Environmental Science and Pollution Research (2021) 28:52392–52404
https://doi.org/10.1007/s11356-021-14471-8

RESEARCH ARTICLE

Co-production in solid waste management: analyses of emerging cases and implications for circular economy in Nigeria

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Received: 28 November 2020 / Accepted: 14 May 2021 / Published online: 19 May 2021

Abstract

Co-production is a paradigm shift from the traditional model of public policymaking and service delivery that advocates for the involvement and participation of end-users of services as co-partaker in the process. In this paper, we examined the emerging models of co-production in solid waste management in Nigeria using a case study methodology. Four cases were purposefully selected for detailed exploration. The results of the analysis show that the involvement of the plurality of the non-state actors in waste management co-production brought in innovation through ICT, financial resources through grants, and increased public awareness. And have also given the service receivers a change of orientation that makes them perceive waste as a source of income rather than all rubbish needed to be discarded. However, possible exploitation of informal waste pickers, unclear business models, and absence of prior arrangement for coming together of both state and non-state actors in designing the service production are challenges to the emerging co-production cases. The current study further shows that the emerging co-production efforts have huge potential in promoting circular economy as it creates a better avenue for the implementation of extended producer responsibility (EPR), the establishment of eco-industrial parks, and safe integration of informal waste recyclers.

Keywords Waste disposal · Waste recycling · Informal waste picking · Resource recovery · Waste Policy · Waste reuse

Introduction

Municipal solid waste is a pervasive urban development challenge of the twenty-first century plaguing both developed and developing societies. Poorly managed solid waste constitutes a source of potential threat to environmental sustainability and public health (Hoornweg and Bhada-Tata 2012). As such, its management has become a major issue of deliberation among policymakers, researchers, governments, businesses, and even international organizations. One major factor that problematizes solid waste is the issue of material and resource requirements that characterize its management which entails incurring both capital and recurrent expenditure. Capital expenditure is required in terms of procuring waste management facilities such as compactor vehicles, recycling equipment, and landfill construction. Recurrent expenditures are in the form of costs for fuelling vehicular equipment, payment of staff salary, and so on. Because of these associated material and financial burdens, providing efficient waste management delivery cannot often be adequately carried out by state actors, especially in low- and middle-income countries where economic resources and other critical capacities are limited (Scarlet et al. 2015).

There is a growing understanding that the problems associated with the sustainability of cities and societies such as urban solid waste management cannot be tackled by a unilateral approach alone. Hence, opinion has been conveyed that such problems require the successful integration of stakeholders' efforts towards synergizing resources, knowledge, ideas, and technical expertise (Adelle et al. 2019). This position is in rhythm with the sustainable development concept that strongly emphasizes multiple levels of cooperation and

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collaboration towards solving global problems together (Ngan et al. 2019). Co-production, therefore, is a paradigm shift from the traditional model of public policymaking and service delivery that advocates for the involvement and participation of end-users of services as co-partaker in the process. This new public governance model recognizes variants of collaborative arrangements as viable governance options at different levels (Howlett and Ramesh 2017). In high-income societies, the inclusion within the governing processes of the plurality of actors has gained wider acceptability and is increasingly being regarded as a proactive way of addressing complex societal problems (Clarence 2002; Sorrentino et al. 2016). But it is also recognized that in the low- and middle-income countries, where resources are usually limited due to incomplete development, that co-production is practically inevitable in public service delivery (Linders 2012).

In recent times, few research works have been carried out on the adoption and implementation of co-production as a public policy delivery method at the developing locations of the globe (Lu and Sidortsov 2019; Mangai and De Vries 2018; Mukherjee and Mukherjee 2017; Gutberlet 2015). But most of these works are largely conducted outside Africa explicating the other global south experience especially in waste management (Gutberlet 2015; Lu and Sidortsov 2019). The heterogeneous characterizing features of cities and societies along global regional lines in terms of social, political, economic, demographic, and even cultural peculiarities make it unavoidably necessary to study other regional and countries' experiences towards contributing to the global discourse of co-production in waste management. Nigeria being the most populous nation and the highest producer of urban solid waste in Africa is more appropriately situated to be studied as a case study. The current work will, therefore, provide a departure point for understanding co-production in solid waste management in Africa's context. Moreover, the previous works on co-production in waste management had dwelled more on fewer components of waste management systems. For instance, waste sorting (Lu and Sidortsov 2019; Di Liddo and Vinella 2020); waste reduction and sorting (Mclaren and Agyeman 2015); waste collection (Landi and Russo 2020); and informal recycling (Failor 2010; Gutberlet 2015). The current work discussed more components such as waste conversion, waste transportation, e-waste management, recycling, informal recycling, and resource recovery.

The paper is structured as follows: the introduction describes the background of the research study; the next section is a brief literature overview and conceptual framework; Section "Methodology" explains the study methodology; the results and findings are discussed in the section "Research findings and discussion." The final section is the conclusion.

Literature/conceptual framework

Waste management status in Nigeria: brief overview

With a population currently estimated at 198 million people in 2019, Nigeria is struggling with enormous socio-economic challenges which have been predicted to persist into the future due to (i) unmitigated growth in both general and urban population and (ii) lack of attendant growth in the country's critical capacities such as state-of-the-art urban infrastructure, advancement in technology and economic resources (Ezeudu 2020; Ezeudu et al. 2020). Thus, the continuous population growth results in the proliferation of both urban and urbanizing areas and the resultant rise in the quantities of solid waste generated by communities (Ezeudu et al. 2019). The quantity of waste generated by 106 million people currently living in Nigeria's cities is about 67,000 tonnes per day (TPD), and this value is projected to exceed 125,000 TPD by 2040 (Ezeudu et al. 2021). Unfortunately, both in the past and the present, Nigeria's waste management procedures, policies, and institutional arrangement has followed a top-down structural approach where qualitative laws are made with little or no considerations to the input of the non-state actors in the policymaking and service delivery cycle of commissioning, design, delivery, or assessment (Agunwamba 1998; Ezeudu et al. 2020). This has led to undesired waste management outcomes in the form of poor waste collection services, inefficient recycling, and resource recovery schemes, and abysmal waste disposal methods which have characterized many Nigerian cities (Ogwueleka 2009; Nnaji 2015). The current status of waste management in Nigeria is also characterized by the absence of waste management data, absence of waste sorting schemes, lack of conceptual planning for waste minimization, inadequate financing mechanism, and poor waste management policy regimes (Ezeudu et al. 2020). Detailed discussion on the past and current waste management practices in Nigeria can be found in Ezeudu et al. (2020).

Meanwhile, today's conceptualization of sustainable waste management operations has gone beyond adequate waste collection and efficient disposal, to include business and economic possibilities towards achieving a *circular economy* (Centobelli et al. 2020). The heightening awareness that the global resources are finite in availability has triggered a growing focus by businesses exploring better resources and process efficiency at different stages of production and consumption to promote the principles of circular economy (Patwa et al. 2021). Circular economy principles promote waste reduction, waste reuse, eliminating waste and pollution, optimal use of products, and regeneration of natural resources (EllenMacArthurFoundation 2021). Previous works on the circular economy in solid waste management in Nigeria has identified the key enablers to circular economy adoption as the presence of informal waste recycling activities, the existence

of government agencies that serve as formal regulators, proven marketability of the solid waste streams generated across the country (Ezeudu and Ezeudu 2019), and collaboration among stakeholders (Ezeudu et al. 2021).

In recent times, many co-production efforts have continued to emerge in Nigeria to tackle the country's monumental waste management challenges. The aim of this paper is, therefore, to analyze these co-production efforts to synthesize their prospective challenges and opportunity and also to recommend scientific solutions and guidance that will reposition them towards effective public service delivery in Nigeria. The current work will further discuss the implications of this co-production in waste management for a circular economy.

The concept of co-production

Before the 1970s, the dominant interaction method between the public administration and public service receivers was passive, where governments provide services to the public with the limited active participation of the citizens (Sorrentino et al. 2018). The introduction of co-production as an alternative method of *public service delivery* is principally hinged on the belief that the production and delivery of services, unlike the production of goods, is often difficult without the active participation of the recipients (Ostrom 1996). Hence, the *citizen's contributions* have proved necessary for the production and delivery of hard services—such as police, military service, and waste management—and soft services such as education, health, and disaster management (Parks et al. 1981). The advantage of this change in service production method is that it has turned the receivers of public services into consumers that can exercise choices, while at the same time reframes the co-production as something that can be added to the repertoires of services delivery arrangements to improve efficiency (Alford 2009).

The concept of co-production as a public policy mechanism has evolved from traditional methods that constitute mainly of organization and competition in public service delivery to non-traditional methods characterized by different collaborative arrangements and multiple actors' involvements (Sorrentino et al. 2018). The taxonomy of co-production in public service has also been highlighted in the extant body of literature (Bovaird et al. 2015; Mukherjee and Mukherjee 2017). The commonly agreed facts among scholars are that the actors in co-production can be broadly categorized into two which include (i) the *state actors* or agents acting on behalf of the government either through direct or indirect contracts and (ii*) non-state actors* that interact with the state actors in public service delivery. Another classification in co-production also exists along with the roles and objectives of the actors which include *individual co-production* and *collective co-production*. Individual co-production is defined as a production arrangement where a client or a customer, individually or in a group participates in the production or part-production of the services they use while receiving benefits that are largely personal (Brudney and England 1983). In the collective variant, co-production includes efforts from citizens, volunteers, and other non-governmental partners, intending to provide benefit to the entire community. Nabatchi et al. (2017) classified co-production according to four service cycles in which it can occur. The first is *co-commission* which entails working together of state actors and non-state actors in strategizing, prioritizing, and identifying the needed public services, outcomes, and users. *Co-design* involves undertaking public service delivery planning decisions together (state and non-state actors). *Co-delivery* means joint actions undertaken by the two parties at the point of delivering the services while the last stage which is *co-assessment* means post evaluation and monitoring of public services by the two actors. Recent scholarships have also posited that (i) the extension of the co-production process to accommodate *behavioral changes* among the citizens in the design and implementation of public service delivery is equally essential in assessing the outcome of the service production (Mukherjee and Mukherjee 2017); (ii) positive attitude on the part of public officers could improve the co-production outcomes (Landi and Russo 2020). One of the key enablers to co-production in public service delivery in modern times is advances in information and communication technology (ICT) (Sorrentino et al. 2018). Through the creation of an interactive platform, ICT builds a platform for extensive input from users, knowledge integration, and user participation which are essential elements required for effective co-production in public service delivery (Frissen et al. 2008). Although the impacts of digital technologies on different elements of co-production could be evaluated through an analytical framework (Lember et al. 2019). Table 1 summarizes the conceptual framework.

Methodology

This study is conducted adopting a qualitative method for the following reasons: (i) survey-based methodologies and quantitative measurements are either less-preferred or inappropriate for examining organizational processes such as co-production arrangement (Strauss and Corbin 2007; Yin 1994); (ii) when the specific objective of the research is to gain an understanding of richness and complexity of the phenomenon, quantitative methods such as survey-based and quantitative approach are less capable of providing detail and capturing insights, making the qualitative method more appropriate (Lincoln and Guba 1985); (iii) qualitative research methods provides a unique avenue for understanding complex, nuanced situations where interpersonal ambiguity and multiple interpretations exist (Austin and Sutton 2014). We, therefore, use an exploratory case study (Yin 1994) to assess

Table 1 The summarized conceptual framework for co-production

Attributes of Co-productions	Description
Actors	Actors are broadly categorized as state actors and non-state actors
Grouping based on roles/objectives	Individual co-production and collective co-production
Grouping based on public administration and service delivery methods	Traditional and non-traditional methods. Traditional methods mean organization and competition in public service delivery, while non-traditional methods involve different corroborative arrangements and multiple actors.
Classification according to service cycle	Co-commissioning, co-design, co-delivery, and co-assessment, behavioral change assessment.
The key enabler to co-production in service delivery	Information and Communication Technology (ICT)

the problems and challenges of co-production arrangements in waste management in Nigeria. Four cases were selected for the exploration through purposeful sampling methodology which is a criterion-based selection method that allows sampling only by predefined profile and "information-rich cases" (Patton 2001). This is to ensure that a great deal about matters of importance can be synthesized for in-depth study (Patton 2001). The criteria for the selection of the first three cases is that the case will be substantially involved in the components of a waste management system which include, waste minimization, waste sorting, waste transportation, waste recycling, resource recovery, waste collection, and/or waste disposal. The initial data collection and analysis show that these first three cases had similar motivations for involving in co-production. The fourth case was added to explicate the roles of ICT in co-production (as mentioned earlier in the conceptual framework) to enrich the study. The research data was collected through public available archival sources such as company websites, news documentaries, project documents of international aid agencies archived, YouTube interviews/documentaries, magazines, and newspapers. The data obtained from different sources were triangulated and it shows a high degree of consistency (Denzin and Lincoln 2005; Miles and Huberman 1984). The data was analyzed using the iterative process of case comparison. The cases are described in section "Case description."

In addition to this, we conducted a focus group discussion (FGD) to complement the case data. Multiple data collection in qualitative research aids in obtaining maximum insight into specialized topics (Hammarberg et al. 2016). FGD as a research method is unique as it employs an interactional but guided discussion as a means of generating ' the rich details of complex experience and the reasoning behind actions, perceptions, beliefs, and attitude' (Carey 1995). Also, FGD is appropriate where the existing knowledge of a study is limited and elaboration of pertinent issues is necessary (Powell and Single 1996). Adopting the purposive sampling method as recommended by Patton (2001), ten professionals were selected from the waste management industry. Purposive selection adds potency to the focus group discussion since the best-desired data can be generated through 'rich information cases' (Patton 2001). Participants were recruited and selected specifically 'because they can illuminate the topic being studied' (Hammarberg et al. 2016). The ten selected participants include four active researchers in the area of waste management, two waste management professionals from the private sector, two waste managers working with the government and the remaining two participants serve as observers. The two observers will observe to ensure impartiality in the process (Powell and Single 1996; McLafferty 2004). A letter of invitation and information leaflets were sent to the participant ahead of the discussion. The FGD lasted for sixty minutes and was video/audio recorded transcribed and analyzed. The themes of the focus group discussion were developed to complement the case research data. The following themes were highlighted during the discussion.

(i) The prospects and opportunities of the emerging co-production models in waste management in Nigeria
(ii) The challenges and limitations of the emerging models of co-production in waste management in Nigeria
(iii) The future directions of the emerging models of co-production in waste management in Nigeria
(iv) The implications for the Circular economy

Case description

Case 1: Wecyclers—a waste recycling initiative

Lagos is the African most populated city and therefore the largest city producing urban solid waste in the continent. The population of Lagos was estimated at 20 million people in 2016 concentrated in a localized land area of 3577 km^2 which makes the city among the most densely populated in Africa. The public institutions responsible for the waste management in the city cannot properly manage its waste due to factors such as poor street network, traffic congestion, inadequate staff, poor technology, and limited economic resources. This has resulted in tremendous waste management

challenges that impose an imminent potential threat to the urban environment and public health. Heaps of waste dumped beneath the bridges, water channels, and railway tracks are a common sight in the city. The collection services are limited to the visibility areas while low-income areas such as slums and ghettos are left out (Ezeudu et al. 2020). The only known existing private participation in waste management in Lagos is through the traditional public-private partnerships where some private entities join in the service delivery through contract terms (Aliu et al. 2014). Going by the full and rounded meaning of co-production, this practice meets the criteria as co-production in the traditional sense but has limitations in today's narrowed conception of co-production that distinctively separate state actors (or contract agents of government) from non-state actors. Motivated by the problem caused by the city's poorly handled waste, MIT graduate, Bilkiss Adebiyi co-founded "Wecylers," a waste recycling outfit in 2012. Wecyclers first started as a local innovation that collects solid waste from Lagos's poor urban households. The initial aim was to bring waste management services to the underserved population and households in the municipal city. Due to poor street networks, the state waste management authorities are not able to access these areas with standard waste collection trucks and other vehicular equipment. Wecyclers designed a tricycle for easy navigation of the streets where the waste will be collected (Fig. 1).

They will take the waste to the designated center for sorting and informs the households through mobile phone messages on how many points they have earned for trading their discarded items. The points are converted and rewarded to the households in the form of food items, cleaning products, and cell phone call units. At present, the Wecyclers waste management initiative is operating a model that integrates low-cost recyclables waste management facilities which uses technology to raise awareness on the importance of recycling. As of January 2020, Wecyclers has collected over 6200 tons of waste, serviced over 20,000 households, and employed over 80 people (Guardian 2015; Wecyclers.com 2020). Further partnerships have been created with small and medium-scale industries and multinational companies that place a demand for recyclables. Recognizing the impact of this service on the city dweller, the Lagos State Waste Management Authorities has also formed a partnership with the company in the policy framework that will ensure the sustainability of the operation. At the onset of the initiatives, the company visits households to register them as customers/partners, but over time more and more people are visiting the company to register on their own as they want to be part of the reward system (Guardian 2015). Another incentive to this is that the waste management regulation of the state requires the households to pay for their waste collection services, while the Wecyclers offer a reverse model where households get paid for their trash. Wecyclers are also issuing franchises for other entrepreneurs at the various Nigerian locations for recreation of the same waste recycling model.

Case 2: Hinckley Recycling—e-waste recycling outfit

There is clear evidence that formal recycling of urban solid waste is non-existent in Nigeria and the previous attempts by the government to establish recycling schemes on solid waste have not been successful (Nzeadibe and Ajaero 2011; Ezeudu et al. 2020). A large volume of e-waste generated in Nigeria annually together with the ones that come from abroad constitute a serious threat to the public health and environmental sustainability in the country (UNEP 2019). The informal e-waste recycling system in Nigeria which consists of waste pickers, scrap dealers, and middlemen has been in existence but operates with rudimentary methods. This exposes the waste workers to potential harm and toxic substances. Hinckley Group started operations in Nigeria in 1998 as a telecommunications consultancy firm servicing the oil and

Fig. 1 Tricycle designed/constructed by Wecyclers for convenient waste collection services from inaccessible areas (source: authors' production)

gas industry. When the company began acquiring high volumes of non-functional and end-of-life IT equipment, they began to explore e-waste management opportunities. The aftermath is Hinckley Recycling, an e-waste recycling outfit that they established in 2018. Because of the heightening awareness that e-waste embodied some varied amount of hazardous substances (e.g., lead, mercury, and cadmium), its handling requires special skill and specialized training to avoid exposure to harms and health hazards. With collaboration with the Association of Vendors for Used Electronic and Allied Products, the company recruits and trains scavengers on safe methods of e-waste dismantling and handling (The Recycler 2018). Through their program "closing the loop," they partner with local entrepreneurs (e.g., students running a small business, established companies) and waste pickers to collect and store scrap e-waste material for onward shipment to the developed countries following Basel Convention guidelines and the Nigerian local regulations such as Lagos State Environmental Protection Agency (LASEPA) and National Environmental Standards and Regulations Enforcement Agency (NESREA). Under the "Collect and Recycle Services," Hinckley Recycling offers specialized services that target organizations that have obsolete or unwanted technology equipment for recovering redundant electronic items, securely destroy all confidential and protected data, and manages the safe recycling of e-waste. As of June 2020, it is reported that the closing the loop program has helped over 2000 people to earn additional income through safe employment, and over 2.2 million phones have been collected (ThisDay 2020)

Case 3:Pearl Recycling—waste recovery and conversion initiative

Nigeria's current urban population of 106 million people generates about 67,000 tonnes of waste per day (Ezeudu et al. 2020). The state cannot optimally collect this waste for proper disposal. Consequently, a large proportion of them ends up in unauthorized places such as drainages, roadsides, and canals. Motivated by the need to fill this public service delivery gap, Olamide Ayeni-Babjide founded Pearl Recycling. Pearl Recycling is a social enterprise initiative that collects municipal solid waste components (e.g., tyres, bottles, newspapers, magazines, straws, CD places, plastics) for reuse and in remaking of innovative products such as furniture and decorative wares. The company employs uneducated artisans as waste collectors (or scavengers), while the collected waste is treated before being transformed into sustainable furniture and decorative arts (Fig. 2).

Through the "pay for cash initiative," Pearl Recycling encourages urban dwellers to bring their discarded products to their workshop for exchange for cash or swap with finished products at a discounted rate. The implication is that the outfit is instigating a mindset change among the urban dwellers whereby households individually sort their waste before disposal to remove items that can be traded for a value. Pearl Recycling's workshop has turned into a vocational skill transfer/acquisition center that attracts a large number of unemployed youths that come to learn how to convert waste material into an innovative product. For instance, in partnership with the Ford Foundation through grant funding, the company has trained 100 unemployed youths in Lagos on waste conversion techniques, thereby increasing the awareness and the population of Nigerians with knowledge of waste conversion (Solutionsearch 2020). The company has also partnered with artisans (like vulcanizers) and informal waste pickers to ensure constant and optimal collection of specialized waste such as tyre and discarded CD plates waste. By 2020, the recycling scheme has trained and empowered over 9800 people (directly and indirectly) and sensitized around 3 million Nigerians on waste recycling through social media channels, and have collected and upcycled over 2000 tons of waste (Pearlrecyling.com 2020). Another unique thing is that their finished products made from waste are targeted at also providing affordable consumables to the poor and vulnerable who cannot afford comparable products. The inexpensive nature of the products is probably because the products are made from waste materials. Currently, Pearl Recycling is creating upcycling hubs across Lagos while making plans for expansion within and beyond Nigeria.

Case 4:OkwuEco—mobile App for waste collectors/dealers

OkwuEco is an IT app created by a Nigerian startup that uses image recognition to educate households about recycling and links them with merchants who can trade their waste material for cash credits or mobile data through the security of an online platform (African Business 2020). The app creates a kind of market arena for the interaction of buyers and sellers of waste items. Through the OkwuEco app, users identify, sort, buy, and dispose of solid waste from any location in the country. The transaction could be for cash or product swap. The OkwuEco app further creates a platform for automatic schedules for pickups or drop-offs with waste merchants or disposal services. OkwuEco was incorporated in November 2019 and is currently piloting with 70 users, selected among waste merchants and dealers. The app is user-friendly and supports multiple languages and payment options and is specifically designed to capture the needs of even unbanked segments in the Nigerian urban areas. It has impact tools that offer actionable insights for effective user engagements and decision-making. Just like what is often common to new IT solutions, the mobile app is currently attracting the attention of several stakeholders whose inputs have been useful in fine-tuning the new technology and redesigning the business model. This is to embrace market dynamics and policy landscapes towards efficient quality service delivery. OkwuEco generates revenue

Fig. 2 A decorative household furniture made from the waste tyre at Pearl Recycling (source: Design Indaba.com 2017)

by charging a percentage on transactions made through the IT platform while merchants also pay a subscription fee. Furthermore, the new technology helps the users to mark illegal dumpsites in their living locations, of which they can notify the state authorities about or organize cleanups and earn points. In the long term, the app will help waste merchants and dealers to lower overhead costs on logistics, expand and connect to new market segments, measure the impact of revenue, and could track and report data on recyclables in Nigeria (Disrupt Africa 2020). The summary of the attributes of the cases is presented in Table 2.

Research findings and discussion

Prospects and opportunities

Waste management is a critical and essential public service globally. In most places around the world, the provision of effective and sustainable waste services is the statutory obligation of governments through policies, material deployment, financing mechanisms, and institutional arrangements. Waste management typically involves activities such as waste collection, waste transportation, waste storage, waste recycling, resource recovery, and waste disposal methods. But the poor status of these services at the many Nigerian city locations is evidence to prove the inability of the state actors in delivering and providing these essential services. In the four cases described, the non-state actors were motivated by the need to complement the effort of the state which is a critical element of the non-traditional type of co-production in public service delivery. This position was succinctly captured by Governance International that regards co-production as "professionals and citizens making better use of each other's assets, resources and contributions to achieve better outcomes or improved efficiency" (Governance International 2020). The plurality of actors involved in the four cases that range from entrepreneurs, IT engineers, artisans, to tricycle drivers, and bring multi-dimensional expertise, ideas, and resources towards solving a complex social problem of solid waste management. Consequently, certain elements that were absent in the waste management system in Nigeria such as safe e-waste recycling outfits (case 2), conversion of waste to decorative items (case 3) and monitoring of waste collection through IT devices (case 4) have also been introduced as an innovation towards improving waste service delivery.

Currently, there is no documented data on waste management in Nigeria for the use of the waste management authorities in the country either at the state, local, or national levels (Scarlet et al. 2015; Ezeudu et al. 2020). The prospect here is that with the introduction of the ICT in the waste sectors through IT app, monitoring, evaluation, and collation of waste management data could be made possible. The FGD unanimously agreed that the co-opting of multiple actors with varied professional skills and backgrounds in public service delivery such as waste management is the right thing to do especially in a multi-sectional economy like Nigeria.

Poor awareness and knowledge among the public have often been reported as a major setback to effective waste management in most developing countries (Hoornweg and Bhada-Tata 2012). The four described cases have evidence to show their capabilities in heightening public awareness of waste recycling from waste products. For instance, Pearl Recycling through its programs and operations has made the majority of urban dwellers know that most of their household items perceived to have reached the end of their service cycle could be sold or converted to a new product; Wecyclers waste management initiatives are increasing awareness among the

Table 2 Characteristics of the cases (source: Author's compilation)

Case characteristics	Wecyclers	Pearl Recycling	Hinckley Recycling	OkwuEco
Nature of organization	Hybrid (NPO/business)	Hybrid (social enterprise/business)	Business	Business
Component of waste management system handled	Waste collection, sorting, transportation, recycling, and resource recovery.	Waste collection, waste transportation, upcycling, resource recovery, waste management education	E-waste recycling, recovery, e-waste education. Waste transportation, waste exportation	Waste education, waste collection, waste recycling, mass sensitization, waste data tracking.
Actors involved	Entrepreneurs, informal waste pickers, households, multinationals, international agencies, Lagos state government, tricycle drivers, etc	Uneducated/informal waste pickers, unemployed women and youths, artisans, NGOs, international aid agencies, furniture dealers, entrepreneurs, artisans, vulcanizers, etc	Informal waste pickers, entrepreneurs, business owners, formal companies, multinationals, shipping companies, government regulators, etc	Waste dealer, waste merchants, waste sellers, households, telecommunication companies, IT firms,
Location	Lagos	Lagos	Lagos	Jos

households that they can get value for their waste items in the form of food materials, cleaning products, and mobile phone airtime. The use of daily household goods, such as milk and shampoo, as an incentive to draw citizens into waste management co-production has also been reported in Shangai, China (Wu et al. 2016). Participant #4 during the FGD noted that the emerging co-production in the country could raise the consciousness among the urban dwellers that the waste initially meant to be discarded can be traded for value. This invariably would diminish indiscriminate waste disposal habits and increase waste recycling rates.

In developing countries, municipalities often dedicate about 80–90% of their annual waste management budget to waste collection at the urban centers (Hoornweg and Bhada-Tata 2012; Scarlet et al. 2015). Notwithstanding, the services are not still efficient and often limited to only high- and middle-income areas, while urban low-income areas such as slums, ghettos, and shanties are often neglected (Iorhemen et al. 2016; Solomon 2009). This is usually because of poor street networks that make it difficult to access by waste collection trucks. Wecycler's case concentrated on these urban poor areas to deliver effective waste management. What this means in a broad sense is that additional resources and materials have been deployed from non-state players to supplement the effort of the state government towards delivering an essential public service. Also, the Wecycler case described has shown the ability to attract funds/grants from non-state players to waste management delivery in Nigeria. Wecyclers, for example, attracted grants from foreign universities, while the Pearl Recycling training program for the 100 youths was sponsored by Ford Foundation. The FGD participant #5 explained that for the emerging co-production outfits being able to access funds/grants and supports from donor agencies shows that they met a certain level of organizational standard and operation protocols such as transparency and integrity. The Focus group unanimously commented on the need for emerging waste management co-production models to be further strengthened to attracting more resources for waste service delivery.

Challenges and barriers

Despite the progress and prospects brought by the co-production efforts in waste management in Nigeria as discussed in the foregoing section, several imminent challenges and limitations still abound. Firstly, the waste management policies and institutional arrangements in Nigeria have followed top-down structural settings where the government makes a qualitative law without the input of non-state actors and the so-called laws are often devoid of scientific, economic, and business realities on the ground (Ezeudu and Ezeudu 2019). In the state-of-the-art public service delivery, it is now increasingly recognized that the complex "wicked" policy problem such as waste management requires the successful integration of scientific knowledge with local knowledge of particular social, environmental, and historical circumstances (Coen and Roberts 2012; Gollagher and Hartz-Karp 2013). This is called the co-production of knowledge for policymaking (Adelle et al. 2019). In Nigeria, the first and second stages in the service cycle of co-production (as pointed out in the conceptual framework at the foregoing section), which are co-commissioning and co-design have been non-existent. In all the cases (except Wecycler that has attracted a partnership with the Lagos state towards a sustainable policy), there was no onset arrangement for the coming together of both state and non-state actors towards identifying, prioritizing, and/or planning the waste management service production. Because waste management involves a complex chain of activities—such as waste minimization, collection, transportation, recycling, and resource recovery and disposal

methods—synergistic knowledge at the commissioning and design stages of policy and service delivery is a critical necessity. Waste landfilling, for instance, is an essential component of the waste management system since all other methods of waste handling will eventually yield residues that must be disposed of through landfilling (Hoornweg and Bhada-Tata 2012). All the four cases described are involved in recycling, collection, transportation, sorting, and resource recovery operations, and therefore will still generate a waste stream that would be disposed of through landfill. Landfilling being the final waste disposal method is still abysmally and solely handled by the state actors/agents in Nigeria. Participants # 1, 2, and 7 in the FGD contributed that "In essence without a co-production in all the components of waste management systems, the general progress achieved through the emerging co-production efforts would still be largely undermined."

Secondly, the free-for-all proliferation of the waste co-production models could lead to abuse and exploitation of material and resources if not properly harmonized and regulated. Three of the four cases (Wecyclers, Pearl Recycling, and Hinckley Recycling) largely involve the engagement and recruitment of informal waste pickers. Informal waste pickers consist of the urban poor which are mainly women and children and as such are often prone to exploitation and abuse (Made et al. 2020). At the informal waste recycling system in Nigeria, the exploitation of poor waste pickers by the middlemen has been reported in the past (Nzeadibe and Ajaero 2011). Middlemen in the waste picking value chain are businessmen that buy the picked recyclables from the waste pickers (Ezeudu et al. 2020). Since they often have the fund to mop-up the recyclable in a quantity that the factories can buy, they become more influential in the informal waste picking market and most of often than not control the prices and fix transaction conditions that are unfavorable to the poor waste pickers (Ezeudu et al. 2020). Fear of exploitation of informal waste pickers is an imminent challenge in the emerging co-productions models. For instance, it was mentioned in the case of Pearl Recycling that most of the recruited waste pickers are uneducated which has automatically limited their ability to engage in fair bargains and negotiations. In the Wecyclers case, it was also mentioned that the company rewards households with foodstuff, cleaning products, and mobile phone airtime which probably could undermine fairness in the reward system. The group interaction indicated an agreement that, though informal waste pickers have become an essential element in the emerging waste management co-production, there is a need for a proper guideline to be laid by the authorities to ensure their healthy and safe inclusion in the co-productions efforts.

Third, in all four cases, there is non-uniformity in the business model. It is not easy to understand the exact business model applied by the emerging co-production outfits. Wecycler, Pearl Recyclers, and Hinckley Recycling seem to practice a hybrid model that includes both not-for-profit and for-profit business models. Participants #1, 2, and 8 argued that if these business models are not harmonized through appropriate formal regulations and policies, it could likely lead to two outcomes: (i) not being able to attract funding, incentives, and grants from appropriate quarters; (ii) fraudulent practices like an invasion of taxes. The standard practice is that if an organization declares for non-profit, it could attract funding from charitable organizations and perhaps a rebate from the government to support its public service production. Whereas if it declares for-profit, it then becomes appropriately positioned to pay taxes and levies, while its co-production effort in public service delivery could be measured and categorized under corporate social responsibility.

Fourth, despite the huge potential in urban solid waste valorization as exemplified in the discussed cases, there is still a need for wider consciousness that certain classes of waste such as e-waste (Hinckley Recycling) and tyre waste (Pearl Recycling) still embodied some hazardous substances, thereby requires a special guideline for handling. Although the case report shows that Hinckley Recycling applies international best practices in its e-waste handling operations, and the conversion of the tyre to furniture as done by Pearl Recycling was also after proper treatment; there is still a need for documented, unified, and generalized guideline to be regulated by the state actors through policies and institutions. This is crucial for other prospective entrepreneurs that would want to recreate the models in the country.

Future directions and implications for circular economy

Contemporary deliberations on urban solid waste management are largely overlapping with the concept of the circular economy. The circular economy involves the application of practices, policies, and institutions towards ensuring a regenerative and restorative approach to waste and resource management. It leads to an increase in waste recycling rates, job creation, business profitability while ensuring the current and future sustainability of the environment and safeguards of public health. The implications for the circular economy as it concerns the emerging co-production models in waste management in Nigeria will be discussed in what follows:

(i) Eco-industrial park

The eco-industrial park is an essential element of a circular economy system where industries, factories, and businesses are located in proximity to each other for mutual benefit and for the goal of waste reduction and pollution control and achieving environmental quality promotions at large (Sacirovic et al. 2019). Participant # 7 contributed that "the emerging models of co-production in waste management in

Nigeria are already creating an avenue for collaboration among businesses and undertakings that share mutual objectives and goals. It, therefore, has created an avenue for the establishment of eco-industrial parks in a meso-level circular economy system through appropriate policies." Although the Henckely Recycling case tends to observe standardized methods in its operations, there are still no clear indications that the e-waste recycling facilities are located far from household settlements. Environmental pollution resulting from e-waste recycling activities is tipped as a major contributor to negative health impacts in the communities where this informal recycling takes place with women and children being the most vulnerable (Perkins et al. 2014; Singh et al. 2020). Group discussion submitted that the emerging co-production efforts have created the opportunity for the onset planning for eco-industrial parks especially for e-waste recycling outfits that would be sited far from human inhabitants.

(ii) Extended producer responsibility

Nigeria's waste management policy landscapes and practices have not extensively integrated extended producer responsibility in the circular economy manner (Ezeudu and Ezeudu 2019). One key factor that is likely responsible for this could the absence of information and lack of knowledge on how EPR could be implemented. However, the vast majority of items used in Nigeria can be linked to either a foreign or local producer. The Hinckley Recycling case described has shown the practical possibility of shipping e-waste back to the developed countries, while Wecyclers entered into partnerships with indigenous multinationals (e.g., Coca-Cola, GlaxoSmithKline) on the return of recyclables. Even in absence of a formal proclamation of circular economy in the country, the studied co-production cases have established effective collaborations in the form of EPR. Participant #6 suggested that these existing EPR could serve as an avenue and key enabler to the implementation of EPR in the country in a circular economy manner.

(iii) Informal waste pickers/job creation

Informal waste pickers often regarded as the informal economy plays a key role in the circular economy by promoting the integrated management of the city's solid waste (Siman et al. 2020). It is an activity that mainly involves the urban poor that use the most rudimentary method to retrieve a value from waste material for onward recycling. Safe inclusion of the activities of informal waste pickers requires taking measures that will ensure that their occupational health and safety are guaranteed. The major challenge associated with informal waste picking is their lack of organization, poor economic status, illiteracy, and vulnerability to harm and illness. The co-production efforts studied have shown that informal waste pickers are crucial to urban waste management delivery in Nigeria. Therefore, the advent of interactions between waste pickers and formal/corporate businesses is a development that will foster circular economy introduction in Nigeria. Nevertheless, this will require a policy change that will ensure that their interests and health will be protected.

(iv) End-of-life waste treatment practices

For a complete articulation and implementation of a circular economy model in waste management, there is a need for effective and environmentally efficient end-of-life waste treatment methods (Ferronato et al. 2019). None of the four co-production cases described involves end-of-life waste treatment. However, it is already indicated that the co-production outfits will eventually produce waste residues that still require treatment and disposal. This is another good opportunity for the integration of modalities for final waste treatment in the co-production models. For instance, the majority of the residue that will be generated by Hinckley Recycling (e-waste) would best be handled by incineration. Although, the high cost of incinerators has been hinted at as the major impediment to its massive deployment in sub-Sahara Africa (Scarlet et al. 2015). But through appropriate policy incentives, the waste management recycling outfits could be supported by the government/NGOs (through grants) to acquire incinerator facilities for appropriate waste treatment. Another way to look at it is that the large quantity of residue from co-production outfits (e.g., Pearl Recycling and Wecyclers) are usually non-recoverable resources (leftover after resource recovery/recycling) and therefore only suitable for final disposal in the landfill. Depositing only sorted waste items in the landfill prolongs its lifespan, minimizes the cost of maintenance, protects the underground water sources, and reduces environmental air pollutions. All these attributes are essential in effective circular economy implementation in solid waste management.

Further policy implications

Successful implementation of circular economy requires the design and implementation of appropriate policies and enforcement of regulations (Morseletto 2020). The existing waste management practices in Nigeria are typically such that state actors collect waste from designated locations and dispose of them at the dumpsites and landfills (Nnaji 2015). Asides from the payment of waste management levies, the existing policies never specify the roles and contributions of the citizenry in urban solid waste management. Consequently, the vast majority of Nigerians only participate in waste management by only self-delivering their wastes to community bins with little or no effort at sorting or separating from the source. This has indirectly affected the country's waste

recycling rates and also negatively reflects on the overall waste management status. Restructuring of policies is therefore a way forward. The Wecyclers and Pearl Recycling experience have shown that with incentives the urban households can be co-opted into waste sorting and recycling. It has therefore given a clue on how incentivize policies can affect the attitude and interest of the masses on waste management. We believe that the current waste management policy framework can be finetuned as it was done in Shanghai, China where the local government in collaboration with the Bank of China introduced a household "Green account" (Wu et al. 2016). Through the initiative, household waste sorting results in points in the account which can be redeemed for items such as milk and shampoo, and/or deductions in utility bills (Lu and Sidortsov 2019).

Meanwhile, there is an urgent need for regulation of the existing and emerging co-production efforts through policy and institutional frameworks. The targeted areas of this regulation should be on ensuring optimal occupational health and safety conditions of the participating informal waste pickers, harmonization of the business models, and involving the waste management co-producers in the design and commissioning stages of service production. It is our opinion that the existing waste management authorities in the various states of the federation should be restructured to undertake these functions and empowered by law to enforce them.

Conclusions

Waste management is a complex and hard public service. A large body of evidence has also shown that due to multiple socio-economic challenges such as poor economic resources and inefficient urban infrastructure, cities in low- and middle-income countries cannot adequately tackle their waste management problems relying solely on the resources and efforts of the state actors. Participation and contribution are required from the citizenry. Based on this understanding, the current work examined the different models of co-production in waste management in Nigeria, to synthesize and analyze their prospects, challenges, opportunities, and future direction towards possible circular economy adoption. The result of the study rightly shows that several actors with varied skills and professional backgrounds are already partaking in waste management delivery in the country. These actors have introduced increased awareness on waste recycling, extra resources through grants, and innovations through ICT and waste conversion thereby complementing the efforts of the government. However, lack of onset arrangement on co-commissioning and co-designing of waste management service production, non-uniformity in the business operating models, and absence of generalized guideline for regulation are challenges to the effective waste management co-production in the country. Also, the studied co-production cases have huge potential in fostering the adoption of circular economy in the country especially in promoting the establishment of eco-industrial parks, extended producer responsibility, and safe integration of informal waste recycling.

Acknowledgments We gratefully acknowledge the support received from UNN/SHELL Centre for Environmental Management and Control, University of Nigeria, Enugu Campus, Nigeria.

Authors' contributions **OBE** conceptualized, investigated, curated the research data, formally analyzed the research data, and wrote the original manuscript. **TCO** revised the manuscript. **JCA** and **UCU** supervised the project.

Declarations

Competing interests The authors declare that they have no competing interests.

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