A Perspective on a Locally Managed Decentralized Circular Economy for Waste Plastic in Developing Countries

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Unsound post-consumer disposal is the primary pathway of plastic into the ecosystem. One way of addressing this problem is through the establishment of a circular economy for plastic. Much of the unsound disposal comes from economically disadvantaged regions where waste disposal and recycling infrastructure is limited. In economically disadvantaged regions however, the establishment of a circular economy for plastic must be locally managed and decentralized, meaning that the disposal, collection, remanufacture, and use must all occur within the same community. We suggest that waste plastic abatement strategies must be targeted to reduce, reuse, and recycle plastic waste onsite at the local level, initiating a circular economy appropriate for infrastructure limited regions. Technologies for recycling plastic must be low cost, economically viable, socially acceptable, and not adversely impact the environment, and also produce a product that has a ready local market. This is critical because unless proposed solutions are also economically viable and socially appropriate, they are unlikely to be successful, especially in underdeveloped regions. Using big data analysis, a metric for identifying countries that will have the most potential to benefit from a locally managed decentralized circular economy for plastic has been developed. The information obtained from this metric will help researchers and policy makers promote a locally managed decentralized circular economy of plastic for managing the accumulation of waste on land and its eventual migration into waterways. Additionally, we present a case study of a proposed locally managed decentralized waste plastic abatement strategy in the municipal solid waste infrastructure limited country of Uganda. © 2018 American Institute of Chemical Engineers Environ Prog, 2018

Keywords: alternate fuels, sustainability

INTRODUCTION

Plastics are used in every country on earth and none is able to successfully collect and manage 100% of its plastic waste. Once produced, plastic enters the global supply chain and is used in all regions of the world. In fact, our world is generating, consuming, and discarding more plastic than ever, and the rates are increasing [1–5]. The growth rate of plastic production has increased at 5% per year worldwide [1]. In 2010, approximately 270 million metric tons (MT) of plastic were produced, with 99.5 million discarded as waste by coastal populations living within 50 km of the coast [6]. Additionally, it was estimated that of the plastic waste generated that year, 31.9 million MT were mismanaged on land and 4.8–12.7 million MT entered the oceans [6]. If current trends continue, by 2050, 33 billion MT of plastic are likely to be produced, with approximately 12.2 billion MT disposed of as waste, 3.9 billion MT mismanaged on land, and 0.6–1.6 billion MT eventually entering the oceans [2,6]. This is a 122-fold increase in a matter of 40 yrs, meaning that global plastic production is increasing exponentially. Just between 2015 and 2026, we will make as much plastic as has been made since its production began [3].

There are numerous potential resting spots for waste plastic in the ecosystem including disposal in landfills, recycling, incineration, and unregulated dumping. Disposal on land is the most common option with previous studies showing that globally 60% of plastic municipal solid waste (MSW) is discarded in open space or in landfills [1]. A key challenge is that in much of the world, appropriate waste disposal options are unavailable, including properly managed landfills, leading to waste plastic simply being dumped on open unestablished plots, accumulating on sides of roadways, and on outskirts of rural residential areas. This accumulation of plastic waste on land can become a breeding ground for mosquitoes, cause clogged waterways and drainages, and reduce the general aesthetics of the community [1]. As plastic can take thousands of years to decompose, both landfills and unregulated plots of land will remain unusable long after the dumping ends [7,8], and if not managed properly, chemicals can leach from the plastic into surrounding habitats [2]. Eventually, this plastic waste will be disposed of in, or migrate to surface waters, generating pollution and threating both terrestrial and marine life. Specifically in major bodies of water, plastic waste is ingested by marine life and bird species, resulting in adverse health effects, entanglement, and death [2–4,9–11].

Figure 1 shows plastic bags collecting in a drainage canal in Kampala, Uganda, due to unregulated dumping. This is a common problem in many resource-constrained or infrastructure limited parts of the world, where lack of effective governmental policy, MSW management administration and planning, along with insufficient household education, economic pressures, limited perspectives on hazards associated with waste accumulation, and scarce stakeholder involvement affect how

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Figure 1. Waste plastic and other trash clog a spillway in Kampala, Uganda. [Color figure can be viewed at **wileyonlinelibrary.com**]

waste is disposed or managed [12,13]. Other factors include growing economies, urbanization, and increased standards of living, which led to rapid increases in waste generation in developing countries [14]. In rural regions particularly, access to centralized collection and recycling methods are often unavailable. Consequently, uncontrolled growth coupled with lack of sufficient infrastructure and regulation in underdeveloped regions of developing countries compounds the waste management problem [15–18]. Because these factors include economic and social as well as environmental components, it is critical that proposed solutions include them as well. Therefore, in our view, without considering the three pillars of sustainability, MSW management solutions are unlikely to achieve long-term success.

A Perspective on a Locally Managed Decentralized Circular Economy

Unfortunately, there are currently no globally effective strategies to keep waste plastic out of the ecosystem that meet the challenges of both developed and developing countries. This is primarily because waste plastic is not a point-source pollutant. As plastic enters the ecosystems from numerous points, it has been a major obstacle for control [5]. Moreover, low-income and low-to-middle income countries lack the resources to address this problem. In fact, in addition to lack of waste collection and management infrastructure in underdeveloped regions, researchers have identified that simply the lack of convenient waste disposal containers can affect household waste disposal decisions [15,19]. If people have to walk long distances to reach a suitable disposal location, they will simply dump the waste nearby on streets, underdeveloped plots of land, or burn it, leading to potentially toxic smoke, especially if plastics are present. This underscores our assertion that locally managed decentralized solutions—targeting waste where it is generated rather than focusing on centralized processing—may be more effective in communities where governmental waste solution efforts are minimal. This type of approach empowers individuals and small communities to adapt and invent solutions rather than waiting on central authorities to enact policies and regulations to address the problem. As a result, a locally managed decentralized circular economy of plastic products is generated, encouraging direct users of plastic to consider and benefit from opportunities of providing waste plastic a value, or by generating new life cycles for plastic products through a cradle-to-cradle approach [20].

We assert that a decentralized circular economy of plastic at the local level can have tremendous benefits in reducing the accumulation of plastic waste on land and its eventual migration to major bodies of water. An industrial circular economy replaces the produce-consume-discard model by reusing, recycling, or reentering products into their manufacturing supply chain on an industrial scale [20–28]. However, at the local level, especially in rural regions, remanufacturing of plastic products, or creating the infrastructure networks to reenter them into their respective supply chains is difficult. Traditional solutions, like centralized recycling of plastic waste, are also often impractical in remote regions, or regions lacking well-developed infrastructure due to the transportation costs, making large-scale recycling operations uneconomical. Hence, a locally managed decentralized circular economy functions to manage waste on small scale in rural regions, without the need of industrial technologies or developed infrastructure. Viable solutions are those that are low cost, can be implemented utilizing the region's technical knowledge, and most importantly provide an incentive for local people to collect, reuse, and recycle themselves.

In many economically disadvantaged regions, an informal local recycling sector exists via a system of waste pickers that sort through dumpsites to collect saleable materials such as metals, plastics, glass, and papers [21,29–33]. Often, waste pickers travel throughout communities of rural regions and cities to collect recyclables from house-to-house as well, or set up recycling drop-off locations, paying individuals a small incentive for valuable materials. Afterward, the waste pickers will sort through collected materials, clean, and sell them to recycling companies for a profit. These companies then shred and process the materials as desired by manufacturing organizations. In this way, rural communities and heavily populated urban centers of developing countries benefit from a decentralized circular economy of recyclable materials, including plastics.

However, not all plastics that are recyclable are of value to waste pickers due to a nonexistent recycling market. For instance, polyethylene shopping bags are generated in large volumes globally, but they are recycled in extremely low quantities [21], accumulating on sides of streets, dumps, and landfills in developing countries. Even in the United States, 380 billion plastic bags are consumed annually, with only 5.2% being recycled [7,8]. So, unless waste plastic items, such as polyethylene bags can be given a value, they will continue to be unsustainably used and discarded. Therefore, we assert that a locally managed decentralized circular economy with informal recycling playing a vital role in decreasing the accumulation of plastic waste is needed. Furthermore, we believe that including social and economic considerations in addition to environmental are critical to successful waste plastic abatement strategies in underdeveloped regions, which has been lacking in most plastic abatement strategies.

In Figure 2, we propose a strategy for establishing a circular economy at the local level by applying the three principles of sustainability to decentralized waste plastic management. This strategy is thermal decomposition of waste plastic to fuel oil at temperatures of 400°C–450°C [34,35]. High-density polyethylene, low-density polyethylene, polystyrene, and polypropylene plastics [7,8,34–45] can be easily converted to fuel similar in composition to diesel and kerosene by individual entrepreneurs utilizing appropriate technology (AT), providing a potential path to a locally managed decentralized circular economy. AT is simple nonautomated technology requiring little to no electricity, designed for a specific region to meet specific challenges according to available resources [34]. An AT solution for thermal decomposition of waste plastic is the UKATS Processor [34,35]. This invention is constructed locally utilizing existent construction materials, available infrastructure, technical knowledge of intended users, and from easily acquired locally generated plastic wastes. For instance, the UKATS Processor is wood fired to allow for the skills of rural communities that operate wood fired cookstoves to be readily applied. Moreover, the desired plastics can be easily collected by waste pickers or entrepreneurs by either identifying the plastic recycling numbers (2, 4, 5, and 6, respectively) or by performing a simple density test of the shredded plastics in water. That is, if the waste plastics float on water, they are suitable for reprocessing to fuel oil.

Consequently, a locally managed decentralized circular economy gives waste plastic an economic value, which incentivizes people to collect and use it locally, reducing waste accumulation. It further significantly reduces the need for physical and technical infrastructure to implement an industrial circular economy of plastic by involving local community participation as shown in Figure 2. In addition, this approach is socially and environmentally appropriate. For instance, as accumulation of waste decreases, sanitation issues decrease, improving community health. Likewise, environmental benefits are reaped by decreasing waste leachate into soil and reducing toxic hazards associated with incineration of plastic waste—a commonly practiced alternative to managing accumulation in rural regions and near slums [38,40]. The fuel oil itself also does not have sulfur dioxide emissions as sulfur is not present in the carbon-hydrogen plastic polymer chains, reducing greenhouse gas sulfur dioxide emissions in comparison with traditional petroleum derived fuels [34].

Identifying Regions of Greatest Potential for a Locally Managed Decentralized Circular Economy

We propose that in order to identify countries that will have the greatest potential for a locally managed decentralized circular economy, the three pillars of sustainability—environmental, economic, and social acceptability—should be incorporated. Hence, waste plastic abatement strategies cannot simply focus on the environment; they must also be economically viable and socially acceptable. We believe that unless solutions are targeted to be appropriate for the communities for which they are intended, they will ultimately be unsuccessful. To validate this perspective, we developed a simple metric that utilizes a big data approach to analyze countries' outlook in each of the three pillars of sustainability, highlighting regions where a locally managed decentralized circular economy for plastic is likely to have the highest positive impact.

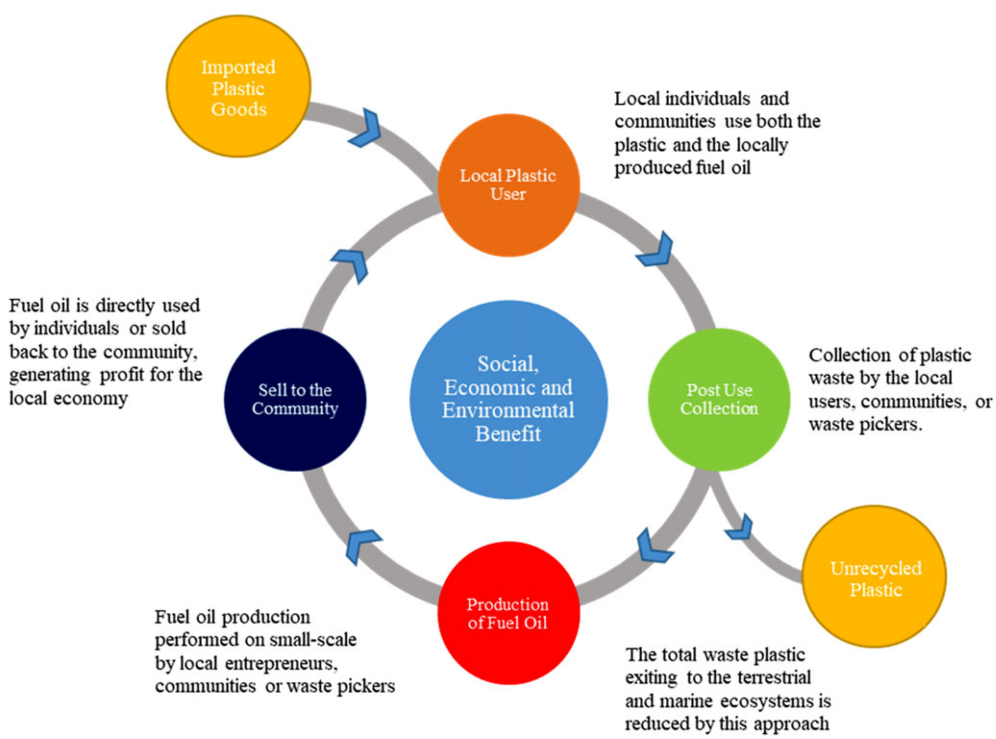

Figure 2. A locally managed decentralized circular economy for waste plastic in infrastructure limited regions. [Color figure can be viewed at **wileyonlinelibrary.com**]

Table 1. Indicators used to develop metric for identifying regions most suitable for a consumer-focused decentralized circular economy.

Sustainability indicators	Units	Justification
Economic		
Gross domestic product (GDP)	Billion USD	This indicator gives a general overview of the wealth of the country, which is directly associated with the availability of developed infrastructure.
GDP *per capita*	USD	As GDP alone is not enough to characterize the economic wellbeing of a country's population, this indicator was included as well.
Environmental		
Estimated MSW generation	MT/day	This indicator shows the magnitude of the MSW generated in a country.
Environmental stress	MT MSW/km^2	This indicator shows the concentration of MSW by including the country's land area.
Estimated plastic waste in MSW	MT/day	This indicator is specific to the key focus of this perspective, which is waste plastic.
Estimated unsound waste disposal	MT/day	This indicator provides an overview of the suitability of a locally managed decentralized solution targeted at mismanaged waste.
Social		
Population	capita	This indicator shows how many people can be potentially impacted by proposed perspective and abatement solutions.
Population below poverty line	%	This indicator shows the general wealth of the population and how likely they are to benefit from entrepreneurial opportunities associated with waste management.
Population density	capita/km^2	This indicator relates population to the rate of waste accumulation per land area, identifying hurdles of waste collection as crowded countries often have infrastructure challenges.

Today, data availability is better than it has ever been. Governments, private corporations, and NGOs are collecting ever increasing volumes of data, and much of that data is now publicly available and readily accessible via the Internet. This data is useful in conducting sustainability assessments for individual countries and regions. Here, it is organized and analyzed to identify countries which can potentially benefit from a plastic circular economy at the local level with decentralized waste plastic abatement strategies. The purpose of this metric is therefore to identify countries that have specific challenges with any or all three of the pillars of sustainability in meeting their waste management challenges, in return directly affecting the way plastic waste is handled.

Often waste management is a priority in urbanized regions of developing countries, with little attention given to rural regions. Challenges such as variation in income level, conditions of road infrastructure, and perception of communities toward waste, including education regarding hazards associated with waste influence the way waste is handled in both urban and rural regions. As a result, wealthy communities experience regular waste collection, while slums outside of a city are perceived as dumping grounds for waste. Thus, our approach considers the challenges facing each country or region, in terms of economic, social, and environmental concerns to propose decentralized waste plastic solutions that are tailored to the region's availability of infrastructure, capital, and technical knowledge. Moreover, if community participation is prioritized, engineered AT solutions are more likely to be accepted, leading to intended uses and benefits, reducing the dependency on central waste collection and management for rural regions, specifically.

In this metric, a list of 200 countries was analyzed using nine indicators, representing the three pillars of sustainability—economic, social, and environmental. These indicators are described in Table 1 and were chosen because they identify countries with widespread poverty, underdeveloped infrastructure, weak governmental institutions, and an existing MSW management problem—key indicators for determining the suitability of a locally managed decentralized circular economy. The development of the metric (see Eq. 1) considers assigning specific and global weighting factors to each of the nine indicators mentioned in Table 1 to highlight the importance of each indicator and the environmental, economic, or social outlook of the countries. As a result, a country's specific and global weighting factors can be individually adjusted to ensure that the country's outlook, challenges, and advantages are equally highlighted. Afterward, the sum of indicators and respective weighting factors results in a comparison score of each country's viability for a locally managed decentralized circular economy. Further details of this approach are described in the Supplementary Information.

$$\sum_{i=1}^{n} G_{\mathrm{EC}}\left[(I_{\mathrm{EC1}}*S_{\mathrm{EC1}}) + (I_{\mathrm{EC2}}*S_{\mathrm{EC2}})\right] + G_{\mathrm{SC}}\left[(I_{\mathrm{SC1}}*S_{\mathrm{SC1}}) + (I_{\mathrm{SC2}}*S_{\mathrm{SC2}}) + (I_{\mathrm{SC3}}*S_{\mathrm{SC3}})\right] + G_{\mathrm{EV}}\left[(I_{\mathrm{EV1}}*S_{\mathrm{EV1}}) + (I_{\mathrm{EV2}}*S_{\mathrm{EV2}}) + (I_{\mathrm{EV3}}*S_{\mathrm{EV3}}) + (I_{\mathrm{EV4}}*S_{\mathrm{EV4}})\right] \quad (1)$$

where G is the global weighting factor, I is the indicator type, S indicates specific weighting factor corresponding to an individual indicator, EC denotes economic, SC denotes social, and EV denotes environmental.

This metric can be utilized by researchers, policy makers, and other users to achieve an in-depth understanding of a country's waste management outlook, particularly with respect to the economic and social indicators, which are often overlooked. Users can adjust local or global indicator weighting factors according to a region's unique challenges or to emphasize a specific category that contributes to plastic waste mismanagement. Hence, opportunities for managing waste can be identified, with a locally managed decentralized circular economy being a viable approach.

Utilization of the Metric

For the base case, all local and global weighting factors for each of the nine indicators were weighted equally. The results of the big data analysis metric for identifying key regions

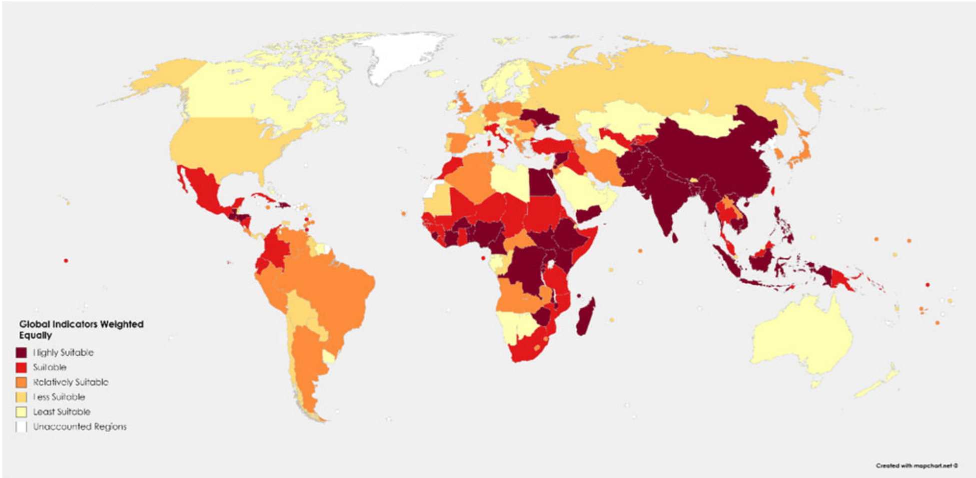

Figure 3. Suitable regions for a locally managed decentralized circular economy for plastic. [Color figure can be viewed at wileyonlinelibrary.com]

suitable for a locally managed decentralized circular economy are illustrated in Figure 3. Darker colors represent countries that are most likely to benefit from this approach. It can be observed that sub-Saharan Africa, East Asia, Southeast Asia, and South Asia are the most promising regions for applying decentralized solutions to plastic waste management. This information indicates that typically, developing highly populated low-middle to middle income countries are the most important targets for locally managed decentralized waste plastic abatement strategies. The reason being that even though the citizens of these countries generate less waste *per capita*, the consequence of higher population density results in an overall larger amount of MSW generation than developed regions. Coupled with limited financial resources, lack of infrastructure and reliable access to energy [20], waste is increasingly susceptible to unsound disposal in open dumps, streets, and waterways, especially in rural communities. Contrastingly, developing nations considered by the metric that may consume greater amounts of energy and generate higher amounts of MSW *per capita* are not ideal locations for a locally managed decentralized circular economy due to the reasons of improved collection, strong waste management infrastructure, controlled waste disposal, and an existent centralized, industrial circular economy, leading to reduction in unsound waste disposal.

The usefulness of this metric can be additionally demonstrated by weighting one of the three sustainability categories greater than the rest as per the user's interests. To illustrate this, the weighting of global sustainability indicators was varied by

Table 2. Comparison of 20 countries most suitable for decentralized waste plastic solutions according to different sustainability category weightings.

Country suitability	Global indicators weighted equally	Economic indicator weighted highest	Social indicator weighted highest	Environmental indicator weighted highest
1	Bangladesh	Burundi	Bangladesh	Bangladesh
2	Burundi	Malawi	Burundi	Pakistan
3	Haiti	Haiti	Nigeria	Vietnam
4	Pakistan	Rwanda	Pakistan	Nigeria
5	Malawi	Comoros	Haiti	India
6	Nigeria	Togo	Malawi	Philippines
7	Rwanda	Syria	Rwanda	Sri Lanka
8	Syria	Bangladesh	India	Syria
9	Vietnam	The Gambia	Syria	Haiti
10	India	Congo, Democratic Republic of the	Philippines	Guatemala
11	Philippines	Yemen	Vietnam	Burundi
12	Guatemala	South Sudan	Guatemala	Malawi
13	Yemen	Madagascar	Congo, Democratic Republic of the	Egypt
14	Congo, Democratic Republic of the	Pakistan	Togo	Rwanda
15	Togo	Sierra Leone	Yemen	China
16	Sri Lanka	Burkina Faso	Ethiopia	Yemen
17	Cambodia	Cambodia	Sri Lanka	Cambodia
18	Ethiopia	Afghanistan	Egypt	Thailand
19	Comoros	Benin	Myanmar/Burma	Congo, Democratic Republic of the
20	Myanmar/Burma	Liberia	Nepal	Myanmar/Burma

assigning a value of 50% to one, while the other two were set to 25%. This analysis is presented in Table 2 and signifies that when weighting the global economic indicator higher, countries with relatively low GDP *per capita* and high percentages of population living below the poverty line rise to the top as most suitable regions. In like manner, for social sustainability, countries with the greatest population numbers or population density are recommended. Meanwhile, estimated plastic waste in MSW 2016 and estimated unsound disposal of plastic waste in MT/day were found to be the biggest contributing factors for environmental sustainability highlighting regions suffering from uncontrolled waste accumulation. Lastly, the metric also depicts the impact of environmental stress, or the amount of waste generated per km^2 of land. Countries that rank highly in this category include the United States, many western European nations as well as high-income Southeast Asian countries, such as Hong Kong, Macao, and Singapore, which have significant environmental stress due to either high generation of MSW, population density, and/or limited land area [46,47].

As an example, India had the position of being 10th overall in this metric analysis, while being 52nd, 8th, and 5th most suitable country when global economic, social, and environmental indicators were respectively highlighted for implementation of a locally managed decentralized circular economy. Therefore, it can be concluded that for India, the lack of waste management education, attitude toward environmental protection, and insufficient collection infrastructure combined with increased waste generation due to population density are the most probable causes of plastic waste accumulation, instead of capital constraints. It is also important to note that even though a circular economy is well established in China, the country currently practices a centralized industrial circular economy [22–24]. Hence, it could likewise benefit from a locally managed decentralized circular economy approach in rural regions due to high waste generation associated large populations.

Although this analysis may appear to simply reinforce well-established beliefs, these results are used to make the point that developing urban and rural regions around the world are different, in return requiring different strategies for MSW and waste plastic abatement. The information obtained from the analysis suggests that African nations vary in their economic, social, and environmental stance compared with developing regions of Asia. This fact in itself alters the way waste management is approached in these countries, as cultural norms associated with perception of waste management vary. Another example is the data highlighting importance of waste recycling in the Americas versus in Europe. Even though both regions are developed, environmentally benign waste management is practiced in many European nations via a variety of waste-to-energy solutions, while a large portion of waste in the United States goes to the landfill. Hence, the data are used to make the case for designing and developing technologies based on each region's outlook, suggesting a locally managed decentralized circular economy in rural regions of developing countries.

Uganda Case Study

The country of Uganda is positioned 32nd in the metric assessment, meaning that it has great potential for a locally managed decentralized circular economy with informal recycling waste management approaches. Uganda has a population of 38.3 million, with a growth rate of 3.22% in 2016 [48]. The size of the country is slightly smaller in area than the U.S. state of Oregon [46]. The nation has abundant natural resources, fertile soil, sufficient rainfall, and small deposits of precious minerals and oil [48]. Consequently, agriculture and service sectors employ a combined 78.9% of the population, with coffee revenues accounting for the majority of the exports [48]. Nonetheless, the U.S. Central Intelligence Agency reports that Uganda is facing economic challenges due to sharp increase in refugees from South Sudan, high energy costs, inadequate transportation and energy infrastructure, insufficient budgetary discipline, and corruption [48]. Furthermore, during 2015 and 2016, the Uganda shilling depreciated 50% against the U.S. dollar [48]. Moreover, the nation's GDP *per capita* is equivalent to 2100 USD, with 9.4% unemployment rate and 19.7% of the population below poverty line [48]. This along with only 15% of the total population having access to electricity, and 19.1% population having access to sanitation facilities, has further led to very high risks of major infectious diseases [48]. Despite these challenges, the nation is poised as a good fit for implementation of decentralized waste management solutions, offering opportunities to recycle plastic waste locally, creating jobs and reducing the spread of diseases due to accumulation of trash.

A case study conducted in Uganda at the Kiteezi landfill in the capital city of Kampala reveals some insight on how the proposed metric has been employed for this region. In 2015, the population of Kampala was reported to be approximately 1.9 million, with 70% of the citizens living in informal settlements scattered around the city [48,49]. However, as the country's capital, it is the home of major markets and a wide assortment of job opportunities which leads to a doubling of the city's population during the day [48], increasing waste generation. Therefore, small-scale decentralized AT solutions to waste management are suggested for this city with both the community's and waste pickers' participation.

Currently, the Kampala Capital City Authority (KCCA), a governmental solid waste management organization, provides collection and cleanup services to the city's five divisions (a total 210 km^2 area) [48], contracting collection of waste from affluent areas to private companies [49,50]. Hence, the affluent areas are charged a waste collection fee, while the rest of the urban population is serviced by KCCA at no cost [49]. KCCA further manages the city's 36-acre 25-m tall landfill site at Kiteezi, where both KCCA and private sector waste collection vehicles unload MSW, excluding industrial waste, free of charge [49,50]. At present, a total of 1300–1500 MT of MSW per day are landfilled, about half of the total waste generated by the city [50]. This means that the other half is openly dumped in areas inaccessible to waste collection vehicles, including drainage channels, wetlands, natural water courses, manholes, undeveloped plots, or on the roadside [50–52]. This is a strong indication that consumer involvement and decentralized solutions to waste accumulation are needed. The composition of the waste mainly consists of bio-degradable food and garden waste (71.4%), stones and debris (8.6%), plastics (7.8%), paper (2.7%), glass and metals (1.5%), textiles (1.3%), and others (6.7%) [37]. KCCA spends approximately 13.4 USD/MT for waste collection and disposal services [49].

Waste to energy solutions and organized recycling services are not yet offered by KCCA. Nonetheless, small independently operated recycling drop-offs exist in the city's districts. As these recycling drop-offs are new to the city, each district only has one thus far, handling merely 3–4 tons of waste per week. Consequently, most of the waste is sent to the Kiteezi landfill, where it is informally sorted for recycling by waste pickers. With 500 in number, the organized community of waste pickers who live surrounding the landfill collect anything that has a well-developed market, such as construction tarps, plastic bottles, paper, glass, and metals [49]. More specifically, the plastic waste that is recycled by the waste pickers is purchased by domestic and international organizations that pay the pickers 500 UGX/kg. A waste picker typically collects around 40 kg/day of plastic, earning 20,000 UGX/day, which is higher than the average city dweller, who earns around 4,500 UGX/day [49]. However, the waste pickers do not collect soft plastics (composition 3.8% of total MSW) [50], such as polyethylene shopping bags—known locally as *kaveeras*—as they do not have a ready recycling market. Furthermore, despite the ban on production of plastic bags in the country, similar to 15 other African nations [53–55], lenient governmental enforcement allows for illegal selling of the polyethylene bags [55]. Consequently, the *kaveeras* are likely to continue to accumulate in the Kiteezi landfill in the coming years unless action is taken.

Therefore, we recommend that close-coupled decentralized circular economy of plastic be encouraged via strategies such as conversion of polyethylene shopping bags and other soft plastics to fuel oil and similar products through AT [7,8,34,35]. This is a viable solution that can further create employment opportunities. Using the statistics previously mentioned, roughly 49,400 kg of soft plastics are brought to the Kiteezi landfill per day. If 40 kg/day of soft plastic waste can be picked by an individual, a resulting 1235 additional jobs could be created at the Kiteezi site. Because the amount of soft plastics brought to the landfill are only half of that generated within the city, a similar opportunity exists for local citizens, entrepreneurs, and communities to recycle the waste plastic to fuel, creating additional jobs. The amount of fuel generated could be used as a substitute for kerosene and diesel applications, especially for cooking, lighting, generators, and farming machinery [34]. This establishment of a locally managed decentralized circular economy could potentially have a monumental impact on the accumulation of nondegradable soft plastic accumulation at the Kiteezi landfill and in the Kampala city, improving the aesthetics of the region, and providing entrepreneurial and job opportunities, which will eventually benefit the entire nation [34]. Thus, by employing the perspective metric established in this research, the results of this case study serve as an example for other nations. The metric's use of sustainability-focused indicators can assist in identifying a region's potential suitability for a locally managed decentralized circular economy for waste plastic management.

CONCLUSIONS

In conclusion, even though all developing countries encounter similar challenges to economic development, waste plastic management practices are likely to vary from region to region, requiring a detailed analysis approach based on the principles of sustainability to determine which nations would most benefit from a locally managed decentralized circular economy for plastic waste. Often, due to lack of capital resources, centralized waste collection infrastructure, and the population's awareness of the consequences of global waste accumulation, rural and developing communities suffer from major sanitation issues and pose serious environmental concerns. Thus, it is our view that decentralized or distributed approaches with high levels of local participation be proposed for waste plastic abatement strategies to be successful. The metric established in this research has been utilized to glean insight for validating this assertion on the importance of including infrastructural, economical, societal, and environmental constraints in deciding how waste abatement strategies and resources should be prioritized. Thus, focusing on simple low-cost technologies, like thermal decomposition, which can be employed at a local level via AT methods, enable the development of a locally managed decentralized circular economies. This approach promotes community-managed collection and recycle of plastic waste directly where it is generated in a sustainable manner.

SUPPLEMENTARY INFORMATION

Details discussing the generation of the metric presented in this study are outlined in the "Supplementary Information – Metric Generation" section. An MS Excel Spreadsheet, Joshi & Seay Waste Plastic Data Analysis Metric.xlxs, is also included for data references and to allow users to test the metric according to their objectives.

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