the waste generated directly from the community, coastal communities might also observe a significant accumulation of waste coming directly from the ocean, especially during storms or the monsoon season. On one hand, this poses a further challenge and burden on coastal communities, and on the other, it might discourage their efforts to stop directly disposing of litter in the ocean [206,207].

Where proper waste management services are lacking, solid waste improperly disposed of in the environment (i.e., house backyard, roadside) is picked up by wind or water streams and transported into the ocean. Moreover, it is not unusual for solid waste to be disposed of directly in the ocean [206,207]. The improper disposal of solid waste into the environment is not the only way for plastic pollution to reach the ocean.

Even in coastal communities where solid waste collection services are available, waste is often either disposed of in open dumps, where it can be picked up by the wind and transported away or discharged into rivers and the ocean through submarine pipes, with little or inexistent preliminary treatment [208].

Fishing and aquaculture activities also contribute to polluting the marine and coastal environment when fishing gear is lost or discarded at sea [207,209,210]. Jang et al. observed that in a rural coastal location in Korea, polypropylene, which is used to make fishing nets and ropes, was more abundant than at both an urban site and an aquafarm. A larger relative abundance of polypropylene in coastal waters of rural areas compared to urban areas was also confirmed by Kwon et al. [209], who also observed a predominance of expanded polystyrene, a material commonly used to float marine gear for fishing and aquaculture activities [209,211].

Tourism, on one hand, is vital for the economic development of rural coastal communities, but on the other, it exacerbates the challenges related to waste management (see Section 3.5). Although touristic destinations are generally better taken care of in terms of cleaning and visual appearance when paid clean-up services are provided by resorts or the local authorities [144,145], tourists are inevitably an important source of marine plastic pollution, and particularly so when they are not educated to properly dispose of their litter [206,212,213].

If left unmanaged, the dirtiness of some coastal areas because of tourism risks giving rise to a vicious cycle, and potentially a negative feedback loop, in which the tourist would not return to the destination due to the visibility of waste on the beach [141,142].

The negative environmental and economic effects of marine plastic pollution are visible and recognized by the inhabitants of coastal communities themselves [138,206,212]. Phelan et al. [206] observed that fishermen in remote Indonesian islands are aware of the negative consequences of plastic pollution of their fishing and seaweed farming activities, which have visibly suffered from the direct disposal and accidental leaving of plastic in the marine environment.

As population density and maritime activities are lower in remote coastal communities than in urban ones, it is likely that, despite the potential lack in waste management services, the former contribute less to marine plastic pollution than the latter. However, to answer this question, more research is needed on the contribution of remote communities to the leakage of pollution into the ocean. The first step to assess and address this issue will be to quantify and find solutions to avoid the improper management of waste, as these data are lacking for the great majority of remote areas (not only coastal) in developing countries [8,135].

5. Development of Rural Waste Management Sector in Low- and Middle-Income Countries in Line with SDGs

5.1. Latin America

Despite the advances in waste management in Latin America and the Caribbean (LAC), which is made up of 48 countries/economies [214], the region still faces many challenges due to the existence of open and uncontrolled sanitary landfills (33%) and low rates of recovery of waste fractions (<4%) in treatment of municipal solid waste [215,216]. Particular attention is required in rural areas which are exposed to severe environmental pollution problems and agricultural activities and industries installed in their surroundings. In Colombia, some remote rural beaches are categorized as "extremely dirty" due to plastic pollution [217]. These issues are in addition to the deficient practices in managing household waste and sanitation, so rural communities struggle to achieve the SDGs following the United Nations' 2030 Agenda [215].

Data from the World Bank show that in the LAC region, 85% of urban waste is collected by waste management services, while in rural areas, this percentage decreases to 30% [5]. As shown in Figure 6, the highest percentage of waste generated in LAC is organic matter (44%), followed by paper and cardboard (17%) and plastics (12%). Overall, there is an urgent need for experiment analysis of municipal waste composition and generation rates across rural communities in the region to update the current flows of plastic waste.

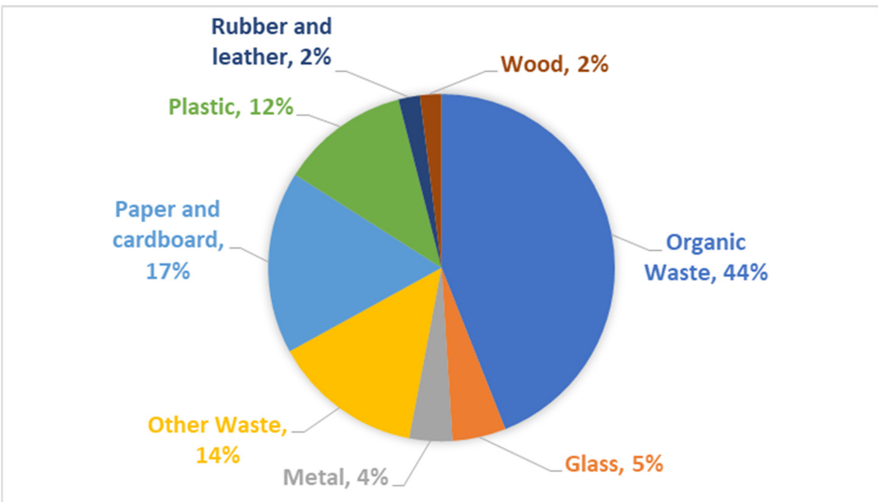

Figure 6. Global waste composition percent LAC region. Source: Own elaboration from "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050" [5].

The rural population in Latin America and the Caribbean region accounts for around 19% of the total population. The countries with the highest percentage of rural population are Guatemala (48%), Honduras (42%), Nicaragua (41%), Paraguay (38%), and Ecuador (36%) [218]. Some exceptions are island states in the Caribbean region with over 50% of the population living in rural areas, such as Antigua and Barbuda, Barbados, or Belize [218]. Most of the countries that have the highest percentage of the rural population have medium-high and medium-low income. Among the countries with the smallest rural population and high incomes are Chile (12% rural) and Uruguay (4%) [218].

These countries have implemented important public policies regarding the use of plastic. In May 2021, Chile passed a law banning single-use plastics, such as cutlery, light bulbs, and pen utensils, among others, which is already implemented [219]. The current policy aims to integrate and reinforce the treatment of single-use plastics at the national level through the limitation or prohibition of single-use plastics as part of the state's public policies to promote a change in human behavior that positively impacts the environment. The aim is to minimize the adverse effects of plastic materials on nature, considering its global production and the increase in the volume of waste. These goals can be achieved through the adoption of specific measures ranging from production and distribution to marketing and warehousing. The objective of this bill is framed within the powers of the National Health Service, which ensures the control or elimination of factors that affect the health and well-being of the inhabitants (DFL 725 Ministry of Health). In the same country, the Law of Extended Responsibility of the Producer and Promotion of Recycling (REP; Law 20920) was enacted in 2016 [220]. Its main objective is to establish an industry that takes responsibility for its products through the prevention of waste generation and its recovery and recycling [216]. Figure 7 illustrates that Chile has the lowest percentage of generated plastic in the region, followed by Cuba and the Dominican Republic, while the countries with the highest generation of plastic are Honduras, Argentina, and Guatemala.

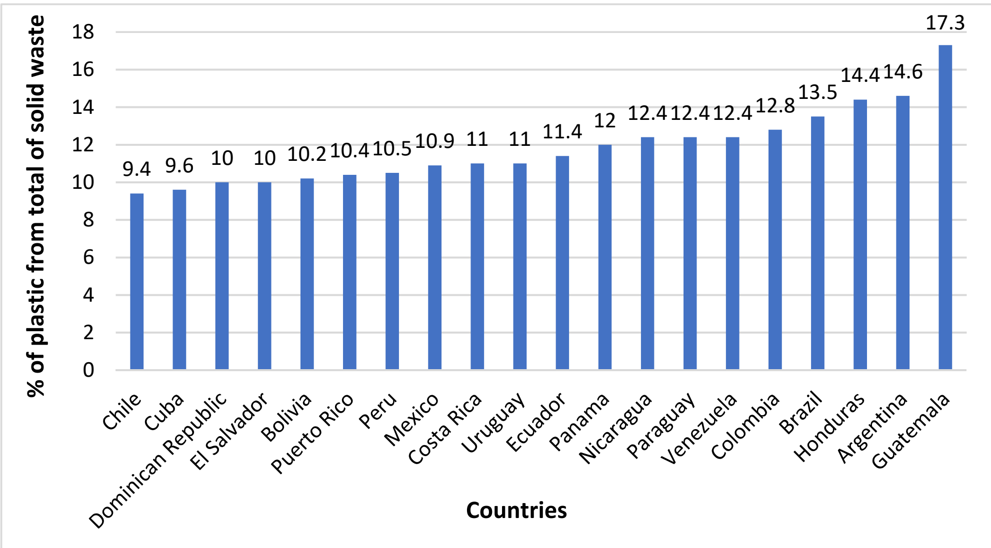

Figure 7. Plastics generated (%) from total of solid waste by country in Latin America and the Caribbean, adapted from [5].

In Uruguay, there is a law regulating the use of plastic bags to protect the environment (Law 19655 of 17 August 2018) [221]. Decree No. 3/019 of 1 July 2019 prohibits the manufacturing, import, distribution, sale, and delivery of plastic bags that are not compostable or biodegradable [222]. Puerto Rico's law number 247–2015, known as the "Law for the Promotion of Reusable Bags and the Regulation of the Use of Plastic Bags in the Commonwealth of Puerto Rico", establishes the elimination and prohibition of the use of disposable plastic bags for the transport of merchandise acquired in commercial establishments [223]. It became effective as of 30 December 2016.

The use of the gross domestic product (GDP) and external factors allows us to deduce that high-income countries and urban areas with a high consumption rate of manufactured products generally have higher waste generation rates than low-income countries and less developed rural communities [224]. However, we know that there is no single universal model valid for all countries and cities. Between countries, even within the same region, there are different collection methods, both for urban and rural areas. This is why despite the political efforts in the LAC region, waste management at the rural level still needs to be explored in depth, mainly due to socioeconomic factors in each country. There could be regional disparities among rural communities influenced by the type of waste collection scheme, the cost of collection, geographical conditions, and the existence of transfer stations, among others [225].

5.2. Asia

The percentage of population living in rural areas is significant in low- and middle-income countries around the world, and several Asian countries have a percentage over or close to 70% of the total population, such as Sri Lanka (81%), Nepal (79%), Cambodia (76%), Afghanistan (74%), Tajikistan (72%), and Myanmar (69%), as estimated by the World Bank [218]. Such percentages indicate that environmental problems and their impacts on human health will lead to an increase in domestic waste generated in developing countries, including rural post-consumer plastic waste.

In Asia-Pacific, where most developing countries are located, the total generation of municipal waste was estimated at 870 million tonnes in 2014, with an average production rate of 1.4 kg.inhab.day^{-1}.

The rate is projected to increase until 2030, generating 1.4 billion tonnes a year [226]. Despite the rapid growth of urbanization in Asia-Pacific, the waste management sector is still facing critical challenges in preventing plastic pollution of the natural environment [227]. The plastic outflow from Asian rivers is estimated to be 92,800 MT year^{-1}, representing around 69% of global input [195]. This fact threatens the achievements of SDGs #14 (Life Below Water) and SDG #16 (Life on Land) without a proper waste management sector, in both urban and rural areas.

Rural communities are not given proper attention for waste management infrastructure in developing countries such as China, Malaysia, India, and Nepal [228], which feed plastic pollution to the rural environment. Open dumping and open burning of plastics are still main options for waste disposal in rural communities from South-East and South Asian countries [229], which is detrimental for several SDGs, such as #3 (Good Health), #6 (Clean Water and Sanitation), #11 (Sustainable Cities and Communities), and #12 (Responsible Consumption and Production).

Municipal waste disposal facilities lack the capacity to handle the waste generated from urban and rural areas because of the rapid growth of municipal waste. Many cities are experiencing a so-called "garbage siege", a condition where cities are surrounded by garbage piled up in suburban or rural areas [230,231].

Due to a lack of research focusing on rural waste, it is difficult to estimate the total rural waste flow (including plastic fraction) from rural communities in the Asia-Pacific region. In fact, many Asian countries lack the institutional capacity to collect and monitor the flow of plastic waste in rural areas [229], while rivers are heavily polluted by plastics [195] and the trend of annual rural waste generation per capita is increasing in countries such as Malaysia and China at a rate of 2% and 8–10%, respectively [232,233]. Therefore, an increase in post-consumer plastic waste is expected in rural areas in the coming years. Rural waste management systems must cope with this increasing trend alongside the legal and illegal import of plastic waste from developed countries [234]. Additionally, rural destinations of developing Asia do not have the capacity to manage an increasing flux of tourists and resulting plastic waste [229].

The uneven distribution of rural management services across China caused by the inequal distribution of resources is another factor that should be considered [169]. Similar problems occur in India, where around 65% population is living in rural areas [218]. Previous studies showed that waste composition, consisting of wet waste, recyclable waste, and non-recyclable waste, is different from that of urban waste [8]. The differences are caused by lifestyle, income variation, and resource availability [135,235]. Frequently, rural waste is handled directly, potentially resulting in various types of infectious and chronic diseases. Waste is transported to a final disposal area, common in developing countries, for open burning, resulting air pollution [236]. In China, about 30% to 60% of rural household waste is dumped in such areas [237].

In developing countries, waste banks are an alternative route for rural plastic waste and other dry recyclables, such as inorganic waste buyback programs [238]. The increasing usage of single-use plastic in rural areas causes degradation of compost quality since almost all organic waste used for aerobic digestion is contaminated by plastic. The determinants are improper final disposal and lack of waste separation [239]. Though there is a pre-treatment stage in composting facilities, the end compost product can still contain a significant amount of plastic debris [58]. Gui et al. [240] found microplastic in the end compost product in two composting centers in China. In Vietnam, the use of plastic shopping bags and bottles is higher in rural than in urban areas [241]. Tong et al. [242] stated that according to data from the Vietnam Ministry of Natural Resources and Environment in 2011, single-use plastic for shopping tends to be used more frequently, followed by plastic wrap/film and plastic straws in rural areas. The increasing trend of plastic use in Vietnam is affected by better living standards and the economy, as today, Vietnam is one of the emerging economies in the South-East Asia region. In 2017, plastic industry consumption of virgin plastic material was about 5.9 Mt, which equals a plastic consumption rate of 63 kg.inhab.yr^{-1}. This value is more than a 10-fold increase compared to the consumption in 1990, which was only 3.8 kg.inhab.yr^{-1}. Thus, the average annual plastic consumption increased by 10.96% from 1990 to 2017 [243].

Akenji et al. [244] identified four key areas to be improved in combating plastic pollution crises in Asia, such as information and knowledge, policy and governance, technical capacity, and markets and finance. Development of waste collection services in rural areas, plus the support of the informal sector combined with sufficient recycling facilities for plastic items, could curb domestic plastic pollution sources [245]. Recovery of plastics from dumpsites and landfills is seen an additional option to prevent marine plastic pollution in Asia [246]. A critical analysis of rural waste management systems is needed to reveal the current knowledge gaps at local and regional levels and to provide sustainable alternatives [247]. Circular economy approaches must be implemented in Asian waste management policies to combat the plastic pollution crisis [248].

5.3. Africa

Around 86 and 32 million tons of primary polymers and plastics products, respectively, were imported between 1990 and 2017 by 33 African countries having a combined population of more than 856 million capita [249]; around 15% of these plastics were mismanaged at the product's end of life [250]. The extrapolation of these data to the continental level indicates that 172 Mt of polymers and plastics were imported during those 27 years, and around 25 million tons of them were mismanaged. Furthermore, 230 million tons of plastics entered Africa as components of products during this period; Egypt, Nigeria, South Africa, Algeria, Morocco, and Tunisia had the largest shares in these imports of around 19%, 17%, 12%, 11%, 10%, and 7%, respectively [249]. Hence, those countries are responsible for around 51% of the total plastics consumption in the whole continent. Egypt, Nigeria, South Africa, Algeria, and Morocco were also identified as among the top 20 countries in terms of mismanaged plastic wastes with respect to waste masses; 62% of the generated plastic waste is mismanaged in those five countries [251]. Furthermore, plastic consumption varies significantly in the continent, ranging between 4.4 and 8 kg.year^{-1} in Nigeria, Kenya, and Ghana; between 13 and 19 kg.year^{-1} for Algeria, Egypt, and Morocco; and in South Africa, it reaches 24.5 kg.year^{-1} [252].

Urbanization in Africa is one of the main factors leading to increasing plastics consumption and waste amounts. It is supported by the ongoing population and economic growth, and the constant immigration of citizens from rural areas to urban centers [253,254]. Plastic waste represents around 13% of the municipal solid waste (MSW) generated in Africa [162] and is mostly originated from single-use plastics [249,253,255]. That waste stream is commonly disposed of with MSW, and there is a paucity in the recycling and energy facilities in Africa; accordingly, most of the waste end up in dumpsites [162,253] or waterways [256], or is openly burnt [5,250], and the most common recycling practices is either reusing or mechanical recycling for the production of low-design products [253]. However, recycling activities and thermal energy recoveries have been initiated in a few countries [162,249,250]. Waste management services in Africa commonly rely on a combination of small-scale, low-cost, decentralized community-driven initiatives; hence, recycling activities need to be scaled up by developing and strengthening the end-use markets on the local and regional scales [162].

A shift is currently being started in African economies from the linear to a more curricular approach, where plastic wastes are being recycled and reused [255]. Moreover, 34 African countries have banned either single-use plastic bags or other single-use plastics since May 2019 [257]. Yet, such efforts are challenged by the ineffective legislation, poor monitoring, and slow adoption of the need for proper practices for eliminating the steadily increasing plastic volumes in Africa [250]. Furthermore, there is an urgent need for effective economic instruments for managing the African solid wastes, such as extended producer responsibility (EPR).

African rural areas have very poor or waste management services [253,256]. Couth and Trois [258] reported that African dry rural waste is commonly scavenged and recycled, while most of the organic waste is utilized as animal feed or composted, highlighting that the carbon footprint from African rural waste is relatively low. A study on rural plastic waste management in Eswatini indicated that plastic waste is commonly managed through dumping or open burning, yet reuse and recycling practices were present in some rural households [20].

Though 60% of the African population lives in rural areas [256], waste collection coverage in the African rural areas is estimated to be only 9% [5] and rural areas are mostly covered by informal waste collection services [162]. In South Africa, where waste management services coverage reaches 95% and 87% for metropolitan and urban areas, respectively, such rates decrease to only 13% in rural areas. Furthermore, 29% of the generated domestic waste in South Africa is not covered by formal waste management services, 85% of which is generated in rural areas [259].

There are African countries where the percentage of rural population is higher than 70%, such as in Kenya, Uganda, Chad, Ethiopia, Eswatini, South Sudan, Rwanda, Burundi, Malawi, and Niger [218]. Therefore, the development of the rural waste management sector in African countries and beyond is a key objective in achieving several SDGs such as #3 (Good Health and Well-Being), #6 (Clear Water and Sanitation), #10 (Reduced Inequalities), #11(Sustainable Cities and Communities), #12 (Responsible Consumption and Production), #14 (Life Below Water), and #15 (Life on Land).

Generally, there is still a knowledge gap regarding the amounts and types of the generated plastic waste in the rural areas of most of the African countries, as well as their disposal and management practices [20]. Most of the available data on solid waste in Africa are on big cities while small and rural towns are often neglected, which presents challenges for planning waste management interventions in African rural areas due to the lack of data [260]. Additionally, plastic waste pollution threats in Africa are alarming after the COVID-19 pandemic, due to the increased consumption of single-use plastics and plastics-based personal protective equipment, in addition to the limited waste management services [261–263]. Therefore, this strengthens the urgency of creating waste management infrastructure for plastic waste management, considering plastic medical wastes, especially in rural areas, to avoid open burning or dumping of such waste streams [261].

In response to the existing gaps in waste management services in Africa, several social and technological initiatives have emerged in the past decade [162]; however, most of these initiatives focused on urban waste management. Currently, there are 41 plastic recycling facilities in Africa, 12 of which are in South Africa, 7 in Nigeria, and 6 in Egypt [264].

There is a growing interest in polyethylene terephthalate (PET) recycling by the private sector such as the PET recycling company (PETCO) in South Africa, which is replicated in other African countries including Kenya, Ethiopia, and Uganda [162,263,265], and with BariQ in Egypt [266]. While Africa has ambitious plans for developing solid waste management according to Agenda 2063, one of which is to recycle at least 50% of the urban waste [267], more attention should be paid to developing waste management services in rural areas.

5.4. Balkan and Eastern Europe

Generally, member states of the European Union have a better situation compared to other countries in the region under consideration. Their national legislation implements sustainable development ideas and establishes full responsibility of the local community for local waste management [268]. In Poland, many villages have a separate waste collection. With an average household waste generation of 272 kg.inhab.yr^{-1}, up to 30% is collected as sorted waste [269]. This is the result of a new law on waste introduced in 2013. Of this amount, plastic waste constitutes 25 kg.inhab.yr^{-1} [270] and has grown rapidly since 2013. This corresponds to 10% of the total household waste weight [271] and is about 1.5 times less than generated in large cities. However, most plastic in rural areas of Poland is still either collected along with mixed waste (only 2 kg.inhab.yr^{-1} of plastic is collected separately) or incinerated in households, although recent studies [270] show that up to 75% of people collect plastic separately. Uncontrolled incineration and unauthorized landfilling remain major problems as the worst solutions for plastic waste. Strzelczyk [272] has found that more than 80% of farmers burn their waste (including plastic) in household furnaces, resulting in significant air pollution. The total number of landfills in rural Poland is 318 [271].

Since accession to the EU, European funds have become an important source of financing for regional development in Slovakia, including rural waste management. Research by Holotova et al. [273] shows significant attention of rural people to the waste problem: for example, more than 85% of people in rural areas are interested in the zero-waste shopping concept because it is seen as environmentally friendly. In contrast to cities, there is a well-working separate collection of biodegradable waste in Slovak rural areas [274]. According to the resolution of the Government of Slovakia, the fee for landfilling has gradually increased since 2018. Thus, currently, the amount of waste landfilled is being reduced. Depending on the locality, household waste in rural areas is collected every few days or weeks. Some type of waste (PET bottles, electronic waste) in many villages is collected on certain days free of charge [275]. Additionally, many villages have waste collection centers, where people can bring various waste. Annual household waste generation in Slovak villages gradually increases and currently is about 300 kg.inhab.yr^{-1}, while separate plastic collection reaches 7 kg.inhab.yr^{-1} [275]. At the same time, Slovakia aims to have 55% of plastic waste recycled by 2030 in accordance with the Packaging and Packaging Waste Directive [273]. Plastic waste in Slovakia is also partially burned in households, and this amount is significantly underestimated by official data [276].

In rural Ukraine, the largest share of waste belongs to food waste and is almost entirely used in households, with only a small amount entering the waste stream to be collected. PET bottles and other plastic wastes are the most intensively growing components of household waste. In Ukraine, an average of 15 kg.inhab.yr^{-1} is used, resulting in 600 thousand tons of plastic waste generated annually [277]. Most of this waste is delivered to landfills, contributing to environmental pollution. Some waste is reused by households, though a large amount still infiltrates the waste stream. In rural areas, plastic waste is often burned in the open air, causing pollution. Although plastic recycling is environmentally and economically feasible, only a very small share of this waste is recycled in Ukraine. Most of the money needed for plastic processing is spent on the collection and procurement of raw materials (plastic waste). Plastic waste processing in Ukraine is almost twice as expensive in comparison to the European Union countries. In many cases, rural settlements do not have an authorized place for waste disposal, so there are many illegal landfills. At the same time, there are examples of effective waste management: some Ukrainian villages actively implement separate collection of household waste (primarily PET bottles) due to the persistence of local authorities. However, such practices are not systematic. Most villages have problems with irregular waste collection and non-compliance of landfills with environmental requirements.

In Romania, the closure of non-compliant landfills combined with long delays in implementation of regional integrated waste management systems led to several environmental threats: low waste collection coverage in some rural municipalities including uncollected post-consumer plastic waste, huge amounts of mixed waste to be transported from one county to another in search of open landfills, the spread of wild dumps in rural communities, and illegal dumping activities including plastic pollution of water bodies associated with such waste management deficiencies [278].

In Bulgaria, due to urbanization and the decline in the rural population, the amount of household waste in rural areas has decreased [279]. In the past, there was no organized waste management system in rural areas. Instead, most wastes were used by households: organic waste for domestic animals, paper and textiles as fuel, metal and glass reused, and only plastic was either incinerated or disposed of [279,280]. However, a centralized waste management system has recently emerged, covering an increasing amount of plastic and special waste. In rural areas, waste generation reaches about 240 kg.inhab.yr^{-1} [279], corresponding to the average value for Eastern Europe. As expected, the largest share belongs to organic waste (almost 50%). The construction of plastic processing plants in Bulgaria has significantly increased the recycling of plastic, also from rural areas [281]. However, source-separation of plastic waste remains low in villages [282], where the majority of the Bulgarian population lives. This fact leads to plastic pollution leakage into the natural environment.

Serbia is characterized by a significant difference between waste generated and collected. This applies especially to rural areas, where waste collection is low or non-existent (most municipalities have waste collection coverage below 50% [283,284]). Moreover, the amount of waste often differs among different communities due to insufficient coverage by waste management services, illegal landfills, etc. Additionally, open waste burning and a large number of illegal landfills are also common in rural areas. Prokic and Mihajlov [284] estimate waste generation in rural Serbia at 219 kg.inhab.yr^{-1} (0.6 kg.inhab.day^{-1}). Organic waste constitutes the largest share (as in other countries of the region under consideration) and is almost entirely used by households. It is difficult to accurately estimate the amount and composition of household waste due to the lack of data and very limited separate collection. Waste from villages is landfilled, which does not have adequate environmental protection (leachate or landfill gas collection systems). This is planned to be corrected by a new waste management plan. The content of plastic in household waste reaches 10% [285]. It is either landfilled (often illegal) or burned in households, leaking into the natural environment. However, according to the Law on Packaging and Packaging Waste, a deposit system must be set up to return plastic packaging for recycling or reuse.

Successful European practices cannot always be introduced in Balkan and Eastern European countries due to social and economic differences between this region and developed countries. For example, some solutions are based on strict implementation without the use of economic instruments. Such a possibility is currently limited (or even impossible) in rural regions. The rural population is still significant in Central and Eastern Europe, with values close or above 40% in Slovakia, Romania, Serbia, and Poland, and 30–24% in Ukraine and Bulgaria), according to World Bank [218].

Another significant disadvantage is the fact that rural waste management is based on statistical data obtained by calculation. These data are often different from the real situation. Therefore, more research is needed in the field of waste management in rural areas to obtain a proper estimate of domestic plastic waste flow. Full coverage of rural population to regular waste management services, including separation of post-consumer plastic items, is crucial in Balkan and Eastern Europe to reduce the rural domestic plastic leakage into the natural environment, in line with SDGs #6 (Clean Water and Sanitation), #14 (Life Below Water), and #15 (Life on Land).

5.5. Island Communities—The Need for a Global Alliance on Waste Management Sector

Island communities around the world are feeling the blunt end of climate change and face numerous other challenges. Indeed, as they seek to meet and implement the United Nations' SDGs, they face unique yet similar challenges. One of the key challenges they face in attaining some of these goals and perhaps one with more than its share of low-hanging fruits is solid waste management. In addition to this, waste management is addressed in the New Urban Agenda as well as the Paris Climate Agreement. For many islands, it is a struggle in isolation against market forces, natural disasters, and poor access to markets.

A review of waste management in small island developing states, such as in the Atlantic, Caribbean, and Pacific, as well as the in Mediterranean and South China seas, emphasized that waste management is a key challenge in these communities [204]. On average, the waste generation rate from this island group was 1.29 kg.inhab.day^{-1}. This higher per capita waste generation rate also includes post-consumer plastic items from domestic and touristic sources. In addition to a higher per capita waste generation, island communities also struggle with a lack of regulation and enforcement of waste disposal practices. In most of the island states reviewed, illegal dumping and landfilling are both common practices. These waste disposal practices often lead to plastic pollution of urban and rural communities. In Asia-Pacific, waste streams that must be addressed are becoming increasingly diverse, as a result of a shift in demographics and lifestyles in urban centers, where most waste is generated [155]. This is most explicitly seen in the marine waste and debris settling on the coasts of islands. In the Pacific region, the total amount of mismanaged plastic waste was 156,000 t.yr^{-1} [155]. A study comparing microplastic abundance between urban and rural sites on the island of Fiji found no significant difference [286]. Therefore, rural communities should not be ignored in terms of plastic pollution sources, but more studies are required in the case of island communities.

For all island communities around the world, the collection and reduction of rural waste is a key component to future island waste management strategies [287]. Poor transport infrastructure to remote rural communities makes it more difficult to connect such rural sites to recycling facilities [288]. Poor accessibility and limited waste management facilities combined with increasing plastic waste flows feed contamination of marine environments [227].

Plastic waste diversion from landfills is compulsory, taking into account the available land pressure in such regions [289]. Islands possess many similarities, but they also have many differences in terms of economy, demography, political structure, and how they relate to other islands and mainland communities. Additionally, cultural or religious features may play a role in combating the plastic pollution crisis by supporting pro-environmental behaviors [290]. Nowhere is this more clearly demonstrated than in how waste is managed on and off each island and the resources that island communities have in managing solid waste. One of the specific challenges faced by any such community is their isolation. A new initiative called the Island Waste Management Global Alliance (IWMGA) seeks to address this specific barrier. This alliance's main aim is to support island communities in managing domestic, imported, and transported waste that accumulates on islands and their respective coastlines. The IWMGA has identified four strategic areas to focus attention on to support a collective and collaborative approach to waste management by islands worldwide. The first of these themes is research and knowledge. It is hoped that a coalition of islands will be able to identify, commission, and disseminate research on waste management and plastic pollution issues. Island communities must often rely on research that has a focus on mainland communities or urban situations that are not relevant to the specific circumstances found on islands. Individual small islands (including rural sites) also may not have the knowledge or capacity to manage such research but have very pertinent research questions that other small islands also have. By supporting collaboration, it is hoped that this initiative will allow for a synergetic approach to furthering knowledge and insight into the key questions surrounding solid waste management in island communities and the plastic pollution problem. The rural population share of the total population is significant in small Pacific island states (61%) and small Caribbean states (48%), according to the World Bank (2020) [218]. Therefore, the improvement of rural waste management practices should be a key objective in combating the plastic pollution crisis of island communities fed by domestic and touristic sources.

The second thematic area of work that the IWMGA is focusing on is that of communications. All communities must have access to not only the latest research but to each other in terms of peer support and professional networks. There is a real need for strong communication, both formal and informal. It is hoped that in the long term, it will be possible to produce a journal of island waste management, but in the short term, the alliance is supporting the development of professional networks. This theme is complementary to the third theme: the area of education and capacity building. It is essential that islands develop expertise within their communities as well as have access to funding for appropriate infrastructure. The IWMGA seeks to support these goals by helping communities access sustainable funding sources where such communities are unable to cover the costs of best-practice waste management themselves. The alliance is also looking at developing a mentoring program that will allow islands to have greater financial and technical capacity to partner with island communities that do not have such access. This again will be another support for communities around the world as they seek to meet this challenge.

Without a strong conceptual framework of legislation and policy, there is always danger of a piecemeal approach rather than the integrated and holistic approach that is required when dealing with waste management and plastic pollution. To address this issue, the final thematic area includes issues such as policy, strategy, regulation, and advocacy. The alliance is bringing together examples of best practices from around the world in these areas so that they can be applied as required by island communities.

There is also a need to allow islands to lever each other on the international stage to further policy change relevant to an island community's needs. The IWMGA hopes to support contributions that allow various communities to be heard, especially regarding international policymaking addressing waste and plastic issues. Beside the benefits of rural waste management for environmental related SDGs, this alliance could contribute to a broad framework of SDGs #16 (Peace, Justice and Strong Institutions) and #17 (Partnership for the Goals).

5.6. Rural Knowledge Gaps in Waste Management and Plastic Pollution

The rural waste management sector is facing many challenges across each major geographical area mentioned in Section 5. The lack of sound waste collection schemes in most rural communities leads to improper waste disposal practices such as wild dumps, open burning of waste, and even direct dumping of household waste in water bodies (streams, rivers, lakes, coastline), including post-consumer plastic waste. Therefore, domestic plastic pollution of the natural environment in rural communities is a direct consequence of low capture of plastic waste flow by reliable waste management services through waste operators, community services, or informal sectors specialized in plastic waste collection.

Island communities have particular geographical restrictions, and without a solid waste management sector, plastic pollution leakage into the marine environment (domestic plus touristic sources) is inevitable. In this context, a global alliance prospect on the waste management sector argued in the above section (Section 5.5) is necessary to address such challenges. An improvement in regional integrated waste management systems (urban and rural municipalities) or decentralized/community systems with a focus on source-separated plastic waste streams is a basic step to reduce the magnitude of rural post-consumer plastic pollution.

Waste statistics data are poor in the case of rural municipalities, which is detrimental for a proper estimation of rural plastic waste flow, particularly in low- and middle-income countries. New global projections related to plastic pollution flow aim to incorporate rural population contributions [291].

In this regard, municipal waste composition and generation rates based on experimental studies are required across as many countries as possible to have a baseline for further analysis.

Traditional waste management systems, based on mixed waste collection and landfilling, prevail among rural communities around the world, but many rural regions lack any waste collection schemes [7]. Thus, most rural plastic waste is mismanaged by uncontrolled waste disposal methods (littering, open dumps, open burning) or conventional landfills which favor plastic leakage into the natural environment. However, this process is less studied in the current literature, with few publications focusing on rural plastic pollution issues [19,20]. Publications related to rural waste management in a broader sense are more available, as shown in Section 5, but this research must cover a large geographic area and address solutions to each unique circumstance of rural waste and its prevention.

Overall, rural communities receive less attention compared to urban areas, with respect to both waste management and plastic pollution issues, with insufficient field data at subnational levels to reveal the regional and local disparities. To improve the current models of plastic pollution leakage into terrestrial and marine environments, rural communities' contributions must be taken into account. Moreover, models adapted to regional scales could better reveal the rural plastic leakage at administrative or catchment levels. Therefore, waste management and plastic pollution issues are closely tied in rural regions, and further investigations are required by academics, institutions, and NGOs to reveal the complex geographies between the natural environment, rural economies, and societies and how to stimulate pro-environmental behavior. Waste-related questionnaires applied to rural communities could fill some knowledge gaps regarding the status of plastic waste management [20], the progress of environmental awareness [292], or the implementation of plastic ban policies [293]. Fieldwork is necessary to examine the role of the informal sector in rural plastic waste diversion from landfills and wild dumps [294]. Citizen science could provide human resources to cover a nationwide assessment of plastic pollution practices including rural communities [295]. Besides domestic and touristic sources of rural plastic pollutions, agriculture and related activities must be further investigated as macro- and microplastic pollution. Plastic waste management from pesticide packaging is a topic of interest as a potential pollution source for rural environments [296].

This review reveals the complexity of macro- and microplastic pollution of the natural environment where rural communities must be part of future studies. Potential solutions to divert plastic pollution from the rural environment are further analyzed in Section 6 under the circular economy paradigm and supported by organizations with global waste management experience, such as WasteAid.

6. Circular Economy Solutions to Reduce Plastic Pollution in Rural Areas

6.1. Transition from Linear towards Circular Rural Waste Management

The causes and sources of plastic pollution in rural areas vary by location, socioeconomic status, regional waste distribution, and waste imports. Low- and middle-income countries often rely on waste management methods that are informal or have negative impacts on public health. Open burning of waste, which is common in rural regions, contributes to global emissions of carbon dioxide and releases hazardous air pollutants [164,297]. However, many developing countries have taken an aggressive stance on battling plastic pollution, including a complete ban on all single-use plastics by Rwanda in 2019 [298]. Waste collection and management remains challenging even in rural areas of high-income countries due to sparser population density and greater transport distance, though these areas are more likely to have the waste infrastructure [14].

A global effort is necessary to meet the needs of both urban and rural populations by transforming the traditional linear (take–make–dispose) economy into a circular one, with emphasis on engaging rural community stakeholders and tailoring circular solutions to the needs of the population. A circular economy would aim to prevent plastic pollution by using a multi-tiered approach to address the sources of plastic waste, the management of plastic materials, and the potential release of plastics (end-of-pipe release) into the environment [299]. In opposition to the linear economy, a circular economy aims to prevent waste generation and mitigate environmental impacts throughout the life cycle of a product. Circularity measures could be implemented in rural areas to reduce the number of plastic waste, design plastics for optimal reuse, recycling, or composting, and recover plastic for use in new products (Figure 8). However, the concept of circular economy can be an ambiguous one that does not always address the social aspects of sustainability, such as equality and human rights [300], or the applicability of certain concepts of the approach to different regions. Many circular solutions for plastic waste are derived from the experience and management of plastic in Organization for Economic Co-operation and Development (OECD) countries and may lack applicability in low-income or rural areas that lack widespread waste management infrastructure [301]. Therefore, approaches must be tailored to the region in which they are to be applied.

Figure 8. A linear vs. circular economy model, including the 6 Rs (reduce, replace, redesign, reuse, recycle, recover) promoted to prevent or recover plastic pollution in rural systems.

Broadly, the implementation of a circular economy in a rural area could address multiple facets of the plastic economy and plastic usage from the manufacture of plastics to their eventual disposal, including:

(1) Eliminating the manufacture and import of unnecessary plastics with suitable alternatives.
(2) Replacing conventional plastics with reusable, renewable, and/or biodegradable alternatives that provide a suitable function and are able to be handled by local recycling and/or composting infrastructure.
(3) Redesigning products with optimal recyclability, reuse, and repair in mind.

(4) Promoting reuse and return schemes by providing local infrastructure and incentives (refilling schemes, deposit-refund systems, zero-waste shops) and enforcing Extended Producer Responsibility (EPR) policies regarding plastic packaging waste.
(5) Collecting and recycling plastic through informal and formal waste collection schemes.
(6) Recovering released, or polluting, plastics for the creation of new, local products, as in a decentralized circular economy (see below).
(7) Promoting creative recycling practices (upcycling) at household and community levels.

In addition to these changes in the economy of plastics, informing policy changes with consideration of the needs and behaviors of relevant communities is essential to incentivize and adopt changes that work for each region.

In the case of many developing countries, plastic pollution may arise from the import of large quantities of waste from countries in the European Union or the United States. This exportation of waste overburdens already underdeveloped and fragile waste management systems, which can lead to abundant plastic pollution and further stifle waste infrastructure development [301,302]. The practice of exporting waste should be monitored, and laws associated with the illegal trade of waste should be enforced to prevent the shifting of responsibility for plastic pollution onto developing countries. Where unnecessary plastics cannot be eliminated by policy, such as bans on single-use plastic bags or waste imports, or by overall waste reduction and reuse, remaining plastics can be sorted and collected with informal or formal waste management.

A life cycle assessment (LCA) of waste management in rural Quilombola communities in west-central Brazil found that a shift in waste treatment from burying and burning to waste separation and collection (home composting, recycling, and landfilling) would improve overall public health and air quality [303]. Rural areas proximate to urban centers with pre-existing waste facilities can incorporate their waste stream using collection points or door-to-door collection schemes [8]. Sparsely populated rural areas may require more innovative, local solutions to traditional waste management, such as creative reuse, in addition to community recycling and recovery [304]. One strategy to manage plastic waste is a locally managed decentralized circular economy, which would create opportunities for the local conversion of plastics to usable products, such as plastic-derived fuel oil (PDFO) from polyolefin plastics [301,305,306].

It is imperative that waste management strategies in rural areas be informed by current waste composition, management strategies, and community approaches. Garbage collectors and waste pickers, for example, recover and sort millions of tons of waste per year [307]. Methods of collaborative community waste sorting, such as waste picking, would benefit from increased support, rather than operating at odds with infrastructural development. This community-level method of handling and sorting waste would be ideal for rural areas that are far removed from existing infrastructure. Some rural areas in Colombia and Romania, for example, are too great a distance from urban centers to utilize pre-existing facilities, and instead burn, bury, or dump their household waste [308]. In some areas, promoting sustainable behaviors that prioritize waste collection and prevent open burning or dumping of waste could be implemented through community programs.

6.2. Rural Plastic Waste Options in the Context of Poor Waste Management Infrastructure

6.2.1. Prevalent Waste Management Practices

Rural communities in low- and middle-income countries usually lack any formal waste management service. In South Asia and sub-Saharan Africa, only 10–15% of the population has regular waste collection and safe disposal, with those provided a service typically living in city centers or wealthier enclaves [165]. Consequently, most people are left to manage their own waste however they think best, and this applies broadly throughout rural areas.

In rural areas, a small number of wealthier residents might have their waste collected and taken to an alternative site for either dumping or burning, with the waste collector having the opportunity to extract any materials of value prior to disposal. However, most residents have the options to either burn the waste in their own backyard or dump it in the local area (in the street, a riverbed, scrubland, or at a central informal dumpsite). Openly dumped waste looks unsightly, attracts vermin that spread disease, blocks waterways, pollutes groundwater, and presents a risk to scavenging people (notably children) and animals (livestock and wildlife) and limits prospects of achieving the SDGs [309]. Open burning of waste is therefore a commonplace risk-reduction strategy, though the impacts on local air quality, human health, and climate remain largely overlooked.

Before economies were globalized and single-use packaging became mainstream, open dumping and even burning did not pose the same kind of problem to communities. Waste materials were composed of locally found or manufactured materials, such as clay and leaves. Disposing of these in the environment posed no risk to people or animals, and so it has continued for as long as humans have walked the planet. The composition of contemporary household waste, however, is different from the wastes of the past. Modern waste streams contain a wide range of synthetic polymers (rigid plastics such as PET, HDPE, and PP; flexible mono-materials such as LDPE, OPP, and PVC; flexible metalized PET and multi-layer sachets; and other plastic items such as hair braids, disposable nappies, and menstrual pads). These items are commonly mixed in with organic waste, such as inedible parts of crops and animals, making the waste stream heterogeneous and complex to characterize.

Culturally, there is often very little awareness or understanding of public health, environmental (including pollution of air, land, water, and seas as well as climate change), and local economic impacts of open burning and dumping of plastic waste. In many cases, people use plastic waste as a cooking fuel, and in others, people are consuming molten plastic by placing an LDPE bag of cooking oil into a hot pan wherein it melts as the oil heats.

The "sachet economy" is also posing a specific and growing risk to waste management [310]. The sachet economy relies on delivering goods in small and sealed plastic packaging materials for one-time or limited use at the household level. These plastic packaging materials are unrecyclable items that pose serious plastic pollution risks for rural communities without efficient waste collection systems. For example, the average national per capita sachet consumption is 1.64 per day in the Philippines, but is as high as 6 per day in more urbanized regions [311]. Large multinational companies with extensive marketing budgets have successfully penetrated rural economies in lower-income countries (via "Bottom of the Pyramid" marketing strategies) by reducing portion size and packaging products in multilaminate sachets. It is now possible to buy a wide range of products in these sachets, from alcoholic drinks to laundry detergent and personal hygiene products. Though sachets provide a degree of convenience and affordability to many products, they also represent poor value for money for the consumer and have an additional long-term cost to society as a complex heterogeneous waste with no current market value or recyclability [310].

6.2.2. Material-Specific Discussion

Rural communities of low- and middle-income countries have restricted access to plastic waste recycling markets or facilities, since these (where they exist) tend to be in large population centers or even overseas. Poor road networks and the relatively high cost of transport fuel makes the transfer of waste for recycling prohibitively expensive. Options for plastic waste management are therefore extremely limited. Plastic waste management options vary depending on the type of plastic material.

Rigid HDPE and PP are relatively easy to recycle, as they have many potential uses in non-food grade applications, such as basins and buckets.

PET bottles can have a high re-use value, for example, to package small quantities of motor oil or homemade fruit juices. The bottles can also be cut into long ribbons, which are extremely strong and can be used as garden twine or baling string. There are also some examples of bottles being used for pencil cases and decorative items, though these are labor-intensive and artisanal applications with very niche markets. Once a PET bottle becomes too dirty or damaged, it becomes a waste for which there is no market. Even industrial PET recycling facilities will reject PET bottles that are too contaminated or sun-damaged. The value of plastics collected for recycling is often coupled with the global price of oil [312], and it is almost always those at the beginning of the value chain who are impacted by price fluctuations. In Kenya, for example, a waste collector has to collect 30 two-liter PET bottles to earn the equivalent of 5 cents (USD). This is in part due to the lack of PET recycling infrastructure and the large number of middlemen and significant transport costs incurred to deliver PET to a recycling facility. It is not possible to recycle PET using simple, low-cost, and low-tech processing equipment. Its high melting point (250 °C) and glass transition temperature (circa 70 °C) mean it does not melt or blend well with other polymers [313]. Furthermore, it is a crystalline polymer, so after melting and reforming, the product is cloudy and brittle, with very few potential applications. Since PET is mostly used in food-grade applications, finding a suitable market for PET that is no longer of food-grade standard remains challenging, and so PET remains one of the most visibly littered items in areas with no waste management system.

Monomaterial flexible LDPE, used commonly for shopping bags, wrap, and pure water sachets, is a relatively easy to handle material with a range of potential products using low-cost and low-tech processes. The main challenge with LDPE is the often high contamination levels (usually with food) as well as its lightweight nature, making it easily blown into watercourses, trees, shrubs, or the wider environment. LDPE can be crocheted or woven on a loom (to produce "plabric") to make artisanal products such as purses, bags, and clothing. These activities can provide income-generating opportunities for vulnerable and marginalized groups (particularly women), though the quantity of throughput is relatively small [314]. WasteAid has also worked with a rural coastal community in The Gambia to collect, sort, and convert waste LDPE into paving stones and roof tiles, which are more durable than alternative products and require no cement or water. The LDPE must be well-sorted and free of contaminants. It is then melted over a low heat until it turns into a liquid, and then mixed with sand to produce a cement-like mixture. This is then turned out into tile molds, where it sets very quickly and produces a long-lasting product suitable for pavements and carparks. This process can make use of a significant amount of LDPE. For example, WasteAid trained 30 people and within 3 months, they had diverted the equivalent of a million plastic bags from disposal or leakage into the environment [315].

Metallized plastics and multi-material laminates including tetrapak and sachets are the least likely to have any kind of market. They often represent the least value to waste collectors due to the number of items that need to be collected (for example, to collect 1 kg of material), their dispersal through the mixed waste stream, the level of contamination (usually with foodstuffs, but also with detergents and personal hygiene product residue), and the lack of global recycling markets for these materials.

For the majority of flexible plastics in the global waste stream, there remains no recycling option. For rural communities, ecobricking can offer a sticking-plaster solution. Here, non-recyclable flexible plastic is compressed into PET bottles and used as a basic construction product for outside walls, toilet blocks, etc. Provided the ecobricks are covered with mud or render to protect them from the sun, they offer an interim solution to this non-recyclable waste stream. The concept of ecobricking began in a rural community in South America [316] and has spread to South East Asia [317] and Africa [318]. While it is generally acknowledged to not be a "sustainable solution", it does prevent plastic waste leaking into the environment or being burned, instead using its thermal mass in a long-term application.

As mentioned previously, one of the largest challenges with plastic waste is that it is often contaminated with food waste. In order to reduce the contamination level and improve recyclability, it is equally important to separate food waste at the source. WasteAid works with community-based organizations and municipalities to target food waste from markets. A current EU-funded project is seeing food waste collected from municipal markets in Banjul, The Gambia, from where it is transferred to women's gardens and used to make compost and charcoal briquettes (a low-smoke cooking fuel). This type of activity reduces dependence on dumpsites whilst enhancing climate resilience and providing a dry stream of waste materials that can then be sorted and, in some cases, valorized [319].

7. Conclusions

Despite the general interest in the theme of plastic pollution, this review reveals significant research knowledge gaps related to rural communities. Therefore, this work provides a broader analysis of the threat posed by plastic pollution (Sections 3 and 4) and rural waste management challenges around the world (Section 5) to highlight the importance of future plastic pollution, waste management, and circular economy research in rural regions.

Rural communities' relation to plastic pollution issues is presented here by examining rural areas and populations both as plastic *pollution destination sites* and as *plastic contributors* to the natural environment (air–water–soil–biosphere nexus). This dual approach points out new insights regarding how rural communities around the world should be included in future plastic pollution research and the key environmental compartments for further research. Future studies need to better reflect the magnitude of plastic waste flows in rural communities, supported by reliable rural waste indicators (improved waste statistics, monitoring and field measurements, policy, and economic incentives), and to cover various geographical areas at global scale. Future plastic pollution research must also investigate the interactions between terrestrial, atmospheric, freshwater, and marine contamination routes and rural communities. Rural–urban linkages between waste management status, EPR policies, and plastic pollution should be further investigated.

This study also argues the role of the global alliance in improving island waste management practices affected by domestic and ocean plastic pollution. Practical solutions to reducing plastic pollution in less developed regions and circular economy opportunities relevant to rural communities, such as upcycling (artisanal goods) or using plastic fractions in building materials (ecobricks, paving stones and roof tiles), are examined in Section 6 based on peer-reviewed literature and on-field expertise provided by the organization WasteAid.

Rural settlements are heterogeneous with various natural, socio-economic, and cultural backgrounds, and decisions regarding plastic waste management options must have community support. Circular economy opportunities and interventions to reduce plastic pollution in rural areas depend on the one hand on the improvement of the formal waste management sector that feeds recycling industries, and on the other hand on community efforts, informal sector contributions, or rural entrepreneurial incentives in less developed rural regions. Overall, rural regions cannot be further ignored in the current plastic pollution crisis and the transition efforts of countries towards a circular economy.

Author Contributions: Conceptualization and methodology, F.-C.M.; writing—original draft preparation and revision per section: Section 1 (introduction), Sections 2, 4.3.2, 5.6 and 7 (conclusions), F.-C.M.; Section 3.1., L.A.M. and F.R.K.; Section 3.2., C.G.; Sections 3.3 and 3.4, S.G.; Sections 3.5 and 4.3.2, A.O.; Section 4.1, J.G.; Section 4.2, N.R.-B.; Section 4.3.1, F.R.K.; Section 5.1, P.L.-M. and M.M.-S.; Section 5.2, C.M.; Section 5.3, S.E.; Section 5.4, V.I.; Section 5.5, S.P.; Section 6.1, L.A.M.; Section 6.2, Z.L.; original/adapted figures, L.A.M., F.-C.M., P.L.-M. and C.G.; writing—review and editing of sections of the manuscript, F.-C.M., A.O. and L.A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors appreciate the support of Mostafa Ahmed Abdelsattar Ahmed in the data collection for plastic waste management in African rural areas (Section 5.3).

Conflicts of Interest: The authors declare no conflict of interest.

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