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Technology acceptance and readiness of stakeholders for transitioning to a circular plastic economy in Africa

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ABSTRACT

Scholars and practitioners have highlighted the importance of digital innovations in the drive towards a circular plastic economy. Therefore this paper investigates the role of digital innovators and the public's response to digital innovations on the African continent. The study draws from four focus groups, and cross-sectional surveys of 33 digital innovators and 1475 community members across 20 low-middle income communities in five African countries. The results indicate that, while digital innovators are strongly optimistic and highly motivated, their engagement and impact on the circular plastic economy ecosystem are limited by a range of institutional, infrastructural and socio-cultural factors. Furthermore, results from the regression models of cross-sectional data of community members show that understanding of the technologies and perceived ease of use have significant positive impacts on uptake of technological innovations for the circular plastic economy, and perceived ease of use is also a significant moderator of barriers to adoption. The findings underline the need for a well-informed and motivated cohort of digital innovators to promote diffusion of circular plastic innovations. It also emphasizes the importance of a more collaborative, multistakeholder and multi-sectoral synergy to create a critical mass of the consumer public needed to break the linear economy lock-in mechanisms and accelerate the transition to a circular plastic economy in Africa.

1. Introduction

For a long time, the global economy has been locked in the linear paradigm of take-make-dispose in production and consumption patterns. Within the past decade, the entrenched habits of the linear economy have increasingly exacerbated the waste problem, including plastic waste. Between 2010 and 2020, the annual global production of plastics increased from 270 million tonnes to 367 million tonnes (Statista, 2022). Only 9 % of these plastics are ever recycled and about 8 million tonnes of plastics, annually, end up in the world's oceans (United Nations Environment Programme, 2022). At this rate, according to one estimate, there will be more plastics than fish in the world's oceans by 2050 (United Nations Environment Programme, 2022). Plastics' detrimental environmental and health impacts, including waste, degradation of natural systems, carbon emission, and toxic chemicals, have therefore been the subject of increasing global concerns and discussions in recent years (Schroeder et al., 2021). The urgency of addressing the plastics production and use problems has also been heightened in recent years as part of the global conversation about the consequences global carbon emissions and climate change. Furthermore, the global covid-19

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pandemic has precipitated a significant 300 % increase in single-use plastics products (Economist, 2022). Therefore, a transition to circular plastic economic (CPE) has been identified as an imperative, if the global community is to address plastic pollution's wicked problem while driving sustainable development and growth. CPE can ensure a significant reduction of plastic use and robust and responsible management of plastics throughout their lifecycle. This requires a systemic change in how manufacturers design and produce plastics and how households use them through their lifecycle. In other words, a transition from a linear to circular plastic economy requires a transformation of the entire supply and value chains. This transformation requires a multi-stakeholder, multi-sectoral buy-in into the circular paradigm of production and consumption.

Digital innovations can play an essential role in facilitating the systemic changes needed to transition towards a circular plastic economy and resource efficiency in the plastic sector (Barrie et al., 2022). To date, the majority of CPE initiatives have focused on physical materials and resources, which are often run as individual projects and not at the scale to address the plastic pollution problem meaningfully. Digital innovations can act as a facilitator, accelerating the CPE solutions at a global level and across industries. Coherent and inclusive digitalisation efforts at the local, national, and international levels are paramount to achieving the environmental, economic, and climate targets of CPE (World Economic Forum, 2021). To achieve this, appropriate incentives are needed from governments to enable technology innovators to develop the digital backbone and disruptive digital technologies that support CPE transition. Sharing data, open-source software, CPE digital toolbox, and adopting the concept of 'a global public good' will reduce the cost, time, and business risk for adopting these digital innovations (World Economic Forum, 2021).

In the context of Africa, the circular plastic economy potentially offers a great opportunity for skills development, employability, economic progress, and value creation. There have been many examples of innovative CPE projects across Africa, mainly focusing on social enterprise for plastic repurposing, female entrepreneurship, and community empowerment. African CPE players are contributing to green growth by creating green jobs and green products (e.g. Berg et al., 2018). For instance, converting plastic waste to artefacts and pavement blocks in Ghana reduces waste, effectively enhances resources and creates sustainable jobs and skills training (Debrah et al., 2021). The challenge is that these otherwise important examples of CPE initiatives are not sufficiently at scale across the continent to make significant aggregate impact on the plastic waste problem in Africa. Besides, these notable examples of circular plastic initiatives are typically undertaken by social enterprise innovators and NGOs who often work in silos from governments, university and other industry and community stakeholders. Digital innovations can play a key role in connecting stakeholders from a whole spectrum of backgrounds and sectors, and thereby help to drive scaling of innovative CPE solutions across the continent. Thus, in this paper, we argue that the diffusion of these innovative solutions will depend on the attributes and approach of the innovators, and the characteristics of the technological innovations designed to accelerate transition to a circular plastic economy in Africa. Our paper therefore addresses two complementary research questions: what is the readiness level of digital innovators to design and promote CPE innovations? And what factors influence the uptake of CPE innovations among consumers and community members?

While the African continent has witnessed the rapid expansion and growing impact of tech hubs (Atiase et al., 2020), there is a gap in understanding technology readiness and uptake to support and enhance CPE initiatives across the continent. The diffusion and scaling of CPE innovations is currently slowed and limited by, among others: (1) a lack of awareness of digital innovations (2) the role they can play in specific CPE projects, (3) lack of appropriate backbone digital infrastructures to enable adoption of the innovations, (4) limited digital literacy and technological know-how, (5) affordability and accessibility, and (6) the lack of appropriate policy and financial incentives. These factors are even more important within the context of the need to break the linear economy lock-in and the grave consequences of continuing in the linear economy trajectory. By 2030, for example, plastic waste is expected to double to 165 million tonnes per year particularly in countries such as Egypt, Nigeria, South Africa, Algeria, Morocco, and Tunisia (Ellen MacArthur Foundation, 2021). The Ellen MacArthur Foundation report further indicates that this type of increase in plastic imports without appropriate technological systems for end-of-life treatment of plastic waste will inevitably contribute to a negative environmental, social and economic impact. For example, mismanaged waste and plastic pollution results in the spread of communicable diseases such as malaria or diarrhea which impacts the most vulnerable in the communities disproportionately (He et al., 2021; Meng et al., 2021).

A limited number of studies investigated the role of digital innovations in CPE across Africa (e.g. Berg et al., 2018; Cagno et al., 2021) and concluded that significant changes to the current regulatory structures are needed to enable robust adoption of digital innovations for CPE. Also, facilitating investment in tech entrepreneurship and technology disruptors and improving technology backbone infrastructures across Africa are critical enablers of CPE at scales. Liu et al. (2021) investigated the trends of integration of the digital economy and circular economy. They proposed an integrative framework approach that includes digital technology toolkits and an all-inclusive strategy across lifecycle stages to generate sustainable impacts for CE and CPE projects. This proposed integrative framework can be beneficial to support the use of digital innovations in CPE across Africa.

Therefore, this study adopts a Technology Acceptance Model (TAM) approach to illuminate the factors influencing the adoption of digital technologies among ordinary consumers and the general public in Africa. TAM provides a deeper understanding of how technology users perceive, accept, and subsequently use new technologies. To achieve a comprehensive understanding of stakeholders' readiness in adopting a specific technology, TAM considers both the functionality of the technology and the broader parameters, including socioeconomical issues such as education, gender, and accessibility.

Perceived Usefulness (PU), and Perceived Ease of Use (PEOU) measures are also essential metrics within TAM that can quantify how functional a specific technology can be to a stakeholder (Davis, 1989). Quantifying PU for a particular digital technology is a function of costs, availability, and know-how for a specific stakeholder. Meanwhile, PEOU describes the ease of use of a technology as enabler or barrier to adoption of the technology by a stakeholder. Venkatesh and Davis (2000) further developed the Technology Acceptance model (i.e. TAM2) to incorporate and quantify the other variables influencing user acceptance. These parameters include; 'Social influence processes (subjective norm, voluntariness, and image), Cognitive instrumental processes (job relevance, output quality, result demonstrability, and Perceived ease of use) significantly influenced user acceptance'. Investigating the role of these parameters for stakeholder readiness, particularly within the context of CPE in Africa, is very important. For example, subjective norm denotes a collectivist approach (Lee and Wan, 2010), and in the case of CPE this can be translated to a collectivist approach to technology, particularly concerning 'how' and 'whether' others associated with a particular stakeholder can find a technology useful in equal measure.

In addition to investigation of adoption behaviours of ordinary community members, this paper also adopts the technology readiness approach to examine the motivational attributes and attitudes that shape the engagement of digital innovators in the circular economy landscape. This enables us to explicate the critical role of these innovators and early adopters in the diffusion of innovation across the rest of society. It also underlines the imperative of a multi-stakeholder, multi-sectoral approach to accelerating transition to a circular plastic economy in Africa. In other words, given that there are several different types of stakeholders in CPE, this paper focuses on investigating technology readiness of digital innovators and start-ups, and technology acceptance of community members. These three groups are of particular importance, given that (i) digital innovators are in the forefront of driving any technological innovations that will eventually become mainstream and taken up by users; (ii) Startups want to be in the forefront using technology innovations to boost up their chances of success and upscaling their business model; and (iii) community members are front end users of technologies, and a key indicator of effective socio-technical transition to the circular plastic economy. This multi-faceted approach to data collection and analysis underlines the imperative of a multi-stakeholder approach to transitioning to a circular plastic economy on the African continent.

2. Theory and hypotheses

2.1. Technology acceptance and technology readiness

Innovation scholars have proposed several theoretical and analytical frameworks to explain the factors that influence the uptake of innovations or the likelihood that an individual will perform a behaviour. For example, the theory of planned behaviour, drawing on the precursor theory of reasoned action, identifies motivational and volitional factors as two key pillars in predicting behaviour, including but not limited to the uptake of technological innovations (Ajzen, 1991; Kolade and Harpham, 2014). In other words, a person's performance of a behaviour is a function of their intention to perform the behaviour, on the one hand, and the resources and capability they have to complete the behaviour on the other. Without this volitional control or perception of the same, motivation is not enough as an antecedent of behaviour. While the theory of planned behaviour addresses the key limitation in the original theory of reasoned action with its inclusion of volitional control, it still does not adequately account for technology-specific factors that explain how individuals respond to technological innovations and ultimately adopt or reject them. Whereas the theory of planned behaviour speaks to behaviour in a broad, generic sense, the technology acceptance model explicitly addresses attitude to, and use of, technological innovations in particular.

Thus, the technology acceptance model (TAM) (Davis, 1989) builds on Ajzen and Fishbein's theory of reasoned action (1980) and Bandura's self-efficacy theory (Bandura, 1982) to provide a more focused analytical framework for predicting uptake of technological innovations. The technology acceptance model highlights five key dimensions or factors that predict adoption of technological innovations: Perceived Usefulness (PU), Perceived Ease Of Use (PEOU), Attitude (ATT), Behavioural Intention (BI), and Actual Use (Davis, 1989; Rajak and Shaw, 2021). Perceived usefulness is the degree to which an individual believes that using a particular innovation would enhance performance. On the other hand, perceived ease of use is how a person believes that using a specific technological innovation will be free of effort. Perceived usefulness and ease of use are the two principal antecedents in the technology acceptance model (Davis, 1989). The distinction and linkages between the two are similar to the difference between outcome expectation and self-efficacy in Bandura's framework (Bandura, 1982). Self-efficacy refers to people's perception of their capability to organise and implement actions required to achieve designated outcomes and performances (Bandura, 1986). While self-efficacy focuses on an individual's response capabilities, outcome expectation refers to the imagined consequences of performing particular behaviours. Outcome expectations can be physical, social, or self-evaluative. Thus, concerning technology adoption, perceived usefulness defines the attributes of technology about the belief of individuals that the technology can facilitate desired outcomes. On the other hand, perceived ease of use focuses on the amount of effort required to use the technology and the individual's perception of volitional control or capability to apply the effort.

In the present study, we draw from Hong et al. (2014) to highlight the context specific variations of the technology acceptance model in the study context of circular plastic economy in Africa. First, we identify technical, financial, political and socio-cultural barriers, in combination, as a critical external factor that influences uptake of circular plastic economy innovations. In addition, we incorporate into our conceptual framework the interactions between perceived usefulness and aggregate barriers to uptake of innovations for the circular plastic economy. The ensuing decomposition of the TAM model enable us to grapple with contextual variations in two dimensions: first in the context of a developing country with generally less developed institutional environment, where innovators, adopters and other stakeholders have to grapple with different challenges and new opportunities to promote uptake of innovations.

The conceptual decomposition is also essential in a discussion of the role of, and attitude to, digital innovations within the context of the circular plastic economy. Firstly, the transition from linear to the circular plastic economy is challenged and complicated by lock-in mechanisms associated with "old" technologies, sunk investment, and entrenched societal consumption habits (Geels, 2010; Oyinlola et al., 2022). Technological lock-in arises from the self-organising market process through which early adopters of a competing technology influence subsequent adopters to take up the same. The subsequent aggregation of network externalities and increasing returns associated with the technology induce an economy to lock itself in outcomes that are not necessarily superior nor easily altered (Arthur, 1989). This is the case with societal lock-in to the linear paradigm of take-make-dispose in production and consumption patterns (Sopjani et al., 2020). Thus, the emergence of new and superior technology is not enough to dissolve a lock-in. Instead, a breakout from technologies requires a "perfect storm" arising from the interlocking networks of markets and the attractiveness of the new technologies for users (Dolfsma and Leydesdorff, 2009). In effect, the transition to the circular plastic economy requires a critical mass of users motivated by the ideals and vision of the circular economy and is willing and able to use technology to achieve the outcome expectations. This combined force of motivational and volitional factors, captured in the decomposed TAM model, is required to overcome collective societal inertia to new technologies and thereafter create network externalities needed to drive new, circular production systems and consumption habits (Araujo Galvão et al., 2018).

The preceding discussion underlines the critical importance of innovators- the first in line to develop or adopt innovations- in the diffusion of technological innovations (Rogers, 1995). Digital innovators and champions of new technologies need to possess the requisite technical aptitude and innovativeness and heightened consciousness and motivation concerning the latest technologies. In this study, we conceptualise and interrogate these motivational attributes of innovators in terms of technology readiness. Technology readiness is "an overall state of mind resulting from a gestalt of mental enablers and inhibitors that collectively determine a person's predisposition to use new technologies" (Parasuraman, 2000, p. 308). It reflects the propensity of people to create, embrace and use new technologies (Sun et al., 2020).The technology readiness index (TRI) comprise four key dimensions that can be classed into two sub-categories: motivators (optimism and innovativeness); and inhibitors (discomfort and insecurity). Optimism entails a positive view of technology concerning its various possibilities, while innovativeness implies a technology pioneer tendency. On the other hand, discomfort refers to a lack of control over technology, and insecurity implies distrust of the technology (Parasuraman and Colby, 2015). The technology readiness is therefore an effective framework to map the motivational attributes and personal traits of the five categories of adopters originally outlined by Rogers (1995): innovators, early adopters, early majority, late majority, and laggards. Thus, as other scholars have reported, innovators are typically individuals with higher TRI's scores on optimism and innovativeness. They also tend to be more comfortable and more trusting of new technologies (Walczuch et al., 2007).

Therefore, the technology readiness index (TRI) is a complementary analytical framework to the technology acceptance model (TAM) in analysing attitudes and responses to new technologies. While TAM focuses mainly on the cognitive dimensions of technology response, TRI emphasises affective, motivational factors. In the present study, we aver that these affective factors are especially important for assessing the readiness of digital innovators to adopt, develop and promote digital innovations. We also argue that both volitional and motivational factors are important explanatory variables that can help explain the process through which society embrace innovations in order to break free from the lock-in mechanisms of the linear economy in the drive towards the circular economy. The following section draws mainly on the technology acceptance model to set out the hypotheses related to the key factors that influence the general public's attitude to new technologies for the circular plastic economy. In a subsequent section, we focus attention on the technology readiness of digital innovators and their role in the diffusion of digital innovations for CPE.

2.2. Hypotheses development

In the context of competing technologies, such as the case with technologies driving linear and circular economies, ordinary consumers need a certain threshold of informational knowledge and functional understanding of the new technologies to break the lock-in. For example, a study of Industry 4.0 technologies adoption among SMEs indicates that knowledge accumulation triggers opportunity recognition among SMEs who, by gaining a deeper understanding of the benefits of the technologies, can deploy them in their operations (Ricci et al., 2021). A similar study finds that consumers' adoption of battery swap technology (BST) for electric vehicles is a function of the extent to which they know what the technology is and how it works (Adu-Gyamfi et al., 2022). Other scholars have reported similar findings that potential adopters require a level of functional understanding, not just awareness, about new technologies, especially those related to sustainability and green solutions (Chang and Wu, 2015; Liu et al., 2019). Given the preceding, we propose that:

H1. Technology understanding is positively associated with the uptake of digital innovations for the circular plastic economy (CPE) in Africa.

Following Davis (1989)'s seminal work on the technology acceptance model, several studies have investigated the impact of perceived usefulness and perceived ease of use (see earlier definitions) in a wide range of empirical contexts. These include healthcare (Alam et al., 2020; Kim and Ho, 2021); manufacturing (Chin and Lin, 2015); construction (Man et al., 2021); crowdfunding (Djimesah et al., 2021). However, while there is a growing body of work investigating the role of new technologies as drivers of the circular economy, the circular plastic economy is still a relatively under-researched area. This is especially the case for the African context. Therefore, his study investigating the role of digital innovations as drivers of transition to a circular plastic economy in Africa aims to contribute to this emerging area of research. We make the following propositions:

H2. Perceived usefulness is positively associated with uptake of digital innovations for CPE in Africa.

H3. Perceived ease of use is positively associated with uptake of digital innovations for CPE in Africa.

Technology and innovation studies also grapple with the negative impacts of technical and non-technical barriers to uptake technological innovations, including innovations for the circular economy. Technical barriers include lack of or inadequate technical know-how, reverse logistics and standardisation issues (van Keulen and Kirchherr, 2021). Non-technical barriers include financial barriers such as limited investment in technology (de Jesus and Mendonça, 2018) and the high cost of recycled materials (Hart et al., 2019). There are also political barriers such as policy incoherence, public procurement issues and inadequate regulatory and tax incentives (de Jesus and Mendonça, 2018; Kolade et al., 2014; van Keulen and Kirchherr, 2021). In addition, uptake of innovations for the circular economy can also be hampered by socio-cultural factors, including the social acceptability of circular economy products (Barquet et al., 2020). The impact of these barriers on uptake of circular economy innovations is often felt in combination rather than in isolation. Thus, we propose that:

H4. Aggregate technical, financial, political and socio-cultural barriers are negatively associated with digital innovations' uptake.

In addition to the key variables identified in key analytical frameworks such as TAM and TRI, innovation studies usually account for the impact of socioeconomic and personal factors such as age, educational level, income, and gender (Charef et al., 2021; Kim and Ho, 2021; Sierzchula et al., 2014). These are incorporated as controls or additional explanatory variables in various regression models. However, several studies have identified gender as a significant factor in studying circular economy innovations. For example, in a study investigating users' attitude and perception of end-of-life scenarios (EoLs) for electrical and electronic appliances, it was found that women showed positive attitudes to environment-friendly EoLs- re-use, re-manufacturing and recycle (Atlason et al., 2017). They are, among others, more willing to pay a premium price for environment-friendly e-products. Our empirical context is also an important consideration: women are often seen at the forefront of initiatives to promote sustainability and environment-friendly innovations on the African continent. We, therefore, propose that:

H5. Gender is positively associated with the uptake of digital innovations for CPE in Africa.

Our final cluster of three hypotheses focuses on the moderating effects of two important personal attributes- income level and education level- on (previously discussed aggregate) barriers to uptake of digital innovations for the circular plastic economy. In addition, we also hypothesise the moderating effect of perceived ease of use on barriers to uptake of digital innovations. Education level is typically associated with increased capacity to access and process new knowledge about CPE innovations (Hazen et al., 2017). With increased knowledge and deeper understanding of the CPE ideal, we propose that consumers are more likely to be positively disposed towards CPE innovations and therefore overcome barriers to adoption. Similarly, we propose that the higher the income level of individuals, the more likely they are likely to overcome barriers, including financial barriers, to innovation. Finally, in line with previous discussions about the importance of perceived ease of use (PEOU), we propose that PEOU is not only important as a direct predictor of CPE innovation uptake, it is also important as a potential moderator of barriers to uptake of innovations. Taken together, we, therefore, propose that:

H6. Income level moderates the impact of barriers on uptake of digital innovations for CPE in Africa.

H7. Education level moderates the impact of barriers on uptake of digital innovations for CPE in Africa.

H8. Perceived ease of use moderates the impact of barriers on uptake of digital innovations for CPE in Africa.

3. Methodology

3.1. Study instrument

This study focused on two main groups: (a) the stakeholders (waste management organisations, civil society, academia, digital innovation firm/startups working on plastic waste and policymakers) to determine the technology readiness level of the stakeholders with major emphasis on the Digital Innovators (DIs) who are potential developers/deployers of technology for managing plastic waste and (b) the community, who need to adopt the deployed technology. Quantitative data was collected from both groups using electronic questionnaires. The survey sought to understand the depth of knowledge and the level of engagement of the two stakeholder groups in ten (10) frontier technologies shaping the present and future of digital innovations. These technologies were identified through engagement with stakeholders and literature.

The technologies of interest include Artificial Intelligence (AI), Geographic Information Systems (GIS) BlockChain, Internet of Things (IoT), Robotics (Rob), 3D Printing (3DP), Serverless computing (SC), 5G, Mobile apps and Augmented Reality/Virtual Reality (ARVR). These technologies were identified as critical enablers for the transition to a circular economy by stakeholders during the focus group discussion as well as from the literature. For example, other scholars such Chidepatil et al. (2020) (AI and blockchain technology), Singh (2019) (Remote sensing and GIS), Mdukaza et al. (2018) (Internet of Things), Hoosain et al. (2020), Kristoffersen et al. (2020) and Schot and Kanger (2018) have also identified similar technologies. Oyinlola et al. (2022) have presented a comprehensive list of how these technologies could contribute to the circular plastic economy transition.

A list of organisations using digital innovations to manage plastic waste in Africa was compiled from the literature and databases (see Oyinlola et al. 2022). A link to an electronic survey was sent to 39 organisations, with 17 of them completing the survey. In addition, 16 other stakeholders who are not digital innovators also responded to the questionnaire, making 33 responses for the first group of respondents.

Field workers were hired and trained to administer electronic questionnaires to over 1500 households in 20 low-middle communities across five countries: Kenya, Namibia, Nigeria, Rwanda, Zambia. These countries have a comprehensive representation of Africa; for example, they are geographically diverse (Eastern, Western and Southern), economically different (Nigeria with GDP: $375.8 billion to Rwanda with GDP: $9.137 billion), vary in a population (190 million in Nigeria to 2.5 million in Namibia) and have very clear differences in literacy rates. A total of 1475 completed responses were analysed.

The following questions, using a series of Likert scale items, were administered to both group of respondents except the sixth question which was addressed only to the community:

1. How would you rate your understanding of these technologies?
2. To what extent do you think these technologies are useful for managing plastic wastes?
3. To what extent do you think these technologies are easy to use?
4. Do you currently use any of the following technologies?
5. Do you have an intention to use any of the following technologies?
6. Please rank technical, economic, political and socio-cultural barrier to adoption of the technologies, from most significant to least significant.

As detailed in Oyinlola et al. (2022), engagement with other stakeholders informed the weighting and categorisation.

3.2. Variables and measures

3.2.1. Dependent variable

The primary dependent variable investigated in this study is the uptake of digital innovations. This is measured by computing the participants' responses to the question: "have you ever used any of the following technologies?" The question was followed by a list of 10 digital technologies: Artificial Intelligence, Geographical Information Systems (GIS), Blockchains, Internet of Things (IOT), Robotics, 3D Printing, Serverless Computing (Faas), Augmented Reality, 5G, Mobiles. The response options were a binary yes/no. These were computed as aggregates of responses for the 10 technologies.

3.2.2. Independent variables

The independent variables considered in this study are: Perceived understanding, perceived usefulness; perceived ease of use; and barriers.

Perceived understanding. Perceived understanding is defined as the level of functional knowledge that a potential user has about the operational features of a particular technology. In this study, respondents were asked to rate their understanding of the listed ten technologies on a 5-point Likert scale from 1 (never heard of it) to 5(excellent). The responses were computed using the "sum" function on SPSS vs 26.

Perceived usefulness. Perceived usefulness was defined in the seminal work of Davis (1989) as "the degree to which a person believes that using a particular system would enhance his or her job performance" (pp.321). In this study, we define perceived usefulness as the degree to which a potential user believes that using technology would help them undertake circular plastic activities: reduce, re-use, recycle, and recover. This is operationalised with a question on a 5-point Likert scale (from "not useful at all" to "very useful") in which participants were asked: "to what extent do you think these technologies are useful for managing plastic wastes?". Here again, as for "perceived understanding", participants were asked to rate the ten technologies investigated in this study.

Perceived ease of use. In line with Davis (1989) we define perceived ease of use as the degree to which a person believes that using a digital innovation would be free of effort. Thus, respondents were asked: "To what extent do you think these technologies are easy to use?". The responses to each of the ten technologies were provided on a 5-point Likert scale, from 1 (very difficult) to 5 (very easy).

Barriers. This study also includes barriers as an important explanatory variable. To operationalise this, respondents were asked: "Please rank these barriers to your adoption of digital tools/technology in plastic waste management". The barriers listed were: technical, economic, political, and social-cultural barriers. Respondents were asked to assign a rank score for each barrier from 1 (most significant) to 5 (least significant). The responses were then reverse-coded such that the highest score of 5 was assigned to "most significant" and 1 to "least significant" and other scores accordingly on the spectrum.

3.2.3. Controls

Our model included four key socioeconomic variables as controls: age, gender, education level, and income level. This reflects their putative relevance as predictors of innovation uptake. Previous studies have shown that education level and income level are positively associated with the uptake of technological innovations and that gender often plays a key role (Balta-Ozkan et al., 2021). Others have reported that age is negatively associated with innovation uptake (Mugumaarhahama et al., 2021). Education level is operationalised as an ordinal variable, ranked from primary school (1) to postgraduate (5). Similarly, for income level, respondents self-reported from a scale of low-income (1) to high-income (5). For age, participants chose from a range of: 18–24; 25–34; 35–44; 45–54; 55–64; 65–74; 74+. For gender, we used a binary measure of male/female.

3.2.4. Interaction terms

We also computed interaction terms to investigate the moderating effects of each of income level, education level and perceived ease of use on the aggregate barrier to uptake of digital innovations. To do this, we first computed the aggregates, by sum, for each of the four variables. Next, we mean-centred these variables by subtracting each variable mean from its aggregate score previously calculated. The mean-centred variables were used to compute the interaction terms, e.g. C_INC*C_BAR being the interaction term between centred income and centred barrier.

3.3. Data analysis

3.3.1. Computation of technology readiness index for digital innovators

The objective of this was to examine the motivation, interest, confidence, and depth of understanding of the digital innovators in of each of the selected technologies. These provide an operational measure of their readiness to create, deploy and promote those technologies for plastic waste management and transitioning to CPE. Thus, in order to achieve this we draw both on a quantitative assessment of the readiness levels, complemented with a qualitative exploration, in focus group discussions, of the motivational factors that explains the readiness of the digital innovators.

$$\text{IndTechReadiness (ITR)} = ((A_r{}^*A_w) + (B_r{}^*B_w) + (C_r{}^*C_w) + (D_r{}^*D_w) + (E_r{}^*E_w))/N \tag{1}$$

In the first, quantitative part, we carried out a cross-sectional survey of start-ups and innovators. A total of 33 respondents completed the survey. The survey instrument include items on: the rating of the respondent's understanding of the technology, rating of the respondent's perceived usefulness of the technology as it relates to plastic waste management and CPE, rating of the respondent's perceived ease of use of the technology, rating of the respondent's actual use of the technology and rating of the respondent's intent to use the technology. For each of the technologies, the stakeholders rated themselves on a 5 point Likert scale going from 0.0 to 1.0 with 0.2 intervals i.e. each DI chose from one of the elements in the array (0.0, 0.2, 0.4, 0.6, 0.8, 1.0) for each of the question.

To determine the importance of each technology in developing digital innovations for transitioning to circular plastic economy, a mean of the perceived usefulness rating for each technology was computed and normalised to generate the weight of importance of each technology as shown in Table 1. The perceived usefulness rating of stakeholders with poor or no understanding of the technology was not included in the mean calculation. From Table 2, it can be seen that the most useful technologies based on the current reality for plastic waste management and transitioning to CPE in Africa are GIS, Mobile app, IoT and AI.

The results from the surveys were analysed to determine the technology readiness level of the DIs.

The stakeholders rated ten technologies based on five questions, generating a 10 × 5 matrix. We attributed weights to each of the question categories based on our judgement of what determines readiness, as shown in Table 2. We assumed that understanding technology and knowing its usefulness play a key role in determining the willingness of a DI to deploy such technology. The two categories were given an equal weight of 0.15 each. The same weight applies to the perception of a DI on how easy it is to use the technology. However, we gave higher weights to the actual use of the technology (0.35) and the intention to use the technology (0.20). The rationale for this is that a DI already using technology is more ready and would have practically experienced the usefulness of such technology, its challenges, and its limitations. In the same vein, we proposed that a DI having an intention to use a technology can be considered more ready than those who understood the technology, knew the usefulness and could estimate how easy it is to use it but have no intention to use it.

To compute the readiness, two mathematical models were defined as shown in Eqs. (1) and (2). Eq. (1) computes the readiness of a DI in a given technology, while Eq. (2) computes the overall readiness of a DI given the ten frontier technologies that we believe can facilitate the transitioning to a circular plastic economy. Tables 3 and 4 present the result for the 17 DIs.

where N is the total number of question categories, subscript r refers to the rating from the survey, while subscript w refers to the weight for each question category, as shown in Table 2.

$$\text{OverallReadiness} = \sum\nolimits_{i=1}^{I} (ITR_i{}^*TUW_i \tag{2}$$

where I is the total number of the technologies considered, subscript i stands for each technology, ITR is the tech readiness of the DI in each of the given technology and TUW is the computed usefulness weight for each of the technology as shown in Table 1.

3.3.2. Focus group discussions

Focus group interviews were carried out to explore the views of start-ups and digital innovators across the African continent. A total of four focus groups were conducted, with each focus group having between 3 and 5 participants who were drawn from the region where the focus group was holding i.e. southern, eastern and western Africa. These focus groups were held in Namibia, Rwanda, Nigeria, and Zambia. The focus group participants were asked question to elicit their perspectives on the prospects of digital innovations and the various challenges and opportunities relating to the drive towards the circular plastic economy on the continent.

3.3.3. Regression model for consumers

The variables listed in Section 3.2 were incorporated into a series of OLS regressions, with USE (uptake of digital innovations) as the dependent variable for each model. In model 1, we specify only the controls as independent variables. In model 2, four additional variables were included. In model 3, we added three interaction terms to investigate the moderating effects of income level, education level, and ease of use on barriers to uptake of technological innovations. The model specifications are summarised below:

$$USE = \propto + \beta_1 GEN + \beta_2 AGE + \beta_3 INC + \beta_4 EDU + \varepsilon \text{ (Model 1)}$$

$$USE = \propto + \beta_1 GEN + \beta_2 AGE + \beta_3 INC + \beta_4 EDU + \beta_5 UND + \beta_6 USF + \beta_7 EOU + \beta_8 BAR + \varepsilon \text{ (Model 2)}$$

$$USE = \propto + \beta_1 GEN + \beta_2 AGE + \beta_3 INC + \beta_4 EDU + \beta_5 UND + \beta_6 USF + \beta_7 EOU + \beta_8 BAR + \beta_9 \text{CBAR\_CINC} + \beta_{10} \text{CBAR\_CEDL} + \beta_{11} \text{CBAR\_CEOU} + \varepsilon \text{ (Model 3)}$$

where β is the regression coefficient for each variable and ε is the error term. The 'C' prefixes represent the mean-centred values for the interaction terms, for example, mean-centred value of barriers and income (CBAR-CINC).

GEN = Gender; INC = income level; EDU = Education level; UND = Understanding; USF = Perceived usefulness; EOU = Perceived ease of use; and BAR = Aggregate barriers to uptake of digital innovation.

Table 1
Computed usefulness weight of the technologies.

Technology	Usefulness weight
AI	0.10471
GIS	0.116066
BC	0.091824
IoT	0.107466
Rob	0.098128
3DP	0.094079
SC	0.090439
ARVR	0.085295
5G	0.098234
Mobile app	0.113758

Table 2
Question categories and attributed weights in determining tech readiness of digital innovators.

Question category	Weight
Understand the technology (A)	0.15
Usefulness of the technology (B)	0.15
Ease of use of the technology (C)	0.15
Actual use of the technology (D)	0.35
Intention to use the technology (E)	0.20

4. Results

The results are presented under two categories: technology readiness of innovators and consumers' acceptance of technology.

4.1. Technology readiness of digital innovators

4.1.1. Technology readiness index

Table 3 shows the computed readiness of the DIs for each of the technologies expressed as a value between 0 and 1 based on Eq. (1). Using a threshold of 0.70 to determine if a DI can be considered ready to deploy a technology in their digital innovations, we observed that for seven out of the ten technologies, <20 % of the DIs have what it takes to deploy those technologies in their solutions (cf. Fig. 2). The result of the overall tech readiness of the DIs computed using Eq. (2) is shown in Table 4. Only one DI has an outstanding index of 0.94. Five DIs have an index above 0.60. Setting the threshold at 0.6 implies that only 35.29 % of the DIs are ready to deploy the frontier technologies in creating digital solutions for transitioning to a CPE.

4.1.2. Insights from focus group discussions with digital innovators

Participants in the focus group discussions expressed strong confidence in the potential impact of technological innovations in the various stages of the plastic waste management process. These begin with waste collection, where the innovators highlighted the impact of route optimisation algorithms and automated optical sensors as examples of technologies driving efficiency in the plastic waste collection process:

> We have an application for customers that gets the exact location of a customer and helps connect them to a reliable, affordable and vetted collector in the area…For our waste pickers, we made what we call a route optimization algorithm that helps them navigate through a neighborhood depending on the jobs and locations they have to visit on that day
>
> (Rwanda Innovators Focus Group, Kigali, November 2020)

> Technologies actually have a very massive role in waste collection. Now for normal municipal waste collections, you'll see that having those automated optical sensors that can tell you when a bin is full or half full will prevent waste from staying in one place over a long period of time and allow collection to be done seamlessly
>
> (Nigeria Innovators Focus Group, Lagos, October 2020)

Furthermore, participants indicated high optimism that digital technologies can have a game-changing impact in the plastic value chains, for example in appropriating the use value of plastic waste in additive manufacturing:

> When it comes to plastic in particular, we see digital technology and particularly additive manufacturing or commonly known as 3D printing, being one of those technologies that could emerge from the use of digital technology to actually help reduce and hopefully

Table 4
Overall readiness of digital innovators.

DIs	Score
1	0.50
2	0.94
3	0.67
4	0.53
5	0.67
6	0.48
7	0.55
8	0.68
9	0.57
10	0.46
11	0.64
12	0.67
13	0.54
14	0.30
15	0.16
16	0.43
17	0.50

Table 3
Technology readiness of digital innovators.

DIs	AI	GIS	BlockChain	IoT	Robotics	3D	Serverless computing	AR/VR	5G	Mobile apps
1	0.62	0.36	0.30	0.53	0.53	0.50	0.12	0.39	0.59	0.94
2	0.59	1.00	1.00	1.00	0.94	0.97	0.94	0.94	1.00	1.00
3	0.85	0.56	0.56	0.56	0.56	0.56	0.44	1.03	0.59	0.97
4	0.70	0.47	0.44	0.65	0.76	0.56	0.50	0.39	0.18	0.56
5	0.62	0.91	0.53	0.88	0.53	0.56	0.53	0.62	0.53	0.91
6	0.30	0.53	0.18	0.56	0.30	0.62	0.12	0.56	0.53	0.94
7	0.12	0.91	0.23	0.94	0.41	0.44	0.67	0.29	0.29	0.97
8	0.62	0.94	0.44	0.94	0.50	0.27	0.88	0.62	0.44	0.97
9	0.62	0.94	0.30	0.50	0.47	0.44	0.44	0.56	0.44	0.85
10	0.62	0.44	0.21	0.38	0.41	0.32	0.38	0.18	0.53	0.94
11	0.59	0.62	0.59	1.00	0.36	0.59	0.56	0.39	0.56	0.97
12	0.82	0.88	0.47	0.94	0.50	0.50	0.35	0.44	0.56	1.00
13	0.59	0.47	0.47	0.47	0.47	0.82	0.47	0.30	0.47	0.85
14	0.18	0.27	0.15	0.18	0.38	0.41	0.15	0.15	0.15	0.88
15	0.56	0.03	0.09	0.06	0.06	0.15	0.03	0.03	0.09	0.47
16	0.24	0.47	0.47	0.21	0.50	0.30	0.24	0.47	0.44	0.88
17	0.62	0.91	0.30	0.33	0.33	0.36	0.30	0.42	0.33	0.94

eliminate plastic(sic). The beauty with 3D printing is that you can actually add 100 to 1000 times value to plastic, so we see that as a huge opportunity for all the players in the value chain

(Zambia Innovators Focus Group, Lusaka, November 2020)

Digital innovators are also strongly motivated by what they consider to be the enormous potential of digital innovations to tackle unemployment problems through their applications for the circular plastic economy:

First of all, we understand…and the Funny thing is the waste management sector is a lucrative business, If I could use that phrase, it is a lucrative business in that there are very few people that have a space in this sector. Well look, I mean. Just to give you some figure… Zambia, has a population of about 18 million people and 35 % of that population is the youth. And among the youth, there's a 16 % unemployment rate. So now you wonder to say look, there's an industry here in which resources are largely available. And then you, you wonder to say OK, why isn't there public and private sector engagement? Because this is actually an industry…if I can put it to you honestly, that if we were to mobilize ourselves as a sector and the players in charge, we could reduce unemployment rate significantly

(Zambia Innovators Focus Group, Lusaka, November 2020)

These high levels of optimism and motivation among African digital innovators are tempered by concerns about limited and inadequate infrastructures that can support innovations, including transportation and logistics. There are also concerns about the institutional environment, in terms of limited market opportunities and inadequate policy interventions to incentivise innovators and promote new societal habits along the lines of circular economy values and principles. Finally, innovators expressed concerns about financial barriers, and how public sector finance, in particular, can be difficult to access:

We can get funding if we have a very good business plan. But the challenge is the size of the market for recyclable material. If you get funds from a bank, You have to repay the loan, but if you don't have a large market, it would be a problem to reimburse the loan

(Rwandan Innovators Focus Group, Kigali, November 2020)

It can be quite frustrating doing this business here in Nigeria. Even the logistics of picking up waste was even more expensive than what I was collecting

(Nigeria Innovators Focus Group, Lagos, October 2020 2020)

"Funds in the plastic recycling space? I have never seen anyone get it before. I know it exists, but it's difficult to access that fund. The opportunity is there, but access is very, very complicated

(Nigeria Innovators Focus Group, Lagos, October 2020)

In transportation we are seeing a lot of challenges in… Not only collection of waste for final disposal, but also recovery of materials for use and recycling. One of the biggest problems is double spending… If the transporters are more efficient, more waste can be recovered, and so more waste can be sold to processors and so more revenue can be generated in the market

(Zambia Start-up, Lusaka, November 2020)

4.2. *Consumers' acceptance of technology*

4.2.1. *Profile of respondents*

The community survey was carried out in various low to middle-income communities in several African countries. A greater percentage (29 %) of the respondents were based in Nigeria, with Kenya and Rwanda following closely with 22 % and 23 % respectively, and Zambia and Namibia accounting for about 19.5 % and 6 % of the total respondents, respectively. The survey was administered to individuals between the ages of 18–75+, with the largest portion of respondents (34 %) falling between 18 and 24 years of age. In terms of gender, there were roughly equal numbers of male and female respondents as it was a close 50.5 % to 49.5 % respectively. Though a few of the respondents were either single, widowed or divorced, a larger percentage of the respondents (54 %) were married, and an even larger percentage of all respondents (91 %) lived in households where they were either the head of the home or lived with a member of their nuclear family i.e. wife/husband/child/sibling. The majority of the respondents were educated up to secondary and tertiary levels, and only about 2.5 % had no education at all. Of all the respondents, the majority (41 %) self-reported to be of low-income, while 33.15 % fell into the middle class and only about 5 % claimed to be of high-income level. Table 5 shows the profile of the community survey respondents.

Table 5
Profile of respondents.

		Freq	Percent
Gender	Male	745	50.51
	Female	730	49.49
	Total	1475	100
Region	Lagos	429	29.08
	Kenya	329	22.31
	Rwanda	341	23.12
	Namibia	88	5.97
	Zambia	288	19.53
	Total	1475	100
Age	18–24	504	34.17
	25–34	350	23.73
	35–44	348	23.59
	45–54	191	12.95
	55–64	61	4.14
	65–74	18	1.22
	75+	3	0.20
	Total	1475	100
Household relationship	Head	492	33.36
	Wife/husband	471	31.93
	Son/daughter	324	21.97
	Brother/sister	69	4.68
	Friend/house mate	59	4.00
	Son-in-law/daughter-in-law	18	1.22
	Niece/nephew by blood	14	0.95
	Grandchild	11	0.75
	Adopted/foster/step child	5	0.34
	Parent-in-law	5	0.34
	Help	4	0.27
	Niece/nephew by marriage	3	0.20
	Total	1475	100
Income level	Low income	618	41.90
	Middle income	368	24.95
	Lower middle income	295	20
	Upper middle income	121	8.20
	High income	73	4.95
	Total	1475	100
Educational level	Tertiary	453	35.77
	Secondary	565	35.50
	Primary	212	10.43
	Vocational training	132	9.97
	Post-graduate	67	5.76
	None	46	2.56
	Total	1475	100
Marital status	Married	798	54.10
	Single	624	42.31
	Widow(er)	45	3.05
	Divorced	8	0.54
	Total	1475	100

4.2.2. *Descriptive statistics and correlation matrix*

The summary of the descriptive statistics and correlation matrix is provided in Table 6. The correlation coefficients for the variables are <0.5, except for the use of technology/Understanding and Ease of use (EOU)/Usefulness (USF) which stand at 0.74 and 0.75, respectively. Furthermore, the variance inflation factor (VIF) for any of the nine variables is well below the threshold of 10. These, taken together,

Table 6
Descriptive statistics and correlation matrix.

Variable	Mean	Std. Dev.	Min	Max	VIF	GEN	AGE	INC	EDU	UND	USF	EOU	BAR	USE
GEN	0.51	0.50	0	1	1.06	1.00								
AGE	2.44	1.17	1	6	1.13	0.05	1.00							
INC	2.14	1.19	1	5	1.53	0.14	0.26	1.00						
EDU	2.69	1.19	1	5	1.45	0.13	0.00	0.43	1.00					
UND	22.00	10.00	9	50	2.75	0.18	−0.07	0.35	0.45	1.00				
USF	33.40	13.63	10	60	2.43	0.00	0.13	0.05	0.27	0.48	1.00			
EOU	31.96	14.23	9	60	2.45	0.02	0.18	0.02	0.28	0.45	0.75	1.00		
BAR	13.17	3.72	4	20	1.09	0.12	−0.05	0.21	0.13	0.15	0.01	0.07	1.00	
USE	2.33	2.58	0	10	2.36	0.13	−0.06	0.38	0.38	0.74	0.36	0.37	0.17	1.00

Table 7
Perceived usefulness, ease of use and uptake of digital innovations for CPE.

Variables	Model 1	Model 2	Model 3
GEN	0.320***	−0.068	−0.061
AGE	−0.297***	−0.086**	−0.088**
INC	0.657***	0.327***	0.305***
EDL	0.524***	−0.003	0.005
UND		0.170***	0.172***
USF		−0.010*	−0.011**
EOU		0.019***	0.02***
BAR		−0.037***	−0.032**
CBAR_CINC			−0.037***
CBAR_CEDL			−0.011
CBAR_CEOU			−0.002**
Model summary			
Number of observations	1474	1474	1474
R-Square	0.222	0.575	0.583
Adjusted R-Square	0.220	0.573	0.580

* = P < 0.10, ** = P < 0.05, *** = P < 0.01.

indicate there is no significant concern with multi-collinearity. Key descriptive statistics- mean, standard deviation, minimum and minimum values- were also provided in summary in Table 6.

4.2.3. Regression results

The result of the regression modelling is outlined in Table 7. We specified four socioeconomic variables in model 1. These are gender, age, income level and education level. The result indicated that all four variables are significantly associated with uptake of digital innovations, at 1 % level of significance. However, the impact of age on uptake of innovations is negative, at a magnitude of −0.297. This implies, in effect, that the older respondents are less likely to take up digital innovations.

In the second model, we specified understanding (UND), perceived usefulness (USF), perceived ease of use (EOU) and barriers (BAR) as the main independent variables. The four socioeconomic variables from model 1 were incorporated as controls. In the second model, only age and income level were significant predictors of innovation uptake, with age still negative at 5 % level of significance. Gender is no longer a significant predictor of innovation uptake, as it was in model 1. All the four leading independent variables were significantly associated with innovation uptake, with all but perceived usefulness significant at 1 % significance level. Perceived usefulness is negatively significant at 10 % level of significance. This is counter-intuitive, as usefulness is typically a strong predictor of uptake innovation. However, this unexpected outcome is set within the context of a strong impact of perceived ease of you, which is a significant positive predictor of innovation uptake at 1 % level of significance. At a strong 1 % level of significance, the negative impact of barriers is expected but noteworthy as a backdrop to the third and final model.

For the third model, we specified interactions between aggregate barriers and income level, education level and perceived ease of use. The objective was to examine if, and to what extent these three factors moderate the negative impact of barriers on uptake of digital innovations. The result indicates that income level exacerbates, rather than moderate, the impact of barriers on uptake of digital innovations. Compared with a magnitude of −0.032 for barriers in model 3, the impact of the barrier-income-level interaction term is −0.037 at a higher, 1 % level of significance. Conversely, perceived usefulness is an effective moderator of barriers, at a reduced but still negative magnitude of −0.002, compared with −0.032 for barriers. Finally, education level is an insignificant moderator of barriers.

5. Discussion

5.1. Technology readiness of digital innovators

The reason for computing the technology readiness of the DIs playing in the CPE space in Africa is to identify the gaps and the level of preparedness of the DIs in developing and deploying relevant digital innovations that can enhance transitioning to CPE in Africa. We intended to determine the capability and preparedness of the DIs to use ten frontier technologies mentioned in section – in their innovations. Our results show that most of the DIs are not well equipped to use most frontier technologies. Out of the ten technologies, the results show that DIs in Africa are more familiar with 3 of the technologies (Mobile app, GIS and IoT). Out of the three, only mobile apps seem to be the most used as the record shows that 88 % of the DIs is already using this. Our observation shows that most of DIs have deployed or are in the process of developing mobile applications in managing plastic waste and transitioning to a CPE; 41.18 % are ready to deploy GIS and 35.29 % are prepared for IoT deployment. This means that more empowerment is needed for the DIs to scale their deployment of these 10 frontier technologies in the solutions they are creating. However, as popular as AI is, it was observed that the DIs have not deployed AI even though some professed to use AI in their innovations. This calls for investment in capacity building for the DIs in Africa and a need to create a network of experts and stakeholders for knowledge sharing and co-creation of innovative digital solutions for enhancing CPE uptake in Africa.

The insights of participants in the focus group discussions show that digital innovators are highly motivated and optimistic about the prospects of a digitally enabled circular plastic economy in Africa. However, they are also awake to the reality of institutional challenges, socio-cultural factors and infrastructural limitations that are slowing down the pace of progress on the African continent. In order to drive uptake of CPE innovations across the wider population, digital innovators implicitly recognise the need for greater synergy and collaboration with other stakeholders in the ecosystem. For example, telecommunication and other digital and physical infrastructures provided or facilitated by national governments can have significant impact on increasing uptake of digital innovations by removing or mitigating barriers to uptake. Similarly, better interactions between digital innovators and community groups, local leaders and frontline NGOs can facilitate co-creation of technological and digital solutions that are more relevant, more accessible and more responsive to community user needs, experiences, peculiarities and use-habits. In other words, a multi-stakeholder co-production of digital CPE innovations can contribute to better attitudes of community members and ordinary users to the innovations.

5.2. Community members' attitude to digital innovations

The result indicates, among others, that understanding is significantly and positively associated with consumers' uptake of circular plastic economy (CPE) innovations. This supports hypothesis H1, in consonance with previous innovation studies which identify active knowledge search and understanding as predictors of innovation uptake (Maina et al., 2021; Ricci et al., 2021). We argue that functional understanding of a new technology is especially important for the adoption of CPE innovation in the light of the collective inertia associated with the linear economy lock-in. Understanding CPE innovations' basic technical features and practical value enables consumers to overcome initial misgivings and bandwagon effects associated with linear economy products and technologies. It can also enable them to embrace a long-term orientation about the merits of CPE principles: re-use, re-manufacture, and recycle.

Perceived usefulness (PU) was significantly but negatively associated with uptake of CPE innovations. This rejection of hypothesis H2 appears counter-intuitive, given that previous studies have reported the positive impact of perceived usefulness on the adoption of innovations (Djimesah et al., 2021; Man et al., 2021). However, this unexpected outcome needs to be understood within the context of the significant positive effect of perceived ease of use on uptake of CPE innovations (support for H3). In other words, it is not enough that CPE innovations are perceived to be useful if, say, they require more effort to use. Again, the technology lock-in associated with CPE can also partly explain this, as Dolfsma and Leydesdorff (2009) observed that users' perception that technology is useful or superior is not enough to break technology lock-in and influence adoption. Among a list of comparatively "useful" technologies, users may ultimately choose the ones popular within their networks and the wider society rather than the ones perceived to be more useful. However, perceived ease of use can be a more decisive factor. This stands to reason, because the fundamental psychology of technology lock-in is that older, established technologies tend to be habit-forming. Agents stick with them because it is more convenient and relatively free of effort to do so (Khalil, 2013). Thus, if a newer technology is perceived to be easier to use, consumers may be more incentivised to break free from their habituation to older technologies. This is a pertinent consideration for inventors and innovators designing and promoting circular economy innovations.

The result also supports hypothesis H4 that aggregate barriers (comprising technical, financial, political and socio-cultural barriers) negatively influence CPE innovations' uptake. This is expected, in line with extant literature (Barquet et al., 2020; de Jesus and Mendonça, 2018; van Keulen and Kirchherr, 2021). Therefore, it is pertinent to examine, as hypotheses H6 to H8 seek to do, the moderating impact of some variables on these barriers. In the meantime, we note that gender hypothesis, H5, is not supported in our third and final model, although it was supported in model 1. This implies that in the presence of other factors such as understanding, PU, PEOU and barriers, gender is not a significant predictor of CPE innovation uptake. In other words, both men and women may adopt CPE innovations not because of their gender, but because the technologies are well understood and easier to use. On one level, this appears contrary to the findings of Atlason et al. (2017), who reported a positive impact of gender on CPE products uptake. However, Atlason et al. (2017) also found that perception of the attractiveness of the CPE products plays as important a role as gender.

Finally, we turn attention to the three hypotheses (H6 to H8), looking at the moderating effects of income level, education level, and perceived ease of use on barriers to uptake of CPE innovations. The results do not support either H6 or H7 on the impact of income level and education level, respectively. Indeed, while the impact of education is found to be insignificant, income level is found to exacerbate, rather than mitigate, barriers to uptake of digital innovations. One explanation for this is that education can be a driver of negative confirmation bias, shaping negative attitudes, to CPE innovations. The negative impact of income level is also slightly unexpected but not entirely surprising.

Given that circular economy innovations are about waste reduction and resource efficiency, it is possible that higher-income individuals may not see it as an immediate priority- in the face of technical, political, and socio-cultural barriers. On the other hand, the study supports hypothesis H8 on the positive significant moderating effect of perceived ease of use on barriers to uptake of CPE innovations. This aligns with the significant positive impact of perceived ease of use as a primary factor (H3). In other words, when consumers and users are convinced that a CPE innovation require minimal effort to use, they are more likely to overcome the inertia due to technical, financial, political and socio-cultural barriers.

5.3. Policy implications

Based on the results on the study, there are several implications for the role that policy has to play to facilitate and overcome barriers to the transition to a CPE in African countries.

Digital innovations and the transitions to a CPE are closely linked. Many governments in Africa have and are developing and implementing digital policies to enable widespread digital access and/or the use of digital technology. Examples of such larger strategies include Kenya's National information and communications technology policy (2016), or Rwanda's Smart Rwanda masterplan 2015–2020 (see World Economic Forum, 2021; Schroeder and Barrie, 2022). These are important not only for the CPE but also for industrialisation, education, skills, social inclusion, and sustainable development.

Governments will need to invest more into capacity and skills building for the uptake and use of DIs for the CPE through stronger focus on STEM education, especially for girls and women.

To overcome technology lock-in issues will require closer collaboration across government departments and agencies, especially those departments responsible for science and technology development, environmental regulations, and industrial innovation policy and support. Furthermore, the support of technology hubs and innovation centres, including community-based initiatives, is important (Floyd and Adhikary, 2021).

The public sector needs to avoid disincentivising policies. In recent years, stakeholders in the African innovation eco-system have expressed concerns about hostile policies of national governments to technology entrepreneurs. While there are strong arguments for the merits of regulations, policymakers should realise that these eco-systems thrive on the ideals of open innovation. By adopting a principle of limited regulation and minimal control, African governments can free up the space for digital innovations to co-create new products and services that address core societal needs and drive the transition to CPE.

Thus, in terms of policies for CPE, governments can prioritise the facilitation of the use of recycled plastics in other forms of packaging. In addition, DIs can help with traceability and product information about the quality and composition of recycled contents and thereby support plastic waste related policy implementation.

Financial incentives or taxation can help to drive new job creation in the CPE. Improving access to finance, e.g. through government-backed loans and technical assistance for SMEs and the informal sector, can help them benefit from the DIs and link them to larger industrial value chains and potential trade opportunities.

6. Conclusion

Circular plastic economy is not only essential to stop the wicked and ever-increasing plastic pollution problem, but it also offers robust social, economic, and climate advantages including reduction to the volume of the plastic entering water systems, reduction of greenhouse gas emissions, as well as creating additional jobs in the local economies. This

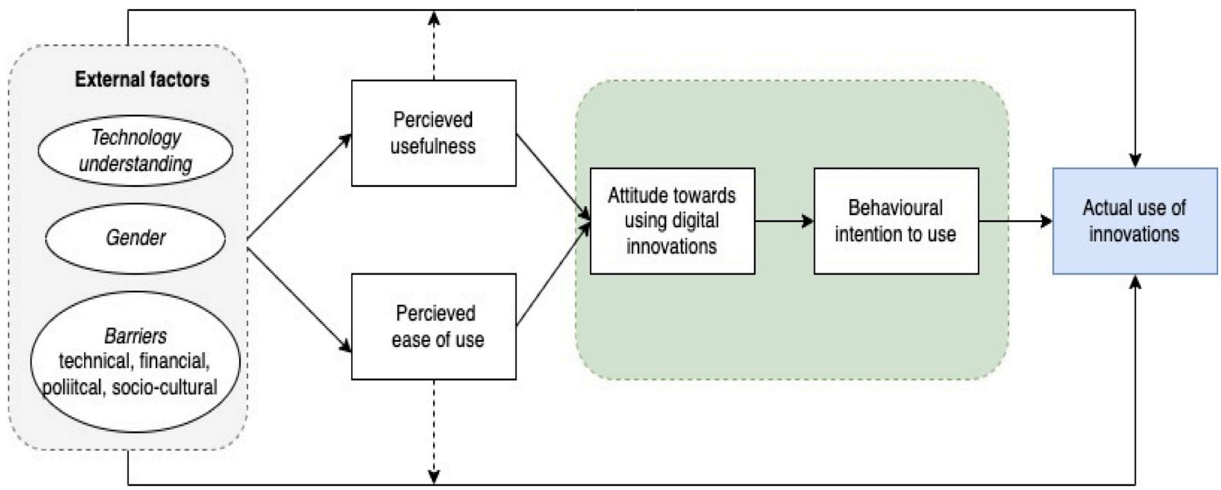

Fig. 1. Technology acceptance model (adapted from Davis, 1989).

study investigates the role of digital innovations to facilitate the transition to a circular plastic economy, focusing on the African landscape, where data on the technology readiness and adoption of digital innovations is particularly scarce. For the first time, a comprehensive dataset was collected by cross-sectional engagement with 33 major circular economy stakeholders and 1500 households across sub-Saharan Africa to assess the level of technological readiness and the range of digital tools adopted for accelerating the transition to a circular economy. A quantitative study was conducted on the survey data to develop a technology readiness model to evaluate the readiness of digital innovators to develop and implement various digital tools for the circular economy across Africa. The potential and likelihood of adopting the range of digital innovations identified in this study were determined using a range of statistical models and by analysing the data obtained from the survey.

The survey conducted in this study identified five key attributes to assess the role of digital innovations in transitioning to CPE in Africa, including understanding the technology, usefulness of the technology, ease of use, actual use of the technology, and the intention to use the technology. A variable weighting system was introduced to provide an overall scoring system for the DIs and develop the technological readiness model. The proposed model was implemented to conduct a comparative study between different DIs, i.e. AI, GIS, BC, IoT, Rob, 3D, SC, ARVR, 5G, and Mobile Apps (Fig. 1). This study also developed three regression models to analyse the survey results further and by looking at specific categories and variables influencing the use of DIs in CPE. The first regression model (Model 1) investigated the four specific socio-economic variables (i.e. gender, age, income, level of education). The second model (Model 2) used the specific understanding, perceived usefulness, ease of use and barriers as the main independent variables, while the four socioeconomic variables were incorporated as controls. Model 3 were designed to examine the interactions between aggregate barriers and income levels, education level and perceived ease of use.

The results show that out of the ten frontier technologies investigated in this study, only three DIs (i.e. Mobile app, GIS, and IoT) have appropriate technology readiness to be implemented in CPE strategies. Mobile apps are the most developed digital tool across Africa, with 88 % of the digital innovators already using mobile apps, followed by GIS with 41.18 % of the DIs ready to implement the technology and the IoT where 35.29 % technological readiness was observed. The results indicate the readiness of the digital innovators to develop and adopt the frontiers technologies; however, this requires capital investment to the innovation hubs across Africa and capacity building.

The study highlighted the need for new actors to emerge as the

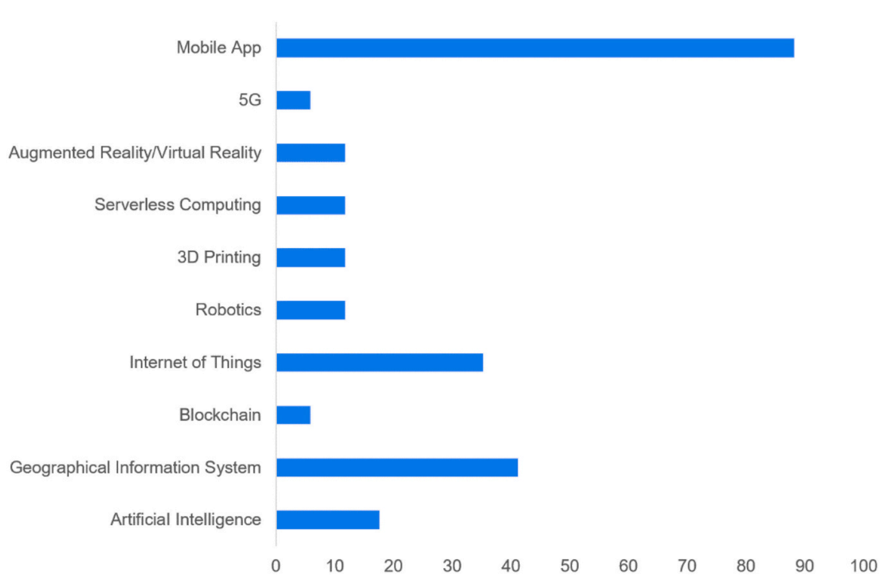

Fig. 2. Readiness index of the DIs in each of the ten frontier technologies.

circular plastic economy drivers. Our recommended approach to addressing this is by fostering an enabling eco-system that synergises the efforts of key players/actors. Such synergies will bring about technical efficiency. This, in turn, will create new opportunities to leverage digital transformation to leapfrog some of the most critical sectors of the circular plastic economy in Africa. Examples include traceability using blockchain and sorting with Artificial intelligence. An enabling ecosystem will help create, transform, and communicate knowledge, thereby nurturing local capacity for the circular plastic economy innovations.

The survey results show the significant role of the community members and end users' engagement with the technology to facilitate the CPE innovations and generate real impact from implementing these digital tools. Detailed analysis of community-level behaviour and their socioeconomic background is significantly important for bridging the barriers and uptake of the CPE innovation. It was found that digital innovations and the transitions to a CPE are closely linked. Policy analysis conducted in this study shows that governments across Africa are developing and implementing digital policies to enable widespread digital access and use of digital technologies. These policies are important not only for the CPE but also for industrialisation, education, skills, social inclusion, and sustainable development. A review of the existing policies and their implications across Africa highlight the necessity of supporting technology hubs and innovation centres, including community-based initiatives, and avoiding disincentivising policies. The government's investment into capacity and skills building for the uptake and use of DIs for the CPE, e.g. through a stronger focus on STEM education, especially for girls and women, is essential. Financial incentives and taxation can further help to facilitate CPE and create more jobs in the local and regional economies.

For the first time, this study provides a comprehensive, evidence-based model to examine the role and technological readiness of digital innovations for transitioning towards a circular plastic economy in Africa. The methodological approach outlined in this study can be used for evaluating technological readiness for CPE in other small and large-scale studies.

CRediT authorship contribution statement

The authors declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the editorial process. He is responsible for communicating with the other author about progress, submissions of revisions and final approval of proofs.

Data availability

Data will be made available on request.

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