

Review

Solid Waste Management in Rural Communities of Developing Countries: An Overview of Challenges and Opportunities

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Abstract: Solid waste management (SWM) in rural areas of many low- and middle-income countries (LMICs) represents a critical and underrated topic. However, almost half of the world's population still lives in rural areas and an adequate SWM is crucial in reducing environmental and health threats. A lack of knowledge and appropriate tools often leads to inappropriate practices such as waste dumping and uncontrolled burning. However, appropriate methods can transform waste into resources and even guarantee a revenue source. This manuscript provides an overview of the state of the knowledge characterising SWM in rural communities of LMICs, analysing common practices and principal issues. Different solid waste fractions are considered. Virtuous approaches are presented, taking into account recent sustainable solutions. Considering that a relevant part of the world population is still living in rural areas, the benefits associated with an appropriate SWM may be enormous. Such activities may improve local conditions from social, environmental and health perspectives; furthermore, they may have a global impact on facing climate change and environmental pollution.

Keywords: rural areas; SWM; LMICs; circular economy; waste hierarchy



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1. Introduction

Solid waste represents a growing challenge at the global level that, when not adequately managed, poses risks to the environment and human health [1–3]. The matter is particularly critical in low- and middle-income countries (LMICs); indeed, such areas often face more economic and technical hurdles than industrialised countries [4,5]. Moreover, people living in rural areas often encounter additional challenges making solid waste more difficult to manage [6]. Notwithstanding, modern products and, consequently, new waste fractions have reached rural areas over the years. Indeed, plastic and e-waste can be found in such contexts [7,8]. Unfortunately, people from rural areas often lack the proper awareness and tools to manage solid waste appropriately and turn to dangerous practices such as open burning or waste dumping [9,10]. Although some rural communities have been trying to make resources from waste, recover precious flows and increase their revenues, they have been using polluting practices in many cases [7].

In addition, it was estimated that total greenhouse gas (GHG) emissions from solid waste contribute approximately 5% of overall GHG emissions into the atmosphere [11], making the sector crucial in fighting climate change through appropriate practices. On the other hand, solid waste disposal sites worldwide are vulnerable to emerging phenomena related to climate change, such as increased rainfall and wind speed [12].

Furthermore, not negligible differences persist between rural areas of low- and high-income countries, starting with road infrastructures being usually worse in LMICs [13], making their rural communities more isolated. In addition, waste characteristics are significantly different and solid waste management (SWM) practices are weaker [4]. Han et al. [14] found a linear relationship between the domestic waste generation rate and the gross

national income per capita in rural areas; however, the study had a very low correlation ($R^2 = 0.3024$). More recently, Gómez-Sanabria et al. [10] projected municipal solid waste (MSW) generation until 2050 in each continent, both in urban and rural areas. The authors assumed different scenarios based on the Shared Socioeconomic Pathways. As expected, MSW generation in rural areas was always the lowest.

However, it is necessary to underscore that an estimated 45% of the world population was living in rural areas in 2018, representing about two-thirds of the people in LMICs [15]. Notwithstanding, challenges affecting SWM in rural communities of LMICs often represent an underrated topic [14]. In many cases, authors have focused more on managing the organic fraction of solid waste. For instance, Patwa et al. [16] conducted a review on solid waste characterisation and treatment technologies in rural areas of India, also analysing other international case studies. However, they only discussed treatment technologies for the organic fraction, overlooking different waste categories, even assuming that rural areas were free of toxic waste. Nevertheless, other waste categories are also critical in rural communities and may pose additional threats. In addition, Anwar et al. [17] assessed which waste management configuration could represent the optimum cost solution for rural villages in developing countries. The authors compared centralised, clustered, and decentralised MSW management systems associated with different technologies (e.g., incineration, landfilling, composting) and made available valuable data in terms of cost for each piece of equipment. In addition, their results showed that an improved waste treatment increased the net profit, i.e., composting and other waste recycling practices resulted in more sustainability than landfilling from an economic perspective. The results can be integrated with the findings of Araya-Córdova et al. [18], who recently highlighted how efficient policy to support recycling programs can be crucial for the most vulnerable population, especially those in rural areas. The policy aspects mentioned by Araya-Córdova et al. [18] appear appropriate, particularly when the authors noted that the lack of economic resources at the national level in MSW management might significantly affect rural areas. However, the approach and conclusions of Anwar et al. [17] overlooked crucial aspects and appeared excessively simplified. Indeed, on the one hand, people from rural communities tend to reduce the cost associated with waste management through illegal dumping and uncontrolled burning of waste [9]; thus, the unsafe but almost unexpansive practices were ignored by the authors. On the other hand, most of the technological approaches described by Anwar et al. [17] could be unsustainable in rural villages of LMICs because of constraints that usually characterise these areas. For instance, it may be challenging in rural villages to organise a centralised waste collection system due to unpaved roads. Furthermore, access to electricity tends to be very low, and it is hard to identify a waste recycling strategy that is technically, economically, and environmentally sustainable [5,9,13,19]. Thus, site-specific strategies and appropriate practices must be analysed in detail before implementation. Such an approach should be based on the circular economy principle, turning goods at the end of their service life into resources and minimising waste generation [4]. Thus, waste reduction, reuse and recycling play a crucial role. The importance of developing expertise in SWM and treatment in rural areas of LMICs was also highlighted in an editorial by He [20].

Despite the topic's relevance, only Patwa et al. [16] conducted a review on SWM in rural communities of LMICs. Still, as anticipated, the authors solely focused on managing the organic fraction of solid waste, underestimating crucial aspects. Therefore, the scope of this review is to fill the scientific gap on a currently underrated topic. It provides an overview of the state of the knowledge characterising SWM in rural communities of LMICs, analysing common practices and main issues. Different solid waste fractions are considered. Virtuous approaches are presented, taking into account recent sustainable solutions. Finally, future perspectives are discussed.

2. Overview of the SWM in Rural Areas of LMICs

2.1. General Aspects Characterising Rural Communities of LMICs

It was estimated that just under half of the world's population lived in rural areas in 2018 [15]. This corresponded to the majority of people living in LMICs. From a geographic perspective, all LMICs are located in Asia, Africa, Latin America and Oceania [21].

It is essential to consider that rural areas of LMICs are usually affected by more constraints than urban ones. For instance, in Ghana, the proportion of people living below the international poverty line in 2017 was 22.1% and 1.9% in rural and urban areas, respectively [22]. In the same country, the proportion of the population using improved drinking water sources in 2017 was 17.9% (rural) and 65.0% (urban) [22]. In Haiti, the population using safely managed sanitation services (SDG6.2.1a) in 2020 was 25% in rural areas and 46% in urban areas [23]. In Mozambique, the difference between urban and rural areas related to SDG6.2.1a was even bigger: 21% (rural) and 61% (urban) [24]. As discussed hereinafter, the difference is also significant in SWM practices and services. Such aspects must be considered when interventions to improve environmental, social and health conditions are conceived.

2.2. Waste Characterisation

The waste generation per capita in rural areas of LMICs tends to be lower than elsewhere [10]. This is mainly due to lower lifestyle, income, and resource consumption [14,16]. Poverty and lack of materials can make people more environmentally sustainable; indeed, they give decisive importance to product reuse [25,26]. In this aspect, such communities have a more sustainable approach than others. They are more in line with the circular economy and waste management hierarchy principles that conceive waste reduction and material reuse as essential [27]. The downside is that people should not be induced to have such an approach because of poverty. Environmental and social sustainability may not be opposed.

Table 1 shows the waste generation rate per capita in rural communities of developing countries, taking recent scientific literature as a reference [28–33]. As can be seen, the values vary substantially, in this case, from 0.18 to 0.57 kg/(inhabitant × day). However, depending on the abovementioned factors, it is possible to find values outside this range. Indeed, the values mentioned by Rajpal et al. [28] and Rodrigo-Illarri et al. [33] were obtained in the present manuscript as an average from the villages surveyed by the authors. Furthermore, local legislation can effectively reduce some waste flow, as the ban on plastic bags in some African countries has proven [34]. Other factors can contribute to reducing waste generation in rural communities; for example, people sometimes use food waste as animal feed [35] or green waste for cooking [36].

Table 1. Waste generation rate per capita in rural communities of developing countries.

Country	Waste Generation per Capita [kg/(Inhab. × Day)]	Source
India	0.18	[28]
Iran	0.26	[29]
Iran	0.44	[30]
Morocco	0.57	[31]
Togo	0.34	[32]
Colombia	0.46	[33]

Waste composition is crucial in identifying the main challenges and the best waste management strategies. It can vary significantly depending on local conditions. Table 2 shows waste composition in rural communities of developing countries. NA stands for Not Available information. Organic waste always represents the prevalent fraction. As shown in Table 2, in which recent scientific literature was taken as a reference [8,28–30,32,37–39], the

organic fraction is usually above 50%, even reaching 90% in very isolated communities [37]. Though some authors have found lower values, i.e., around 40% [8,32,38], factors such as the use of food as animal feed may have influenced the percentage [35]. Plastic is usually the second representative waste fraction, with values ranging from 4% to 20%. However, paper waste can also represent a significant fraction, around 10% in some cases [8,38]. Metals and glass have a substantial variation, between 0.34% and 6.32% for metals and between 0.40% and 4.42% for glass. In addition, in one case [32], soil, dirt and sand (defined as other waste) were the predominant fractions. It can be due to specific habits and material consumption. However, informal waste pickers or local markets for such potentially valuable recyclables may also influence the percentage of metals and glass that become waste [40,41]. Among the other waste categories, hazardous waste is worth mentioning. Indeed, such a waste fraction (including e-waste) was identified by many studies in rural villages of developing countries [8,37–39]. This contrasts with the assertion from the review of Patwa et al. [16], in which rural areas were assumed to be free of toxic waste.

Table 2. Waste composition in rural communities of developing countries.

Country	Waste Fractions [%]									Source
	Organic Fraction	Plastic	Paper and Cardboard	Metals	Glass	Textile	Woods	Hazardous	Others	
Mexico	42.55	14.95	9.50	2.60	3.75	7.40	0.40	0.45	18.4	[8]
India	74.00	4.00	7.00	1.00	0.40	2.00	6.00	NA	5.60	[28]
Iran	50.98	13.58	6.07	0.47	2.09	12.53	0.44	NA	13.84	[29]
Iran	47.38	6.98	6.30	6.32	4.42	4.13	3.95	NA	20.54	[30]
Togo	38.00	11.00	7.00	≈1.00	<1.00	≈1.00	NA	<1.00	41.00	[32]
Brazil (Amazon)	90.00	5.00	1.00	3.00	NA	NA	NA	1.00	NA	[37]
Thailand	43.29	20.62	11.43	0.34	1.40	4.55	1.55	0.29	16.53	[38]
Thailand	66.00	15.00	6.00	NA	NA	NA	NA	1.00	12.00	[39]

2.3. Constraints and Typical Waste Management Practices

Constraints associated with bad road connections to urban areas make waste collection and management exceptionally challenging in rural areas. Indeed, in many cases, big waste trucks can encounter difficulties travelling for long stretches of unpaved roads, and communities or isolated households need to organise themselves independently [6]. Indeed, while in urban areas of low- and lower-middle-income countries, Kaza et al. [4] estimated a waste collection rate of 48% and 71%, respectively, the same authors estimated that in rural areas, the waste collection was much lower, i.e., 26% and 33%, respectively. As a consequence, typical waste management practices at the community level consist of uncontrolled burning of waste, waste dumping, waste burying and reuse of unsorted waste as fertiliser [5,6,9,42,43]. Gómez-Sanabria et al. [10] highlighted that about 80% of waste burning in rural areas involves the uncollected fraction. In addition, waste recycling and livestock feeding can be illegally carried out in dumpsites, as Taghipour et al. [29] reported. All such practices are associated with significant environmental and health risks, such as soil, air and water contamination, infectious diseases, and bioaccumulation of contaminants through the food chain [1,44,45]. In some circumstances, informal waste pickers are involved in collecting precious waste flows, i.e., recyclables [7,46]. However, waste pickers usually do not use personal protective equipment or are unaware of the risks of such an informal job [47].

Improper SWM also affects rural coastal areas [48]. Plastic pollution is one of the most evident effects [49]. In specific contexts, fishery activities may play a substantial role in plastic pollution, both in the Ocean and freshwater ecosystems [50,51]. For instance, research on fisher communities in India and Bangladesh along the Gange River explored the behavioural drivers of plastic waste input [51]. It identified short gear lifespans, high

turnover rates, a lack of appropriate end-of-life gear disposal methods, and ineffective fisheries regulations. Research carried out in the Goiana Estuary, Northeast Brazil, assessed plastic debris in the stomach of catfish species [52], finding that nylon fragments from cables used in fishery activities played a significant role. Research conducted in the Beibu Gulf, China, focused on the impacts of fishery activities on microplastics in sediments finding dominant contaminants (polypropylene and polyethylene fibres) that might originate from the abrasion of fishing gear [50].

Another aspect that should not be underestimated concerns the diffusion of renewable energies, such as photovoltaic systems for rural electrification in LMICs [53]. Indeed, such access to energy may offer significant benefits to the rural population, but the inadequate management of e-waste can pose many environmental and health threats [54]. Indeed, it has to be considered that e-waste is not easy to manage and brings dangerous substances (e.g., heavy metals and metalloids) [55].

Furthermore, although it is not very common, rural villages can specialise in e-waste management. For instance, until recent years, e-waste was informally recycled in rural Chinese villages at the cost of substantial environmental and health issues. An emblematic case is Guiyu. As Li et al. [56] explained, before 1995, it was a poor, rural rice-growing area. Between 1996 and 2015, Guiyu became one of the largest e-waste recycling centres in the world, and many e-waste workshops appeared without any technical support. As a result, environmental pollution and related diseases highly affected this area [57]. Finally, the small workshops were closed, and a government-run industrial park with stricter environmental controls was created [56].

Additionally, the concept of rural environmental injustice should be taken into account. For example, it happens when the urban population obtains most of its food from rural areas causing additional waste flows and pollution in rural regions [58]. It is important to note that acute poisoning by agricultural pesticides is an important cause of adverse human health outcomes worldwide, with millions of farmworkers annually exposed to pesticides in developing countries, often without adequate protective equipment [59].

3. SWM in Rural Communities of LMICs: Analysis of Recent Trends and Approaches

3.1. Management of the Organic Fraction of Solid Waste

Considering that the organic fraction is prevalent, Patwa et al. [16] mentioned composting as the best suitable treatment of solid waste in rural communities. With this in mind, the authors stated that vermicomposting and windrow composting were the most convenient. In particular, they were vermicomposting in terms of higher nutrient contents and lowering GHG emissions, while windrow composting was the most accessible method.

But even such techniques need to be contextualised and cannot always be considered the most appropriate. Indeed, in rural settlements, windrow composting appears more appropriate (1) when a waste collection system involving one or more rural communities is feasible or (2) when big farms are involved [60,61]. In the first case, taking into account that dirt roads usually characterise these areas, waste collection with donkey carts could represent the best choice [6,62,63]. Instead, in the case of big farms that produce a significant amount of agricultural waste, a waste collection system involving other waste producers could not be necessary if such farmers could manage their composting plants [64]. At the same time, the benefits of decentralised composting regarding appropriate waste management and GHG emissions reduction cannot be underestimated, as Yeo et al. [65] have discussed in a case study from Côte d'Ivoire. However, waste composting needs to be combined with source-separated collection to ensure the production of high-quality compost, reducing the risk of contamination [66].

Concerning vermicomposting, further research is still necessary to understand the exact mechanisms involved in pathogen reduction, the composition of bacterial communities, effect on heavy metal content [67,68]. The optimum temperature for earthworms in the vermicomposting process is assumed to be up to 35 °C, and it is usually not enough to remove adequate pathogens. As a consequence, Ali et al. [69] proposed composting and

vermicomposting integration. Thus, vermicomposting currently seems more appropriate when communities of farmers are involved, and they can also handle windrow composting.

A good alternative for biowaste management can be represented by composting bins at the household level. The main advantage is represented by the economic and technical sustainability characterising it. Indeed, it would not require any waste collection system; people would only need a waste bin. The study of Mihai and Ingraio [70] offers valuable hints. Indeed, even if it did not concern LMICs but rural settlements from Romania, the results can be employed for other contexts. In particular, the authors pointed out the role of home composting in diverting the biowaste from landfills and illegal dumpsites for the regions not covered by waste collection services. In addition, a good design based on appropriate technologies can improve the home composting performance in terms of compost quality and net GHG savings compared to landfilling, open dumping and the need for collection with motor vehicles. Such an approach was followed in a project for local development in Ghana involving rural communities [6]. It is crucial to consider that awareness and systematic behaviour change campaigns are fundamental [71]. Furthermore, in a study conducted in rural Vietnam, Loan et al. [72] found that households' decisions to become involved in a home composting scheme and the level of participation were affected by motivational factors such as knowledge about home composting, attitude toward it, and owning a garden.

Furthermore, Manomaivibool et al. [39] presented community-based management (CBM) approach to promote source separation in rural areas of Thailand. In the project followed by the authors, it was asked rural households:

- (1) to install a composting bin;
- (2) to separate recyclables;
- (3) to use the compost they produced in the homegrown garden.

In the 18 pilot villages involved, overall, such a CBM approach was successful. However, this study conceived the use of composting bins at the household level.

A further method to valorise biowaste, which has been seeing growing interest over the last few years, consists of anaerobic digestion to produce biogas at the household level [73]. This is a biological process whereby organic matter is decomposed in the absence of oxygen. The anaerobic digestion process treats biodegradable organic matter in airproof reactor tanks to produce biogas, i.e., energy. It can represent a positive solution from many perspectives. Indeed, rural communities of LMICs often face energy constraints [19]. Energy is required to cook and carry out other daily activities. In many cases, people burn charcoal or wood, contributing to air pollution and deforestation. An often proposed alternative consists of photovoltaic systems or wind turbines [74,75]. However, as discussed in the previous section, even such green technologies can hide environmental pitfalls. Indeed, at the end of their life cycle, they became e-waste challenging to manage in rural areas of LMICs, which also contain toxic pollutants. In such a scenario, the benefits of anaerobic digestion are evident in offering an alternative energy source. As mentioned, it can even be applied at the household level [73]. However, attention needs to be posed to the management of the unit. Furthermore, the waste inflow represents a critical element. Indeed, as Cucina et al. [76] highlighted, in the case of cattle or pig manure, lack of stabilisation and pathogens' presence represented the main issues for the agricultural reuse of digestate. This has also been highlighted by Amato et al. [77]. Here, the authors found that, although biodigester cookstoves can reduce household air pollution, children's diarrhoea may be an unintended health risk when human and animal sludges are used. Vögeli et al. [73] underscored that food and green waste have a significantly lower pathogen content, and using them (without sludge or manures) can reduce the presence of pathogens in the digestate. As a consequence, it could already be used as fertiliser. However, the effluent usually has a high COD concentration; thus, if digestate is not used as an organic fertiliser but is instead discharged to a water body without additional treatments, this would contribute to water pollution [73]. Furthermore, the guide of Ulrich et al. [78] can be taken as a reference for liquid digestate treatment aiming to improve effluent quality, particularly

when pathogens are expected. If the digestate has a high solid content and pathogens are forecasted, the process can be followed by composting [79]. Digestate reuse in agriculture is as strategic as biogas for rural households and small-scale farms of LMICs, and applications already exist [80,81]. It must be noted that in terms of GHG emissions, biogas from solid waste use must be carefully evaluated. Indeed, on the one hand, methane has a greenhouse potential of more than 20 times higher than CO₂. Thus, converting methane into CO₂ through complete combustion is another way to mitigate GHG emissions; on the other hand, such an assumption is valid when the treated organic materials would otherwise undergo anaerobic decomposition, thereby releasing methane [73]. As a consequence, in terms of GHG emissions, other biowaste treatment methods such as decentralised composting [65] are usually more beneficial.

Another alternative, studied by Fajfrlíková et al. [82], is the organic waste treatment to obtain low-pressure briquettes. Such an approach would lead to producing solid fuels to be used in rural areas in place of firewood. In the research, waste agricultural and household biowaste were considered using a manual wooden low-pressure briquetting press. The authors found a positive correlation between education and the level of potential investments.

3.2. Management of Other Waste Fractions

Few examples from the scientific literature are available concerning the recycling of other waste fractions in rural villages from LMICs. In particular, plastic recycling could appear like an excessively challenging solution in rural settlements of LMICs. It represents a practice that only a few authors have discussed. Salhofer et al. [7] analysed this in detail by considering a case study from Vietnam. In this case, plastic waste was sent to rural craft villages for recycling, where it was processed manually and with outdated technology. The basic production unit in such villages was a household enterprise specialising in one or two activities (e.g., waste collection, separation, shredding, or extrusion). Such recycling activities operated under unregulated and uncontrolled conditions, posing significant health hazards and polluting the environment and the surrounding communities. Salhofer et al. [7] described the following plastic recycling activities held in the villages they assessed:

1. Purchase and sorting of plastic waste;
2. Washing of plastic;
3. Burning of sorted-out plastics;
4. Shredding;
5. Plastic extrusion and granulation.

The authors concluded with the following list of measures that should be taken to improve the situation:

1. More selective material intake to the recycling facilities;
2. Personal protective equipment (PPE);
3. Treatment of wastewater from washing and shredding;
4. Gaseous emissions reduction for extrusion and granulation, for example, by using filters;
5. To better organise the disposal of residues.

Notably, only Villa et al. [83] have recently discussed the design of a sustainable treatment plant for wastewater generated from a small-scale centre for plastic sorting (CPS) in a developing country (Mozambique). The CPS was designed according to a classical layout, which includes the acceptance and sorting area, the primary storage for loose material, a washing and drying area, a shredding area, and a secondary storage area for treated material. In addition, the washing tank was connected to the wastewater treatment system with the following units: a septic tank, a grease trap, and a subsurface flow constructed wetland. Therefore, the procedure implemented by the authors could be

taken as a reference to improve environmental conditions associated with plastic recycling in LMICs.

Considering that plastic recycling in rural villages may represent a source of new revenues, efforts to fulfil such measures should be made. National or international funds (for instance, through international cooperation projects) should be allocated. Otherwise, it would be better to shift to other solutions, such as those discussed below. However, if in rural villages people have already been involved in plastic recycling activities, as in the Vietnam context, it would be more appropriate to improve the environmental situation without causing a loss of jobs and revenues.

In addition, Mihai et al. [84] highlighted the need for circular economy solutions to reduce plastic pollution in rural areas. The authors mentioned a series of possible interventions, such as replacing conventional plastics with more environmentally friendly materials; redesigning products with optimal recyclability; promoting reuse and return schemes by providing local infrastructure and incentives; and promoting creative recycling practices at household and community levels.

As anticipated, another approach that people from poor areas often practice consists of reusing packaging and other materials. It is the first way to reduce waste at the source, and it is mentioned by international agencies [27]. A good reference to following such an approach is discussed in a document from the Ellen MacArthur Foundation [85], in which 69 reuse examples are presented.

A similar approach also came from Nair et al. [86]. The authors described how to make photovoltaic systems in rural areas of developing countries by reusing commonly available waste (e.g., plastic bottles) for some components.

Another strategy to follow should consist of a plastic ban. As Godfrey [87] discussed, countries worldwide are taking action to minimise the impact of plastic waste. Banning single-use plastics represents one promising approach that has proven successful in African countries such as Rwanda and Kenya [34]. Overall, plastic waste prevention should be a top priority also to reduce marine pollution [88]. Indeed, it is essential to note that waste collection is not always the best way to face marine pollution, as González-Fernández et al. [89] recently highlighted. Indeed, the authors estimated that more than 300 million litter items are released annually from Europe into the Ocean, with plastic representing 82%. It has to be noted that in Europe, waste collection is already significantly higher than in Africa or Latin America [4].

Another SWM practice was discussed by Yang et al. [90]. The authors assessed the implementation of small-scale incinerators in rural communities. The combusted materials mainly included plastic, household, livestock and poultry waste. No filters were installed to reduce air pollution. However, such an approach appears detrimental from environmental and health perspectives. Indeed, persistent by-products such as dioxins can be generated [2].

Raut et al. [91] discussed recycling paper mill waste in rural areas. The authors proposed a simple procedure to make construction bricks. The machinery used could even work in rural areas of developing countries.

Wang et al. [92] noted that structural factors are crucial for ensuring proper solid waste disposal in rural villages. Multiple collection points should be made available in areas where the distance from a disposal site is more than 2 km.

Furthermore, Struk and Bakoš [93] analysed the long-term benefits of intermunicipal cooperation for small municipalities. The authors underscored the benefits of reducing service costs and other qualitative and non-financial benefits, such as better service quality and the possibility of sharing infrastructures. It is something that neighbouring rural villages should take into account. In addition, as anticipated, Araya-Córdova et al. [18] recently highlighted how efficient municipal resources allocation policy to support recycling programs can be crucial in improving conditions in rural areas of developing countries.

Moreover, the involvement of informal waste pickers can play a substantial role in recovering potentially valuable waste (e.g., metals and glass) [40,41].

In general, it must be considered that if a rural area is close to an urban area, it may be easier to find recyclers. However, in remote areas, the transportation cost of recyclable waste represents an obstacle that cannot be underestimated. Therefore, a preliminary value chain analysis is recommended.

Thus, other solutions could be represented by the temporary storage of recyclable waste that is not simple to recycle in rural settlements of developing countries [20]. Such storage could occur at the community level in a proper area. With a specific frequency, based on local waste production, the availability of waste collection vehicles, and the roads' quality, such waste should be collected and brought to recycling centres. Such an approach should be followed for recyclable wastes, but the organic fraction should not be involved. Indeed, it appears more sustainable when treated nearby, considering its high biodegradation rate. In the case of plastic, sorting polymer waste within the communities can be pivotal. Informal waste workers could be involved. A similar approach can be followed to dispose of unrecyclable wastes in sanitary landfills. Indeed, keeping in mind that sanitary landfills can be expensive and challenging to manage in LMICs, conceiving such systems near more urbanised areas with adequate road connections would represent the most sustainable solution. Furthermore, transfer stations could be conceived to face economic and technical constraints and improve the system's efficiency [94].

3.3. Summary of the Best Approaches

The best approaches discussed in Sections 3.1 and 3.2 are summarised in Table 3.

Table 3. Summary of the best approaches identified for rural communities of developing countries.

Waste Fraction	Suggested Approach	Notes
Organic waste	Decentralised windrow composting	<ul style="list-style-type: none"> • Involvement of one or more communities, or big farms • Waste separation at source is needed
Organic waste	Composting bins at the household level	
Organic waste	Anaerobic digestion at the household level	To contain biological risks faecal sludges have to be avoided, or a post-treatment for the digestate needs to be conceived
Organic waste	Manual wooden low-pressure briquetting press	
Plastic waste	Plastic recycling in rural craft villages	<ul style="list-style-type: none"> • Environmental and health risks cannot be underestimated • PPE needs to be used • Necessity of selective material intake • Treatment of wastewater • Gaseous emissions reduction • Value chain analysis is recommended
Plastic waste	Reuse of plastic waste for some photovoltaic components	
Plastic waste	Banning single-use plastics	
Paper waste	Production of construction bricks	Value chain analysis is recommended
Recyclable waste in general	Involvement of informal waste pickers	
Recyclable waste in general	Temporary storage and subsequent dispatch to specialised centres	<ul style="list-style-type: none"> • It is not recommended for organic waste • Pre-treatments could be helpful (e.g., sorting polymer waste)
Unrecyclable waste in general	Temporary storage and subsequent dispatch to sanitary landfills	The presence of transfer stations could be necessary
Solid waste in general	Government supports and provides specific legislation to promote waste reduction and material reuse	
Solid waste in general	International supports, funds and agreements	
Solid waste in general	Promoting waste reduction and material reuse	
Solid waste in general	Intermunicipal cooperation	
Solid waste in general	Improvement of road connections	

4. Conclusions

As the list of challenges above has highlighted, site-specific conditions need to be evaluated in proposing sustainable waste management practices in rural communities of LMICs. However, successful approaches are already available.

At the same time, uncertainties affecting biowaste management techniques, such as vermicomposting and anaerobic digestion, must be studied further. Indeed, additional studies will be necessary concerning vermicomposting to understand the pathogens' removal rate better. Similar matters concern digestate from anaerobic digesters.

Besides, in the future, additional SWM emerging techniques and their potential implementation in rural communities of LMICs could be investigated.

In addition, although waste recycling represents a positive solution, waste reduction and reuse should receive substantial attention. Indeed, as van Ewijk et al. [95] recently underscored, the potential environmental benefits of recycling are unclear or contested for some materials. Therefore, recycling from a circular economy perspective should be scrutinised for its energy requirements and GHG emissions. A value chain analysis would also be beneficial.

To make recourse to transfer stations for waste collection and recycling or disposal in appropriate units may represent an additional solution. Moreover, a long-term perspective should conceive the improvement of the quality of road connections.

Remembering that a relevant part of the world population is still living in rural areas, the benefits associated with an appropriate SWM may be enormous. Such activities may improve local conditions from social, environmental and health perspectives; furthermore, they may have a global impact on facing climate change and environmental pollution.

National or international funds should be allocated, considering the growing interest in solid waste pollution [96] and climate change [97]. A more vital link between local stakeholders and research centres should be realised to improve the benefits and outputs of many research and development projects. In addition, the training of local stakeholders and the diffusion of systematic behaviour change and awareness campaigns may play a crucial role.

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