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Muyiwa Oyinlola [a], Patrick Schröder [b], Timothy Whitehead [c], Oluwaseun Kolade [d], Kutoma Wakunuma [e], Soroosh Sharifi [f], Barry Rawn [g], Victor Odumuyiwa [h], Selma Lendelvo [i], Geoff Brighty [j], Bosun Tijani [k,l], Tomi Jaiyeola[m], Lukonga Lindunda[n], Radhia Mtonga[n] and Soroush Abolfathi [o]

[a]Institute of Energy and Sustainable Development, De Montfort University, Leicester, UK, LE 1 9BH; [b]Chatham House, UK,; [c]School of Engineering and Applied Science, Aston University, Birmingham, UK B4 7ET; [d]Centre for Enterprise and Innovation, De Montfort University, Leicester, UK, LE 1 9BH; [e]Centre for Computing and Social Responsibility, De Montfort University, Leicester, UK, LE 1 9BH; [f]School of Engineering, University of Birmingham; [g]Kigali Collaborative Research Centre, Rwanda.; [h]Department of Computer Science, University of Lagos, Nigeria; [i]Multidisciplinary Research Centre, University of Namibia, Windhoek, Namibia; [j]Plastic Oceans, UK; [k]Co-Creation Hub Lagos Nigeria; [l]iHub Nairobi, Kenya; [m]CcHub Design Lab, Kigali, Rwanda; [n]BongoHive Lusaka, Zambia; [o]School of Engineering, University of Warwick, Coventry, UK CV4 7AL

ABSTRACT

The paper analyzes the current state of plastic value chains in Africa and the potential of digital innovations adopted by African entrepreneurs to contributing to a circular plastic economy. We provide an overview of plastic waste trade to African countries and an assessment of existing digital solutions that can support the transition to a circular plastic economy. The findings show that various digital innovations are being applied by entrepreneurs including web-based solutions, mobile apps and 3D printing. The case studies also show that multinational companies, especially consumer facing brands, are major players in the national plastic value chains in African countries, acting as seed funders for start-ups as well as buyers of recycled plastics. Current initiatives that are underway are positive signs that changes are in progress to address the environmental and social impacts of plastics value chains in Africa. However, to achieve a transition to sustainable circular value chains, changes at policy level will be required to enable scaling-up of local start-up businesses, address regulatory barriers to digital solutions, create markets for recycled plastic materials and implement extended producer responsibility regulations.

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1. Introduction

Digital innovation (DI) can be defined as the ongoing process of developing and implementing new technologies into existing systems to solve problems and increase efficiency, affordability, reliability, and sustainability (Ciriello, Richter, & Schwabe, 2018; Kohli & Melville, 2019). Today's digital innovation tools include, but are not limited to,

CONTACT Patrick Schröder PSchroeder@chathamhouse.org
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access to high-speed internet and smart mobile devices, the internet of things (IoT), Remote Sensing, Big Data, Cloud Storage, Artificial Intelligence (AI), Blockchain and 3D printing. Applying these tools can lead to considerable economic, environmental, and societal benefits and support rising living standards. Moreover, the uptake of digital technologies and the increased digital capability of firms in developing countries significantly positively impact companies' product sophistication and upgrading in global value chains (Banga, 2019).

In an African context, the application of DIs has led to a significant impact along the value chain of different business sectors. For example, satellite and sensor-based "precision agriculture" as well as AI-based agronomic solutions have been used to support sustainable agriculture in Africa, leading to various benefits to smallholder farmers (SHFs) and their communities (Syngenta, 2019). Mobile finance, i.e., mobile phone-based money transfer system, is another sector where DIs have been successfully employed to facilitate low-cost money transfer and various innovative types of financing, including crowdfunding and peer-to-peer lending. These tools have revolutionized the payments ecosystem in Africa, leading to new innovative approaches to the financing value chain. Moreover, DIs, including advanced geospatial platforms and embedded systems in Pay-As-You-Go units, have enabled the transformation of the energy industry in Africa by allowing real-time demand monitoring adjustment and more intelligent management of distributed power conversion capacity (Annunziata, Bell, Buch, Patel, & Sanyal, 2015).

DIs have also shown potential in contributing to the Circular Plastic Economy in Africa by filling the gap of inadequate waste collection and management infrastructure, thus contributing to achieving a smart community. To date, several innovations have been adopted to transform the plastic value chain into a smart, innovative and sustainable value network by improving plastic identification, collection, transportation, sorting, processing and reuse. For example, waste management web and mobile applications have been developed and used in several countries for compensating waste pickers with digital points that could be converted into mobile data credit or other rewards. However, while there have been many promising DI pilots, scaling capacity and growth have presented challenges, including: technical constraints, policy and regulatory barriers, digital literacy and the ability to manage technology integration.

Recognizing DI's potential in creating jobs, addressing poverty, reducing inequality and contributing to the Sustainable Development Goals, the African Union Commission has developed a comprehensive Digital Transformation Strategy for Africa, setting several specific targets to be reached by 2030 (African Union, 2020). While offering a pragmatic framework, the strategy identifies challenges in scaling-up, education and lack of infrastructure as pitfalls that can impact digitalization. It also highlighted setting up suitable delivery models for connecting stakeholders across the value chain, and holistic mapping of the ecosystem identifying promising solutions that address the entire value chain and can be scaled up in Africa.

While some DIs have changed the traditional value chain dynamics, e.g., in mobile finance and energy sectors, and have shown promising potential for scaling, the extent of scalability which DIs can accomplish in plastic value chains is unknown. This is primarily because, for these models to be profitable, they have been tailored to specific regions and customized to consider the local cultural and technical characteristics. Moreover, the literature has identified hot spots and key intervention points in the African plastics value, however, it shows that there is still only limited systematic information and analysis on how global and regional plastic value chains connect Africa and other world regions through the trade of plastic polymers, plastic products, secondary plastics material and plastic waste.

To this end, this paper aims to investigate the transformative role of digital innovations for transitioning to circular plastic value chains across Africa. This will be achieved by reviewing the literature and cross-comparing this with three initiatives: WeCyclers in Nigeria, Yo-Waste in Uganda, and Recyclebot in Zambia. These case studies provide insight into the role of 1) entrepreneurship and sustainable business models, 2) multinational corporations in African plastics value chains and 3) policy to create circular plastics value chains. This study is significant as it helps identify new gaps, opportunities, barriers and best practices for using digital innovations to accelerate the transition to a circular plastic value chain across Africa.

2. Literature Review

2.1. African Plastic Value Chains and Plastics Markets

Increasing amounts of plastic waste is a global problem. According to the World Bank, in 2016, the world generated 242 million tons (Mt) of plastic waste, accounting for 12% of all municipal solid waste. This waste primarily originated from three regions – 57 Mt from East Asia and the Pacific, 45 Mt from Europe and Central Asia, and 35 Mt from North America (Kaza, Yao, Bhada-Tata, & Van Woerden, 2018). There are ever-growing concerns that the global waste crisis will significantly impact Africa. By 2050 it has been projected that there will be a 197% increase of waste in sub-Saharan Africa, with much of this being plastic (Kaza et al., 2018). Therefore, an in-depth understanding of global and regional plastic value chains is fundamental to creating a circular plastic economy and applying digital innovations successfully.

Currently, there are an estimated 17 Mt of plastic waste generated in sub-Saharan Africa (Ayeleru et al., 2020). Several studies report the primary source of leakage from the plastic value chain occurs at the end of product life. Although there appears to be a divergence in the data about the scope of the problem, in 2010, it was estimated that mismanaged waste for the African continent accounted for 4.4 million metric tons (Jambeck et al., 2018). Further analysis by the United Nations Environment Programme (UNEP) found that by 2015, the loss of plastic to the environment from mismanaged waste treatment in Africa accounted for about 0.93 Mt, or 24% of the world's total mismanaged plastic waste of 3.87 Mt (UNEP, 2018).

Mismanagement of plastic at the end-of-life stage – when a plastic product becomes waste – can be considered one of the most challenging environmental issues and has created a hot spot in the plastic value chain, which needs to be addressed urgently. Yet, despite these reports, academic studies focusing on methods to mitigate plastic leakage, particularly in sub-Saharan Africa, are limited (Ayeleru et al., 2020). Therefore, it is expected that without intervention, the amount of mismanaged plastic waste will be disproportionately high in Africa unless significant investments in waste management infrastructures are made (Lebreton & Andrady, 2019). This problem is further exacerbated by shipments of waste plastics from industrialized countries to Africa. In 2018, when China banned the import of many types of plastic waste, exporting regions such as the USA, UK, Europe and Japan were forced to look for other places to ship waste. This resulted in plastic waste exports to Africa quadrupling in 2019 compared to the previous year (Tabuchi, Corkery, & Mureithi, 2020). Ghana, Uganda, Tanzania, South Africa, Ethiopia, Senegal, and Kenya were among the African countries that received US American plastic waste, of which a high percentage was dumped or burned (Lerner, 2020). A global plastic scrap trade network analysis conducted by Pacini et al. (2021) showed that Africa is typically underrepresented in international networks, which seems to be due to lower plastic usage and informal trade and data reporting constraints.

According to UN Comtrade data, African countries received 82.1Kt of plastic waste and scrap imports in 2019, which accounted for roughly 1% of the global plastic waste trade. While this is still low compared to the overall global trade in plastic waste, there was likely more plastic waste than officially recorded. The three main recipient countries were Nigeria, Senegal and South Africa (see Figure 1).

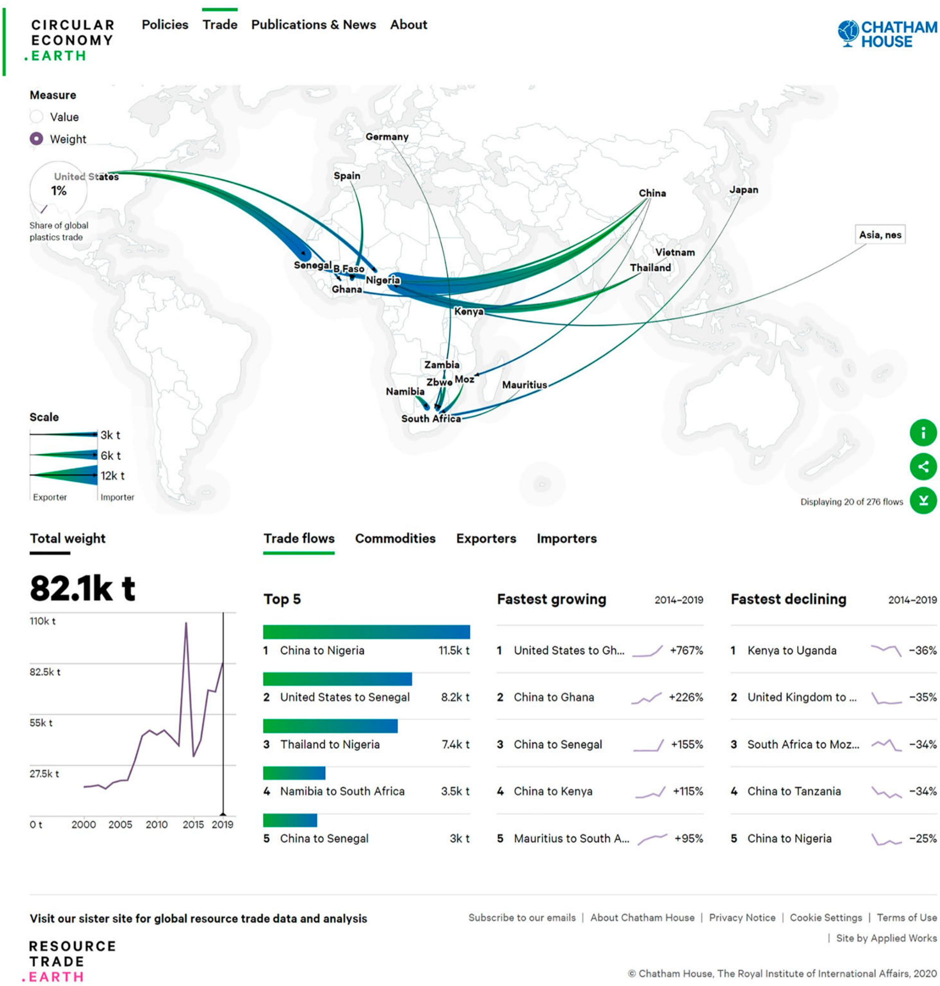

Figure 1. Plastic waste imports to Africa, year 2019. Source: Chatham House 2020, circulareconomy.earth.

At present, the available data on plastic value chains is limited, which is an area that needs to be addressed at international, national and local levels. There are opportunities for DIs, especially mobile technology, to facilitate data collection and innovation to address the plastic leakage and pollution issue (Jambeck et al., 2018).

In addition to importing plastic waste, Africa is also a large importer of plastic polymers and plastic products to meet the growing demands of a rapidly growing and middle-class economy. According to Babayemi at al. (2019), an estimated 172 Mt of polymers and plastics valued at US$285 billion were imported between 1990 and 2017 by the 54 African countries. In addition, components for products were also imported, making the estimated total 230 Mt of plastics. The three main importing countries were Egypt (18.4%), Nigeria (16.9%), South Africa (11.6%).

Currently, primary plastics production in African countries is limited, with the top eight countries' combined production being 15 Mt between 2009–2015 (Babayemi et al., 2019). Consequently, African plastics production feedstock primarily emanates from oil and liquefied natural gas (LNG); however, in South Africa, coal is a significant feedstock (Mofo, 2020). The shift to more regional value chains and increased use of natural gas feedstock has been identified as an opportunity to create higher value for national industries and reduce environmental impacts (Mofo, 2020). One of the largest contributors to global plastic pollution is large multinational companies such as Coca-Cola, Nestle or Pepsi (Break Free From Plastic, 2019). They produce and sell fast-moving consumer goods which are quickly disposed of. Several of these global brands operate across Africa and in 2019 launched the "African Plastics Recycling Alliance". This alliance aimed to address the end-of-life of the plastic value chain by improving the plastics recycling infrastructure across sub-Saharan Africa (IISD, 2019). It was realized that the plastic packaging value chain was also closely aligned and connected with the drinking water supply chain and sachet water packaging is one of the most significant elements of plastic waste seen in Africa. This waste produced by the brands has contributed to other issues such as clogged drains, breeding mosquitoes and localizing floods. (Williams et al., 2019)

Recycling of plastic wastes is also relatively limited with 42 plastic recycling plants registered in the African plastic recycling plants directory. The plants are operated by domestic companies that process plastic waste into new materials. The majority of these plants operate in South Africa (13), Nigeria (7) and Egypt (7) (ENF, 2021). There are likely many more recycling facilities in operation, but these are not registered. In addition, many recycling activities are semi-informal, and the facilities operate with sub-optimal equipment and technologies. As a result, numerous small-scale enterprises, such as digital entrepreneurs, have emerged, aiming to use plastic waste as an economic resource. Such enterprises are gaining support from governments and, increasingly, multinational brands. In addition, they are partnering with other actors in the value chains, e.g., the collection and disposal sector and recyclers, to facilitate sustainable waste management of plastics (Lane, 2018).

2.2. Digital Innovations to Address Plastic Pollution

Digital technologies are considered vital enablers to create circular economy business models and address plastic waste and pollution. Digitalization can help close the material loops by providing accurate information on products availability, location and condition; it also enables more efficient processes and minimizes waste (Antikainen, Uusitalo, & Kivikytö-Reponen, 2018). The available literature is limited, but it suggests that digital innovations are an essential part of the circular economy in Africa. For instance, Horvath, Mallinguh, and Fogarassy (2018) discuss challenges faced by least developed countries concerning plastic waste management systems. They state that adopting circular solutions from advanced economies may not be the best approach for least developed countries with much lower consumption than the high-income countries whose waste affects them. As such, the focus of least developed countries should not be on reducing their relatively low consumption levels but on managing end-of-life issues of products and materials.

Africa's emerging digital transformation has set into motion vibrant economic activity in both analogue and digital markets, characterized by interwoven and concurrent developments (Ndemo & Weiss, 2017). However, it is important to stress that digital technologies need to consider institutional and socio-economic factors. This is because the introduction and adoption of digital innovations do not happen in a vacuum but are contingent on sets of institutions and existing social practices. To this end, Mwanza, Telukdarie, and Mbohwa (2018) identify socio-economic factors influencing household participation in plastic waste recycling programs in Zambia. This means that whatever digital innovations may need to be designed or implemented, consideration of different socio-economic factors which may have the ability to hinder or allow the effective use and implementation of such innovations have to be looked at more critically. For instance, a study on waste management and plastic collection and recycling in Kampala, Uganda, highlights women working in the sectors and the need to reduce such vulnerabilities (Allcot, 2021). Therefore, it is important to consider gender, income and education levels before designing and implementing digitally supported collection and recycling programs. In addition, care has to be adhered to when considering digital innovations to avoid the adoption of certain innovations ending up creating problems like the Ikeja Computer Village in Nigeria. This was a thriving information technology market which imported used electronics including computers, mobile phones, and fax machines and more from more developed countries. However, many of the electronics were irreparable, which created an increase in e-waste (Schmidt, 2006).

Recycling networks such as those demonstrated by de Oliveira, Ruiz, Gabriel Dias da Silva, Struffaldi, and Bocatto (2014) for cooking oil illustrate innovative ways to formulate waste through reuse. Furthermore, Clarke and Mouton (2016) discusses how the effective combination of technologies on producing oil from plastic waste products can help overcome environmental conditions. Mwanza and Mbohwa (2019) also argue for reverse logistics (collection of materials for reusing and recycling them after their initial use and purpose) as one way of avoiding the reduction of plastic manufacturing industries in developing countries like Zambia. However, they acknowledge that there are barriers to achieving this, including a lack of recycling technology and infrastructure and adequate or non-existence legislation for plastic solid waste (PSW).

To overcome the lack of recycling technology that Mwanza and Mbohwa point to, perhaps as digital innovations take root on the African continent, the Internet of Things (IoT) could be one way of innovating. Pratap, Maria Joshy, Mathew, John, and Treesa James (2019) argue for an automated communication mechanism based on IoT technology between the household and waste collecting organizations to help monitor and collect plastic waste, recycle and aid in centralized disposal. As IoT becomes more ubiquitous in the African continent, other digital innovations could also be considered. Meanwhile, Mugo and Puplampu (2020) discuss how smart sensors as a technology innovation can help address environmental pollution and waste management in Africa.

Based on the existing literature, several digital technologies and innovations to close loops in the plastics value chain and reduce mismanaged plastic waste can be identified (see Figure 2).

2.3. Entrepreneurship, Innovation and Markets

The preceding discussions focused on African plastics value chains and digital innovations for the circular plastic economy. The growing problem of plastic pollution, associated with the mismanagement of plastics at the end of life, and the dumping of plastic wastes in African countries, provides an opening for technological innovations to create new markets for products produced from plastic waste. However, in between these advancing technical capabilities and potential new market opportunities in the space occupied by entrepreneurs who recognize the opportunities, and then deploy appropriate innovations to create, capture and optimize value from them.

Entrepreneurship is defined as discovering, evaluating, and exploiting future goods and services (Venkataraman, 1997). Thus, entrepreneurship is associated with the core ideas of opportunity recognition, value creation, and value capture. In line with this, entrepreneurs have been described as individuals with high alertness to new opportunities; a strong propensity for risk-taking; exceptional capabilities to find new, innovative ways of

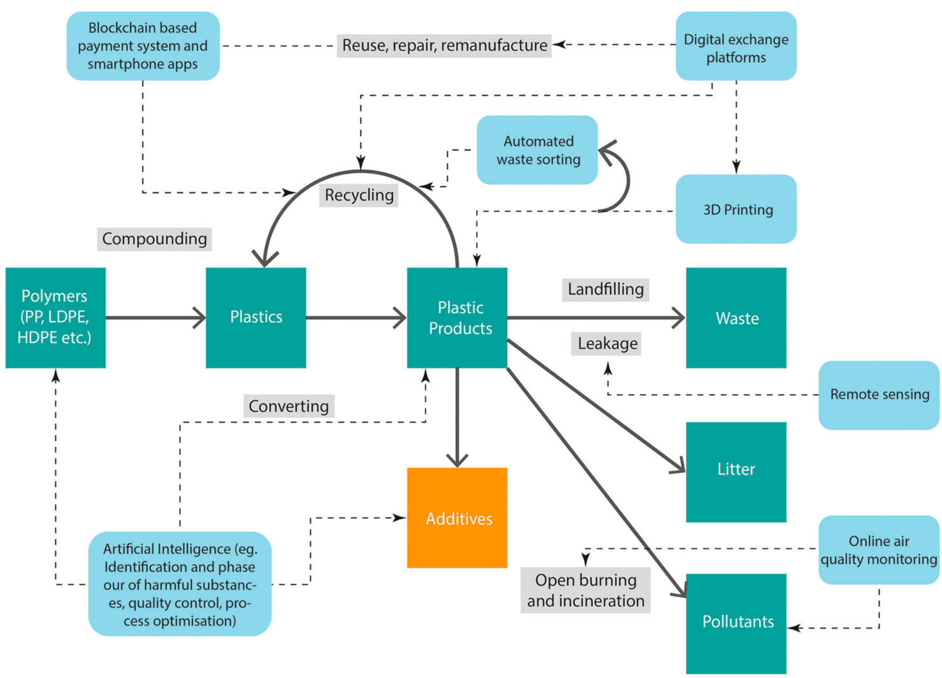

Figure 2. Digital innovations and applications to close loops and increase circularity in the plastics value chain.

doing things; and a high level of confidence, or self-efficacy, to achieve their objectives (Cuervo, Ribeiro, & Roig, 2007; Eckhardt & Shane, 2003; Minniti & Lévesque, 2010).

A review of entrepreneurship in 35 African countries by Kansheba (2020) shows the importance of entrepreneurial ecosystems and product and process innovations as drivers for productive entrepreneurship. Conducive entrepreneurial ecosystems include incubators and affordable professional services, which provide necessary resources that promote innovations among entrepreneurs and support the development of start-ups. Furthermore, entrepreneurial leadership in the informal sector is a critical feature in many African countries. However, informal sector entrepreneurship is still understudied even though this context shapes individual entrepreneurial orientation and the emergence of entrepreneurial leadership in the formal economy (Musara & Nieuwenhuizen, 2020). This also applies to small businesses in the circular plastics economy. In effect, innovations and markets are not sufficient on their own. Still, they must be promoted and supported together with entrepreneurship development as the critical tripod necessary to drive any sustainable agenda for the circular plastic economy in Africa (see Figure 3).

Digital technologies play an essential role in African entrepreneurship, where entrepreneurs productively adopt digital technologies to local markets and conditions. They achieve sustainable business models by scaling based on relationships and customizing digital platform business models for African infrastructure challenges (Friederici, Wahome, & Graham, 2020).

The circular plastic economy is a promising context for exploring the core ideas of entrepreneurship: opportunity recognition, opportunity appropriation, innovation, value creation, and value capture. Moreover, it provides a window to examine the linkages and intersections between entrepreneurship, innovation and sustainable development. In this respect, multi-sided platforms (MSPs) play a key role. MSPs are characterized by the existence of two or more distinct customer groups who are directly affiliated with the platform and can interact directly with one another (Hagiu & Wright, 2015; Trabucchi & Buganza, 2020). In effect, they typically serve as building blocks through which other firms can develop and provide complementary products, technologies and services (Scholten & Scholten, 2012). Thus, the platform ecosystem incorporates both the "stakeholder" ecosystem of the platform owner providing and managing the core offerings and mediating between the service providers and service consumers; and the service ecosystem of complementary products and services for customers (Scholten & Scholten, 2012).

The circular plastic economy is a meeting point and melting point of distinct stakeholders and is well suited to multi-sided platforms. From corporate manufacturers and polluters to households generating plastic wastes and plastic waste collectors and recyclers, a digital platform can connect various stakeholders to develop, provide and use complimentary services and products. From the African perspective, one major challenge for platform owners is facilitating enough network externalities necessary to achieve good returns on investment (Scholten & Scholten, 2012). Governments can make significant contributions in this regard, such as through legislation and policy interventions that incentivize households and require commitment from multinationals.

In recent years, campaigns against plastic pollution have gained significant traction as people have become increasingly aware of the vast amount of plastics entering the ocean

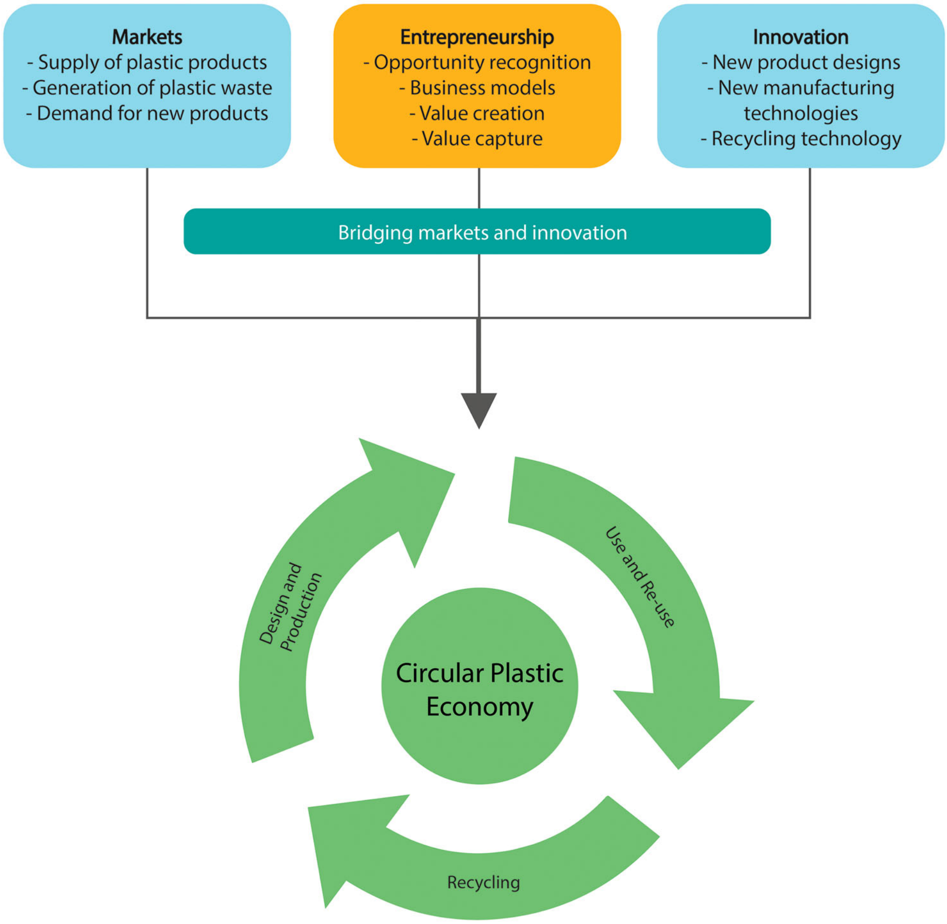

Figure 3. Entrepreneurship, markets and innovation as key drivers of the circular plastic economy in Africa.

(Dijkstra, van Beukering, & Brouwer, 2020). The European Commission identified plastics as a priority category of products to achieve a circular system. (Hahladakis & Aljabri, 2019). The traditional production of primary plastics and management of plastic wastes has remained linear- production, use, disposal. In contrast, the circular economy emphasizes the value of waste and is supported by a wide range of technological innovations to drive recycling and reprocessing plastic (Dijkstra et al., 2020). Organizations and entrepreneurs need to adopt appropriate and effective business models to create and capture value from plastic across the product life cycle.

Circular business models have been defined as a system that identifies potential customers and end-users, engages with their needs, delivers satisfaction, and captures value (Baden-Fuller & Haefliger, 2013). In other words, a business model sets out the strategic logic of the firm to create and deliver value to its stakeholders and capture value for itself. The traditional business model articulates the value proposition; identifies users in a market segment; defines the structure of the value chain; specifies the revenue generation mechanism; defines the firm's position within the ecosystem; and formulates the firm's competitive strategy (Chesbrough, 2007). Thus, the traditional business model focuses on economic value creation as the firm's principal, or singular, objective. However, other scholars and stakeholders have pointed out that economic value creation represents a limited and limiting view of value creation. It does not consider the critical imperative of environmental value creation and the social impacts of organizational activities. In response, Joyce and Paquin (2016) drew ideas from the Triple Bottom Line perspective to propose a triple-layered model of organizational value creation, comprising economic, environmental, and social layers. Thus, while the economic layer focuses on financial outcomes, the environmental layer is based on the lifecycle perspective, while the social layer takes a stakeholder approach. As the economic business model canvas seeks to increase revenue while reducing costs, the environmental business model canvas maximizes environmental benefits while reducing adverse environmental impacts. This is especially pertinent for the analysis of entrepreneurial and business opportunities in the circular plastic economy, where the role of actors is not limited to economic value creation but also viewed in terms of their environmental and social impact. Circular plastic businesses should be profitable to be viable, but their impact is much more.

A 2012 report in Scotland analyzed business opportunities for a) processing of mixed, contaminated rigid plastic waste; b) processing of mixed contaminated plastic film waste; c) collection and compaction of expanded polystyrene waste; d) processing of waste u-PVC window and door profiles; and e) processing of waste plastics from WEEE. The plastic under these categories represented up to 400,000 tons of plastic wastes per annum in Scotland. The report found that four of the five categories of plastics were viable for business (Weir, Taylor, & Welsh, 2012).

3. Methodology

We adopted a comparative case study approach as the analytical framework. The case study framework is suited to analyze and synthesize the similarities, differences and effective practices observed across the selected cases. Comparative case studies are beneficial for understanding and explaining how context influences the success of specific interventions, projects or programs (Goodrick, 2014). Comparative case study approaches have been successfully applied in research about human-environment relationships to formulate or assess generalizations across different cases (Knight, 2001). It has also been used to analyze the sustainability practices in manufacturing supply chains (Mani, Agrawal, & Sharma, 2015) for integrated sustainable waste management in cities (Wilson, Velis, & Rodic, 2013).

This study adopted this approach to produce knowledge that can be used to generalize questions and determine relevant lessons from the existing examples of business models and initiatives to reduce plastic pollution in Africa.

The first step was mapping existing innovation initiatives and entrepreneurial models that apply digital technologies to address plastic waste. We identified several initiatives (see Appendix 1). We selected three case studies for intensive and in-depth qualitative analysis, which provided more insight into the specific case, rather than choosing many case studies for statistical analysis. The scope for the selection of countries and accompanying case studies has been determined by the scope of the DITCh plastic project. We acknowledge this limitation and the selection bias (Bennet, 2012) due to the geographical context of the study. In addition, we recognize that similar businesses and initiatives exist in other African countries not covered by the project activities, which could have been chosen as case studies and would merit academic analysis.

The three case studies selected were based on several criteria (Goodrick, 2014): 1. Geographical differences in the locations of where the cases are situated. 2. Due regard of significance for expected insights and availability of information, data material and access to interview partners. 3. The degree of commonality between the different cases.

Central questions included if there are commonalities and lessons learned from the case studies, which can be helpful in the design of similar initiatives and for scaling-up. The comparative analytic approach we applied focuses on the relationships among combinations of potential causal conditions within and across the cases.

We conducted semi-structured interviews with stakeholders from the three initiatives to collect data and information for the case studies.

4. Case Studies

4.1. Background

As highlighted previously, Digital Innovations (DIs) such as mobile applications, GIS and artificial intelligence (AI), provide a game-changing approach in the transition to a circular plastic economy in Africa. For example, DIs can be used to aid **Recycling** by efficiently connecting consumers, waste collectors and recyclers; **Reduction** by engaging consumers on ways to cut down resource usage and **Redesign** by optimizing processes.

Over the past decade, several entrepreneurs across the continent have founded start-ups that employ digital innovations for waste management. Appendix 1 presents some of these while more comprehensive details are given about three; (1) Yo-Waste, a technology focused waste management company in Uganda, which provides waste recycling and smart city solutions to residents, businesses and governments; (2) WeCyclers in Lagos, which engage and incentivize residents of densely populated urban neighborhoods to recycle their waste; and (3) Recyclebot Cleantech Solutions in Lusaka, which leverage technology and enable consumers to extract maximum value from their waste over the internet.

4.2. WeCyclers

WeCyclers are one of the pioneering waste management technology start-ups. It was founded in 2012 and currently operates across three cities in Nigeria. The team consists of about 200 members in addition to seven franchises which employ about 300 people. Plastics account for about 70% of the 2 000 tons of waste collected annually. Since its inception, WeCyclers has been financed mostly by grants to the tune of US$1.5 million and a US $130k convertible loan. This has come from both local and international organizations.

WeCyclers Innovation

WeCyclers is a software-focused company that has developed apps to manage and optimize waste collection. The solution is a rewards-for-recycling platform that incentivizes people in low-income communities to capture value from recyclable waste. This has evolved from an SMS based platform to an in-house developed mobile application that is used to manage and optimize collection. Waste collectors have access to a fleet of relatively cheap, locally assembled cargo vehicles called "wecycles" that they use to pick up recyclable waste from households (subscribers) and deliver the materials to the collection, sorting, etc. packaging hubs located around Lagos. Service subscribers are rewarded with points per kilogram of recycled waste they give to the collector. WeCyclers exchange the points for essential goods such as food and household items.

The innovation can be split into the following.

- A mobile app (previously SMS service) that updates subscribers about their incentives and balance
- A mobile app for collectors that enables them to service the subscribers properly captures and records relevant details such as address and amount of recyclables collected.
- A mobile app for hub (recycling centers) managers to manage operations
- A mobile app for franchise operations

The above tools interact with a dynamic database which enables day to day operation

WeCyclers operate as a multi-sided platform enabling direct interactions between subscribers who are plastic waste producers (including downstream users and corporate partners); waste collectors who often operate as franchises; and uptakers who buy and recycle plastics. Their main stakeholders include:

- Service Subscribers who use the service. These are mainly from low-income, densely populated urban neighborhoods.
- Uptakers who buy the recyclables from WeCyclers and go on to recycle them.
- Corporate partners and brand owners, mostly MNCs, some of whose products/services result in environmental pollution. These companies partner with WeCyclers to recover waste from the environment.

WeCyclers can be classed as an intermediary in the national plastic value chain, i.e., they recover post-consumer plastics and supply recyclers and are therefore susceptible to external factors both downstream and upstream. For example, an increase in the price of oil (used for producing virgin plastics) increases the demand for recyclables.

WeCyclers have prevented over 6 000 tons of waste from going to landfills. It has also handed out over US$300,000 worth of points to people, especially women in low-income areas. It is worth noting that WeCyclers is the primary source of income for about 90% of subscribers.

It is estimated that WeCyclers capture only about 2% of PET waste in the system, thus suggesting significant opportunities to expand. However, as expected, there are several challenges, funding being a significant barrier. Investors are usually hesitant due to slim profit margins as well as poor regulation in the sector. Several other start-ups have developed in Nigeria e.g., Recycle points and Capture solutions. However, due to the volume of waste, the competition is not in collecting the recyclables, but in other areas such as media attention and grant applications. It is pertinent to note that the sector is characterized by collaboration facilitated by organizations such as Recyclers Association of Nigeria (RAN)

4.3. Yo-Waste

Yo-Waste is a technology-based start-up in Kampala, Uganda, that helps communities and businesses manage their waste by connecting them to different waste management players. It started in 2017 as an education project but became fully registered as a company in 2019. The company currently has seven employees (including the 5 co-founders) who handle software development, communications, etc. Currently, Yo-Waste has about 200 regular subscribers with an average of 200 additional one-off customers monthly.

Yo-Waste's Innovation

Yo-Waste innovation ("an uber for waste"), a mobile & cloud-based solution that connects garbage generators (households, restaurants, schools and businesses) to the nearest local waste haulers in their communities and is efficient, reliable, affordable and convenient. Yo-Waste includes three offerings:

- Yo-Waste Connect: Android and IOS mobile applications allow businesses and households to request and schedule waste collection services on their smartphones.
- Yo-Waste Hauler: Android mobile application that provides sophisticated routing and logistics tools to waste collection trucks. The application allows collectors to maximize waste collection points while navigating around the city. In addition, the application collects household waste data that urban planners can use to plan for their cities with reliable data and improve the recycling rate.
- Yo-Waste Cloud: Cloud based platform that allows waste collection companies and municipal authorities to measure the productivity of waste collection trucks in the field.

Yo-Waste received initial funding from the University of Makerere. Further financing has been in the form of grants from international organizations as well as personal funds.

Like WeCyclers, Yo-Waste also operates as a multi-sided platform (MSP). The main stakeholders consist of both upstream and downstream players, including:

- Subscribers who use the service, mainly residences and businesses from across Kampala.
- Waste management companies, who own and operate equipment for waste collection
- Recyclers who purchase the waste, mainly the Plastics Recycling Industries (PRI), an affiliate of Coca-Cola.
- Corporate partners, mostly MNCs such as BESTSELLER Foundation.l, UNDP, and MTN, who have provided some funding and assistance in exchange for brand promotion

In the waste management chain (generation – collection – recycling – selling), Yo-Waste lies between both generation and collection and collection and recycling. Yo-Waste serves as a link/aggregator and does not influence price, instead of receiving a fixed commission. In addition, several waste collectors in an area enable Yo-Wastes customers to access affordable services. This would otherwise be costlier with a monopoly.

The business model gives rise to opportunities to scale across the continent; however, several barriers have been identified. The two most important are, firstly, grant funding to expand the business; and, secondly, regulations – most policies on waste collection across Africa make it difficult for start-ups like Yo-Waste to operate.

4.4. Recyclebot Cleantech Solutions

Recyclebot was founded in 2018 and is located in Chilanga, south Lusaka, Zambia. It has a staff strength of 5 people (2 founders and 3 independent contractors) and about 20 plastic collectors. Recyclebot has recovered and processed over 120 tons of plastic, metallic and organic waste. Recyclebot has launched in two other countries, Nigeria and South Africa.

Recyclebot Innovation

Recyclebot has developed a digital tool – Recyclebot – which is used across the whole value chain. It provides a mobile app on a decentralized global network as a simple tool for consumers to extract maximum value from their waste over the internet. The innovation allows users to do the following:

- Sell any waste: Separate and post waste where it is generated or discovered by buyers.
- Crowdsource waste anywhere: Recyclebot automatically captures accurate GPS locations, aggregates waste by type and location, connects waste buyers to waste sellers, and creates optimal transfer schedules and routes.
- Reuse and reduce waste: Waste producers gain the ability to reuse and have their waste collected for free. In contrast, waste buyers can access valuable waste they are currently unable to access without paying for separation, transfer and storage.

Recyclebot's mobile platform lets businesses engage with their consumers without the high cost and risk of developing and maintaining a custom mobile app. Instead, companies can focus on their mobile marketing and engagement strategies, and Recyclebot provides the fast and accessible technology infrastructure. With Recyclebot's mobile app platform, businesses can publish their mobile web assets in their own branded mobile app and access a wide range of advanced mobile engagements. Recyclebot's mobile app platform is suitable for various sectors ranging from manufacturers, Recyclers and Waste Disposal Firms.

The technology is evolving to identify waste materials' type, location, quality, quantity and value concerning other stakeholders. With a strong emphasis on machine learning and computer vision, the solution helps reduce human error in the collection, sorting and processing and will ultimately help predict flows in the value chain.

Their main stakeholders include:

- Informal waste pickers
- Uptakers who buy the recyclables from Recyclebot and go on to recycle it.
- Independent waste management companies contracted by the council.

Recyclebot works with consumers and service providers in the waste management chain to foster digitalization of waste collection services, specifically, personalizing services for each stakeholder and making these services available. For example, the digital tool improves transparency, resulting in up to 200–300% earnings increase for waste pickers. There is no interaction with MNCs, which is common in Zambia.

The significant barriers to scaling-up the solution are the lack of funding to provide/access resources such as appropriate skills, equipment, infrastructure and existing technology. Examples of these include providing waste pickers with smartphones, employing staff with the skills needed to improve the business, acquiring trucks and other physical equipment to manage waste. (see Table 1 for a summary of the cases.)

5. Discussion

5.1. The Role of Entrepreneurship and Sustainable Business Models

The case studies provide insights into the entrepreneurial activities of organizations active in the circular plastic economy. Each has deployed digital innovations and adopted appropriate business models to create and capture value. For example, WeCyclers use a gamification strategy via a mobile app to incentivize subscribers and link them with collectors. At the same time, Yo-Waste adopts a three-tier digital platform to provide services to households and businesses, drivers and waste collectors, and bigger companies. WeCyclers have successfully built a growing database, although they have only captured 2% of the PET going into the system yearly. Therefore, there is a bigger scope for scaling, and exploring other opportunities for creating value, including higher-quality finished products.

In line with the triple-layered model of organizational value creation, the impact of WeCyclers can be assessed in terms of profit-making and its environmental and social impact. With respect to its environmental contributions, it has prevented the disposal of more than 6 000 tons of plastic wastes to landfill. In terms of social impact, it has provided income opportunities for thousands of subscribers, including women, from poorer households. All the organizations investigated in this study highlighted the difficulty in achieving financial sustainability; however, their business models make them well-positioned to make a significant contribution to the transition to circular value chains for plastics. This is indeed true for not just these three case studies but also other digital innovation firms. This is one of the major challenges to innovators in this space. There needs to be a better standard way for investors/ funders to access the performance of organizations, so that their environmental and social impact can be amplified. All the organizations investigated in this study operate as multi-sided platforms (MSPs). For example, WeCyclers operate as an MSP enabling direct interactions between subscribers who are plastic waste producers (including downstream users and corporate partners), waste collectors who often operate as franchises, and uptakers who buy and recycle plastics. Like most multi-sided platforms, WeCyclers need to generate more significant network externalities to successfully up-scale and be more profitable (Scholten & Scholten, 2012). WeCyclers can build on its current network size, which comprises hundreds of subscribers and team members across seven franchises. The same applies to Yo-Waste and Recyclebot, which are effectively start-ups in still earlier stages of development. They need to expand their network, not just of subscribers, but cooperate partners to create the necessary network effects required to develop and capture more value.

Table 1. Case studies summary.

Name	Inception	Waste processed (annually) tons	Employees	Grant or Investment	Opportunities	Challenges	Circular economy focus
WeCyclers, Nigeria	2012	2 000	200	Over 90% grants	Significant scope for expansion; only collecting about 2%	Funding Slim profit margins Policy landscape	Recycle
Yo-Waste, Uganda	2017	750	7	Grants	Model allows easy expansion across the continent	Policy Landscape Finance	Recycle
Recyclebot Cleantech Zambia	2018	120	25	Grants	Local manufacturing driven by fintech and capturing data Applying their digital technology in other sectors	Funding Manpower Infrastructure	Recycle Reduce Reuse

The case studies reinforce the importance of a sustainable revenue model. Currently, WeCyclers rely heavily on grants for its investments into digital innovations. In a similar vein, Yo-Waste drew much of its initial financing from the university who funded the digital platforms to host their services. Multiple income streams, including those based on direct returns to services and products and network externalities, are critical for up-scaling, sustainability and long-term viability. The African plastics value chain need not rely solely or heavily on grants as the source of its initial funding. As the market grows and innovations diffuse, it is expected that organizations will deploy the right entrepreneurial skills and strategies to generate income and attract investors. Government policies and strategic public procurement will also play a key role in this.

5.2. The Role of Multinational Corporations in African Plastics Value Chains

This section draws from the three case studies and the literature review to assess the role of multinational corporations (MNCs) in changing the working domains of circular economy ventures identifying gaps, opportunities, barriers and best practices

The three case studies can be considered as intermediaries in the plastic value chains in the respective countries i.e., between the collection and recycling stages. Many of the various upstream production steps of plastic are dominated by MNCs increasingly engaging with and supporting circular economy technology start-ups. For example, the primary buyer of Yo-Waste sorted recyclables is the Plastics Recycling Industries (PRI), an affiliate of Coca-Cola. Also, WeCyclers received significant support from several MNCs whose products/services result in environmental pollution and who wish to compensate partly, in net effect, this negative impact. While some of the activity between the MNCs and innovation companies is highly commendable, there are still lots of unexploited opportunities to engage with these organizations. All three case studies confirmed that they were collecting less than 10% of the recyclable waste. MNCs could work with them to improve these, for example, using existing equipment and infrastructure to improve collection as providing incentives for recycling.

The lower down the value chain a player, the less influence they have. Significant responsibility still rests with the producer. A significant leap that needs to happen for accountability is implementing systems that track the material flow through the value chain and minimize leakage from the circular loop.

All three case studies confirmed cooperative relationships within the sector and that competition was hardly an issue due to the large volume of untapped waste – in other words; there is significant room for expansion by all. To successfully do this, relevant skills need to be developed for the sector. MNCs can play an important role in this area by upskilling current players to embrace digital tools and developing new skills for the sector.

Another area where MNCs can play a vital role is awareness/education about sustainable waste management within the general public, especially the youth, as they comprise a large population. Currently, most of the people do not see waste as a resource, and collectors still struggle to get enough plastics for recycling. Building on advertisement campaigns, MNCs can work with the circular economy ventures to develop and roll out Citizen education, community awareness initiatives and programs (Cook, Abolfathi, & Gilbert, 2021).

All three case studies observed very slim profit margins, which makes it challenging to make an investment case in the early years of operation; instead, grants were more attractive. MNCs were identified as major financiers. Typically, a start-up in this sector would rely on grants for about 3–7 years before ripe investments. In any case, a strong business case is needed to convince investors as the margins are incredibly slim, and the sector is characterized by weak regulation. Multinational consumer-facing brands like Coca-Cola and Unilever have also been active in subsidizing the collection of polyethylene terephthalate (PET), the plastic commonly used in their bottles, because the margins for collectors and logistics companies are too low in many African countries (Ndiso, 2019).

It was observed that the position a player occupies in the value chain is proportional to the profit margin. Therefore, all three case studies highlighted their intention of expanding their range of operations within the value chain. For example, rather than selling to uptakers, become uptakers, enabling interception of the value-added when waste is in addition processed after being collected. Recyclebot is exploring local manufacturing (using 3D printing) driven by fintech. Also, by capturing data on waste collection, they are developing a credit score system in which their collectors can improve a credit score and exploring options to enable payments on the waste management system at zero cost.

Advanced plastic recycling technologies and innovations (e.g., chemical recycling, solvent-based recycling) that can convert plastic waste into various valuable products, enabling a circular plastics economy, are often owned by MNCs or non-African companies. Therefore, a major question remains about how to respect the returns due to intellectual property rights while ensuring local economic benefits through a scale-up process that benefits all parties.

5.3. The Role of Policy to Create Circular Plastics Value Chains

All three case studies emphasized the need to address policy gaps and weaknesses in the plastics value chains.

This confirms findings from the literature that identify policy interventions as the critical drivers of sustainable business models in the circular plastic economy. Necessary policy measures include regulating landfills and end-of-life management, factoring resource scarcity and costs of virgin raw materials, setting industry targets and initiatives, and supporting new material properties and technological advances (Dijkstra et al., 2020). Having assessed environmental innovation practices related to plastic waste in Kenya, Oyake-Ombis, van Vliet, and Mol (2015) conclude that government recognition and guidelines need to be tackled more effectively if effective plastic production and plastic waste are to be tackled. To avoid an increase in low-quality plastic waste imports to African countries, trade policymakers and customs officials need to pay attention to international developments in plastic waste trade. In essence, for any digital innovation to work, robust policies that work in tandem with and for policymakers, industry, waste pickers and citizens need to be clearly outlined and put in place. Local content or labor requirements may be an instrument to support the involvement of MNCs in talent development where appropriate, as regards pollution regulations or concessions for upstream consumers of plastic products.

It is pertinent to note that many good policies on waste management are in place; however, coordination and enforcement is lacking. One area of focus should be the

Extended Producer Responsibility (EPR) scheme, where plastic producers play their part in post-consumer recovery. For example, in Zambia, the Extended Producer Responsibility Regulations are tools that the government will rely on to manage packaging materials such as plastics and their resultant waste in an environmentally sound manner. The EPR Regulations will also regulate non-returnable glass and plastic bottles, cartons, beverage cans, waste oils, pesticide and chemical containers, used tires, electrical and electronic equipment, and resultant waste.

Plastic bag bans are a widely used policy measure, which has been implemented in 36 African countries. However, anecdotal evidence on success rates suggests that plastic ban policies in Africa have largely had mixed results in curbing the influx of plastic products into the waste stream (Attafuah-Wadee & Tilkanen, 2020). A notable exception to this trend can be found in Rwanda, where, through a combination of a tough legal regime and strict enforcement, an arguably successful policy has been implemented since 2008 (Clavel, 2014).

The case studies also revealed that most producers prefer to use virgin plastic materials, which does not help to scale up the market and value chains for recyclables. It is often observed that recycled plastics are more expensive than virgin ones. This can be tackled by introducing supportive legislation on recycled content (for example, mandating plastic producers to include a percentage of recycled content) to drive demand and increase the recycling rate. This sort of policy will encourage MNCs to work more with the circular economy ventures. All three case studies highlighted that incentives are key in making progress. Therefore, policies need to strike the right balance between incentives and penalties.

DIs are being used to increase Africa's low plastic collection rates, which could be further improved if customers paid a refundable deposit when plastic bottles are returned. DIs can enable such deposit scheme transactions where they may have been impractical up until now due to their large number and small size. Glass bottles already require deposits throughout the continent. But companies will not implement deposit schemes unless governments make these mandatory through regulation (Ndiso, 2019).

The analysis of the plastic value chain and the case studies also revealed significant data gaps about the quantities of plastic sources, waste flows and types of plastic waste across Africa. Digital technologies will be crucial to address this lack of data. Establishing baseline data and reliable predictions can help build effective management and remedial strategies (Jambeck et al., 2018) and enable successful circular business models that support entrepreneurship and job creation.

6. Conclusions

Although digital innovations in Africa around plastic waste are gaining momentum, more research and the invention itself need to be carried out. This is because the focus on the plastic circular economy is in its infancy for the most part in Africa and has not garnered enough research. In particular, when it comes to DIs around the circular plastic economy, issues around technology infrastructure, digital knowledge, accessibility and use mean that there is still more to be done. It should also be recognized that the complexities around waste management as a regulated industry with considerable material flows mean that data will always be a core requirement if the system is to operate optimally.

DIs can be a significant aid to gathering and analyzing relevant data and enable that effective research.

Where there is no established waste economy for plastic in place, and the recycling system is being developed anew, assessing the deployment of digital technologies from the outset would look to be essential. As discussed in this paper, there is already a recent history – for example, on financial services applications - where digital innovation has enabled African countries to move forward further and faster than adapting from systems in place in more developed countries. But to make those strides, digital innovation has to be a critical enabler and address the barriers to creating a circular plastic economy.

DIs can be used to grow the local projects at a granularity appropriate to the demography and geography for Africa, from urban to rural communities. DIs in the form of apps can support the efficient collection and transport of waste plastics to aggregators and enable the efficient optical sorting of the plastics to fit the reprocessing need. This is helpful to allow a "bottom-up" approach for waste management and progress in local pollution reduction measures. But the absolute power of DIs will be in how they can be deployed to organize waste plastic to achieve circularity at the system scale. Taking this forward will need research. In turn, deployment of DIs enables research through the generation of spatial and temporal data, informing the assessment of the systems and processes behind the management of waste plastic. Examples include:

Market development: digital platforms can be used to establish virtual marketplaces, supplying plastic from waste collection to the processor of that plastic to the purchaser of the recycled materials who will reprocess the flake into recycled pellets. Government's ambitions should be to optimize the recycling (and indeed recovery) of waste materials for beneficial use and prevent pollution. While creating online marketplaces is straightforward, a critical research question is how it performs with or without market regulation or support and how this can support effective governance around waste commodities. Governments ought to be driving such markets online because it is easier for them visibly to:

- Assess the throughput of materials, imports and exports, and their destinations
- Underpin transparency in the waste plastic market
- Ensure that waste crime and environmental pollution are minimized through traceability.

Policy development: Governments need to constantly assess their policy and measures to manage waste arisings from their communities and businesses effectively. Digital platforms that provide the oversight of waste movements and processing will provide the evidence base for the policy and waste strategy development, ensuring the outcomes sought by governments at all levels are achieved. But importantly, digital platforms can provide the evidence base for research into the effectiveness of measures underpinning those policy objectives, for example, the management of environmental risk, basis for the chain of custody for waste materials for the duty of care, need for market interventions (regulation) or reform, and drive priority infrastructure development.

Influencers on waste arisings: the role of significant business in the creation and growth in sales of plastic-packaged fast-moving consumer goods has been well-documented in the feature-length films *A Plastic Ocean* and *the Story of Plastic*. However, evaluating the success of the MNCs to reduce their waste impacts, and improve their product's recyclability are critical research questions that DIs can inform and support, for example, enabled through blockchain technology. This generates a solid evidence base that governments can use to influence such packaging on the market and research effective market measures such as Extended Producer Responsibility.

Future research questions: For the academic research community to address is the data gap on plastic waste and pollution in Africa. Furthermore, key research questions from a value chain perspective would be: How can a digital circular plastics economy create higher value for the various stakeholders involved? What is needed to ensure that small local businesses and informal waste pickers benefit from the transition to a circular plastics economy?

In conclusion, the drivers for a circular economy for plastics in Africa are compelling – a growing, youthful population, increasing consumption of FMCGs, and limited infrastructure for waste management creates real opportunities for DIs. To move far and fast will require rapid development of situational awareness, an intelligent basis for policy creation and effective measures and infrastructure to mitigate risk and extract value. DIs have the ability to operate across sectors and can be the basis to enable a systemic change towards a circular economy for plastic in Africa.

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Notes on Contributors

Dr. Muyiwa Oyinlola is an Associate Professor in Engineering for Sustainable Development. One area of his research focuses on utilizing Digital Innovations to promote and accelerate the transition to a Circular Plastic Economy in Africa.

Dr. Patrick Schröder is a senior research fellow at Chatham House, Royal Institute of International Affairs. His research focuses on the issues of policy, finance, trade and technology innovation in the circular economy.

Dr. Timothy Whitehead is the Head of Design and Senior Lecturer in Product Design with a research interest in developing tools and approaches to improve the design of products distributed in low-income countries. Timothy has worked on a number of GCRF projects which utilize design methods and new technology to improve the livelihood of those living on less than US$1 a day.

Dr. Oluwaseun Kolade is a Reader in Strategic Management at De Montfort University, where he also leads the African Entrepreneurship Cluster. His research covers the broad areas of transformative entrepreneuring, digital transformation, and SMEs strategies in turbulent environments.

Dr. Kutoma Wakunuma is Associate Professor Research and Teaching in Information Systems at De Montfort University. Her research interests are in understanding the social and ethical implications of ICTs and the role that emerging technologies play in both the developed and developing world.

Dr. Soroosh Sharifi is an Assistant Professor of Water Engineering at the University of Birmingham where he leads the Hydroinformatics research team. His research addresses a variety of topics related to modelling and optimizing sustainable environmental systems including net carbon water infrastructure, sustainable urban drainage systems and low-cost water and wastewater treatment technologies.

Dr. Barry Rawn studies the deployment of sustainable energy infrastructure in developing countries. As associate teaching professor at Carnegie Mellon University Africa, he teaches power and energy related courses while facilitating local industrial collaboration and international research activities. He obtained his PhD from University of Toronto, Canada, in 2010.

Dr. Victor Odumuyiwa is the acting Director of the NITDA ICT Hub, and a senior lecturer in the Department of Computer Sciences, University of Lagos. His research focus includes user information behavior, collaboration systems and knowledge management.

Dr. Selma Lendelvo is a Senior Researcher and Head of the Life Sciences Division of the Multidisciplinary Research Centre, University of Namibia. Her research focuses on the sustainable management of the environment and natural resources.

Dr. Geoff Brighty is a highly experienced and passionate environmentalist with a 30-year career in roles that span research, strategy, policy and operations in environmental regulation and management.

Bosun Tijani is co-founder and CEO of Co-Creation Hub; a pan-African innovation enabler that work at the forefront of accelerating the application of innovation and social capital for a better society.

Tomi Jaiyeola is an international development professional with progressive project management experience directing education, technology, and economic initiatives across Eastern and Western Africa.

Lukonga Lindunda is a Startup Ecosystem Builder, and Co-founder of BongoHive Group of Companies, in Zambia, which includes BongoHive Innovations, an award-winning innovation and technology hub changing the landscape of innovation and entrepreneurship in the region.

Radhia Mtonga is a Zambian social entrepreneur whose driving passions are social entrepreneurship, environmental sustainability and the circular economy. She is the founder of *Ulubuto*, a tech-based recycling initiative that is working to establish and promote a culture of recycling as well as sustainable and responsible resource usage.

Dr. Soroush Abolfathi is Head of Environmental Sustainability Theme of Global Research Priorities at the University of Warwick. His research interests include pollution transport in the environment as well as resilient infrastructures to natural hazards, climate change and flooding.

ORCID iDs

Muyiwa Oyinlola http://orcid.org/0000-0002-5760-672X
Patrick Schröder http://orcid.org/0000-0002-4550-7900
Timothy Whitehead http://orcid.org/0000-0001-8751-1484
Oluwaseun Kolade http://orcid.org/0000-0002-1125-1900
Kutoma Wakunuma http://orcid.org/0000-0002-8236-3221
Soroosh Sharifi http://orcid.org/0000-0003-0717-1729
Barry Rawn http://orcid.org/0000-0001-7416-9130
Victor Odumuyiwa http://orcid.org/0000-0002-1050-892X
Selma Lendelvo http://orcid.org/0000-0002-9793-6950
Geoff Brighty http://orcid.org/0000-0002-0566-4493
Bosun Tijani http://orcid.org/0000-0002-2156-6738
Soroush Abolfathi http://orcid.org/0000-0001-7319-4289

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Appendix 1. Selected initiatives using digital innovations in Africa.

Initiative name	Country	Year	Digital technology	Weblink
AfricWaste (Veolia)	Côte d'Ivoire	2017	Smartphone payments for collection	https://www.veolia.com/africa/en/africwaste
Capture Solutions	Nigeria	2019	B2B ICT applications; IoT, app and web-based solution which fully automates and digitizes the PET recovery process	https://givosolutions.com/
Chanja Datti	Nigeria	2015	online portal for collection; phone top-up and electronic shopping vouchers	chanjadatti.com
Coliba	Côte d'Ivoire	2017	Mobile app & SMS platform for waste sorting and collection; app for reporting waste dumping	http://coliba.ci/
Coliba	Ghana	2016	Mobile app & SMS platform for waste sorting and collection; app for reporting waste dumping	https://coliba.com.gh
Ecofuture	Nigeria	2015	Web, mobile app & SMS for collection and recycling; redeemable points for food, health insurance and cash	ecofuture.com.ng
Eco-Post	Kenya	2009	Ap-based reward system for suppliers, electronic points for airtime, shopping vouchers or mobile money.	http://www.ecopost.co.ke
eTrash2Cash	Nigeria	2016	Web, mobile app and SMS technology for direct waste to cash payments	http://etrash2cash.com/
Mr Green Africa	Kenya	2014	App-based collection services and integration of informal waste pickers into manufacturing supply chains	https://www.mrgreenafrica.com/
OkwuEco	Nigeria	2019	Education app, GPS to connect collectors, merchants and households	https://okwueco.com/
Packa-Ching's	South Africa	2017	e-Wallet solution for collections and cashless payments; waste hotspot identification	https://www.packaching.co.za
Reaval Uno Limited	Ghana	N/A	Digital technology for buy-back schemes and collection	https://reavalworld.com/
Recyclan	Nigeria	2018	Mobile app and SMS service to incentive people to recycle their waste.	https://recyclan.com/
RecycleBot AI Solutions	Zambia	2018	Innovative digital tool – Recyclebot and mobile app	http://www.recyclebot.app/
Recycle points	Nigeria	2012	Points-based collection program; SMS notification service for recyclers and collectors; iRecycle Store to redeem points	recyclepoints.com
Rent-A-drum	Namibia	1989	Mobile phone-based collection; incentive awards and e-wallet for digital payments	N/A
Scrapays	Nigeria	2019	Mobile app, web app and Internet of Things (IoT) technology for collection and recycling	https://scrapays.com/
Takacycle	Tanzania	2019	Smart mobile collection and recycling platform & rewards	http://www.takacycle.com/
Techbionics Ventures	Nigeria	2018	3D printing, scanning and laser cutting to recycle hazardous plastic waste; customized prostheses for people with disabilities	N/A
Ulubuto	Zambia	2019	Mobile app for information and finding recyclers for collection	N/A
Vicfold recyclers	Nigeria	2016	Web-based service for recyclables collection and electronic Green Points reward system	http://www.vicfoldrecyclers.com.
Virdismart	Kenya	2019	Smart bins for automated collection and electronic reward systems	virdismartco.ke/
Waste Recycling App (Wrapp)	South Africa	2008	WRAPP business app for large collections and payments	https://wrapp.co.za
Wastezon https://wastezon.com/	Rwanda	2018	Wastezon app connects households/individuals and recyclers	https://wastezon.com/
WeCyclers	Nigeria	2012	WeCyclers app for collectors to store recycling data	http://www.wecyclers.com/
Yo-Waste	Uganda	2018	Yo-Waste mobile app and website and waste data platform	https://yowasteapp.com/