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How do individual-level factors influence the adoption of low-carbon technology? Proposing and validating the bioeconomy technology acceptance model in the context of Africa

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The bioeconomy seeks to efficiently transform biomaterials into value-added products to achieve circularity. A circular bioeconomy is a circular carbon economy based on bio-based resources. There is a dearth of information in the literature about how psychological factors affect public acceptance of the bioeconomy, especially in Africa, where the adoption of bioeconomy is scant. Addressing this gap, this study characterized bioeconomy as a low-carbon bio-based technological innovation to combat climate change and developed the Bioeconomy Technology Acceptance Model (BTAM) to explain the effects of individual-level factors on public acceptance of bioeconomy and investigated it in a survey (N = 465) using questionnaires that were carried out in Lagos, Nigeria, in 2022. The respondents were chosen by proportional stratified random sampling, and descriptive statistics, Pearson's correlation coefficient, and structural equation modeling were used to analyze the data obtained. The strong influence of perceived usefulness from bioeconomy and intention to accept bioeconomy in BTAM suggests that the Technology Acceptance Model (TAM) is suitable for predicting public acceptance of bioeconomy. Considering the strong influence of belief about climate change on the perceived usefulness of bioeconomy and intention to accept it in this study, it is imperative to promote climate change education among Africans to accelerate acceptance of bioeconomy on the continent. The identified psychological factors provide a reference for scholars, policymakers, and manufacturers to effectively develop individual-oriented intervention strategies and promotion schemes to enhance acceptance of bioeconomy in Africa in particular and other climes where there is not yet widespread acceptance of circular bioeconomy.

KEYWORDS

bioeconomy, circular economy, climate change, psychological factors, technology acceptance model, Nigeria

1 Introduction

The application of circular economy principles is a helpful approach to improve global sustainability. The application of the circular economy is primarily concerned with preventing the consumption of resources and optimizing the structure of the energy and material cycle in various sectors such as industry, waste, energy, buildings, and transportation, and at various levels: enterprises and consumers at the micro-level, economic agents integrated in a symbiotic manner at the meso level, and cities, regions, and governments at the macro-level (Rincón-Moreno et al., 2021; Yang et al., 2023).

The bioeconomy entails substituting fossil fuel-based resources with bio-based resources and fossil fuel-derived products with bioeconomy products to combat climate change (Mukhtarov et al., 2017; Yang et al., 2021; Nagarajan et al., 2022; Perišic et al., 2022). Bioeconomy products have been recognized as a feasible path for the shift from a linear to a resilient bio-based circular economy (Lokesh et al., 2020). The focus of circular economy and bioeconomy is on what resources should be managed and how. The two have overlapping goals and are distinct aspects of the same reality, according to scholarly reviews (Chutipat et al., 2023; Kaewhao, 2023). The circular bioeconomy, according to Aguilar et al. (2018), is a more sustainable framework that combines the ideas of the circular economy and the bioeconomy in a practical and efficient way. Ultimately, the circular bioeconomy actually refers to a circular carbon economy that is bio-based. Adopting all aspects of circularity, such as eco-designing products, using procedures and services that promote holistic thinking, focusing on sustainable production and consumption of renewable biological materials, and giving preservation and enhancement of natural capital top priority, is the only way to actually establish a truly sustainable, circular bioeconomy (Holden et al., 2023).

The notion of the bioeconomy is not new in Africa. Traditional African societies were bio-based, relying on nature for food, fuel, medicines, and building materials. The local population relies on biomass such as fuelwood and charcoal to cook, light, and heat their dwellings. However, the adoption of advanced and sustainably refined circular bioeconomy products and materials is scarce in Africa (Feleke et al., 2021; Ncube et al., 2022; Fertahi et al., 2023), despite the huge potential of tapping into its abundant bio-resources to support the bioeconomy (Callo-Concha et al., 2020; Antar et al., 2021; Aworunse et al., 2023).

The European Commission (2018) defined the bioeconomy as an economy that uses renewable biological resources from the land and sea (e.g., animals, crops, fish, forests, and microorganisms) to produce energy, food, and materials. Bioeconomy remains an emerging concept (Bauer et al., 2018; Bröring et al., 2020; Mijailoff and Burns, 2023; Trigkas and Karagouni, 2023). Successful development, adoption, and diffusion of such new technologies depend on public acceptance, which in turn fundamentally depends on multidimensional constructs (Chen and Lou, 2020; Choung et al., 2022; Jayawardena et al., 2023). These include the adopters' individual-level psychological factors (Rajaee et al., 2019; Klein et al., 2020; Zwicker et al., 2021; Choung et al., 2022; Piwowar et al., 2023) and their individual behavioral beliefs, such as perceived usefulness (Al-Tarawneh, 2019; Bagheri et al., 2021; Zhang and Liu, 2022; Naseri et al., 2023). Exploring and understanding psychological factors that could influence the acceptance of bioeconomy in society is not only relevant in explaining, predicting, and increasing its acceptance and diffusion but also in defining, envisioning, and implementing bioeconomy as climate action. This underscores the importance of this study.

Determining whether consumers are willing to buy circular bioeconomy products and figuring out the best way to market them are prerequisites for making significant investments in bioeconomy sectors. Nevertheless, research on public acceptance in bioeconomy discourses is scarce (Ramcilovik-Suominen and Pülzl, 2018; Navrátilová et al., 2020), and they are dominated by how the general public views the bioeconomy rather than considering people as individuals involved in shaping societal change (Eversberg and Fritz, 2022). Furthermore, the drivers and factors influencing consumer choice for bioeconomy products are not well known, and only a few studies have been carried out in this field (Sijtsema et al., 2016; Scherer et al., 2018a; Klein et al., 2020; Gaffey et al., 2021; Wilke et al., 2021). None of these studies analyzed consumer choices or public acceptance relating to the bioeconomy in Africa. In particular, authors have acknowledged that the knowledge base for the bioeconomy lags behind in Africa (Bambo and Pouris, 2020; Perea et al., 2020; Feleke et al., 2021; Mougenot and Doussoulin, 2022). A literature search shows no past research has attempted to explore, at an individual level, public acceptance of bioeconomy as a low-carbon technological innovation to combat climate change. This study seeks to fill these identified gaps by investigating the influence of selected individual-level psychological factors and individual belief (perceived usefulness) on public acceptance of bioeconomy as a low-carbon technological innovation to combat climate change in Nigeria. Three hypotheses that were tested to achieve the research objective are summarized as follows: (H1) Lagos residents' perceived usefulness from bioeconomy is not influenced by their individual-level psychological factors; (H2) Lagos residents' intention to accept bioeconomy is not influenced by their individual-level psychological factors; and (H3) Lagos residents' intention to accept bioeconomy is not influenced by their perceived usefulness from bioeconomy. The study also developed a model to explain and predict the acceptance of bioeconomy based on dominant individual-level factors of residents of Lagos, Nigeria.

The study modified and extended the revised version of the Technology Acceptance Model (TAM) by Venkatesh and Davis (1996) as a primary reference to build and empirically test a model aimed at predicting intention to accept bioeconomy as low-carbon technology to combat climate change and examine it in a survey to be conducted in Lagos, Nigeria. Like most commercial and industrial capitals across Africa, Lagos is experiencing a population explosion and rapid globalization with the accompanying increase in demand for food and other products, as well as greenhouse gas (GHG) emissions. Furthermore, carbon footprints in many locations in Lagos did not comply with both local and international standards (Bola-Popoola et al., 2019; Okafor et al., 2021). These challenges are compounded by Lagos' coastal location and other demographic trends (Bhattacharya et al., 2020; Twumasi et al., 2020). The choice of the three external psychological variables—subjective knowledge, environmental attitude, and belief about climate change—was influenced by Stern's Value-Belief-Norm (VBN) theory of environmentalism (Stern, 2000; Kim and Kim, 2018; Liu and Wu, 2020; Rizkalla and Erhan, 2020).

In this line and given that individual-level factors can influence the uptake of new technology like bioeconomy, this study aims to contribute to the scarce literature on public acceptance of bioeconomy by investigating how individual-level factors affect acceptance of bioeconomy and validate the Bioeconomy Technology Acceptance Model (BTAM), an extended version of the Technology Acceptance Model (TAM), among residents of Lagos, Nigeria. As for why this problem is being addressed, it is due to the emergence of the bioeconomy as a means of tackling important societal issues such as climate change.

Following the introduction, Section 2 provides a brief overview of relevant literature; Section 3 outlines methodology concerns, including research design, instrument development, data collection, validity and reliability of the measurement model, and data analysis; Section 4 presents the findings; and Section 5 discusses the findings, makes recommendations, and highlights contribution to knowledge.

2 Literature review

2.1 Conceptual review

The concept of bioeconomy possesses interpretative flexibility in ways that can be employed to the specific challenges and meet the needs of diverse actors and objectives (Meyer, 2017; Barañano et al., 2021; Mijailoff and Burns, 2023; Trigkas and Karagouni, 2023). Recent theoretical developments acknowledge the technology-based implementation pathway to bioeconomy (Leitão, 2016; Meyer, 2017; Hernández-Pérez et al., 2020; Bröring and Thybussek, 2023).

Previous research has confirmed that TAM is a valid model that represents an important theoretical framework to explain and predict acceptance of low-carbon technological innovations such as bioeconomy (Tran and Cheng, 2017; Liu et al., 2018; Ali et al., 2020; Bagheri et al., 2021; Khoza et al., 2021; Park, 2021; Yang et al., 2021). The TAM is widely employed in explaining and predicting the acceptability of innovative products and technologies (Liu et al., 2018; Al-Tarawneh, 2019; Ali et al., 2020; Dhagarra et al., 2020; Naseri et al., 2023). A revised version of TAM by Venkatesh and Davis (1996), referred to as TAM2, proposes that the influence of external factors on behavioral intention (BI) is mediated by perceived usefulness (PU) and perceived ease of use (PEOU). The external factors, which are antecedents of PEOU and PU, are crucial in explaining technology adoption behavior (Al-Tarawneh, 2019; Khoza et al., 2021; Zhang and Liu, 2022). Several TAM-related studies have revealed the evolving role of users' psychological characteristics on their acceptance of new technology (Rajaee et al., 2019; Hsu and Lin, 2021; Khoza et al., 2021; Acikgoz et al., 2023).

This study employs an extended TAM comprising Stern's Value-Belief-Norm (VBN) theory of environmentalism (Stern et al., 1999; Stern, 2000) influenced external psychological constructs, namely subjective knowledge, environmental attitude (measured by New Environmental Paradigm, NEP), and belief about climate change. Pro-environmental behavior intentions in response to climate change have been predicted using the VBN theory, which focuses on finding predictors of environmentally significant behavior (Hartmann et al., 2018; Joffre and King Jr., 2020; Zhang et al., 2020). Prior VBN studies have employed the three external psychological factors in this study to understand pro-environmental behavior intentions: subjective knowledge (Rajaee et al., 2019; Rizkalla and Erhan, 2020; Wang et al., 2020), the New Environmental Paradigm (Chen, 2015; Han et al., 2018; Liu and Wu, 2020), and awareness (belief) of climate change problem (van der Werff and Steg, 2016; Kim and Kim, 2018; Liobikienė and Poškus, 2019). Subjective knowledge is involved in this study because it influences behavior and decision-making more than objective knowledge (Eberhardt et al., 2020; Acikgoz et al., 2023; Viot et al., 2023; Zheng et al., 2023). Attitude is a predictor of behavior, and environmental behavior is predicted by environmental attitudes—the overall relationship between humans and the environment. The NEP is a widely used unidimensional measure of environmental attitudes. An ecocentric orientation that reflects a commitment to the preservation of natural resources and environmental protection is indicated by a higher NEP score (Matsiori, 2020; Sh Ahmad et al., 2022; Gansser and Reich, 2023). The role of society in mitigating climate change is particularly important. Belief about climate change describes a person's attitude toward climate change and predicts pro-environmental behavior (Shadiqi et al., 2022; Tarinc et al., 2023).

2.2 Empirical review

Public acceptance is a major dimension of the diffusion and adoption of bioeconomy in society (Bröring et al., 2020; Nagy et al., 2021; Oguntuase and Adu, 2021). Typically, acceptance studies focus on identifying factors that foster or inhibit the adoption of bioeconomy among the population, including the purchase and consumption of bioeconomy products and the desirability of contemporary scientific and technological developments in a bioeconomy (Rudolph, 2018; Hempel et al., 2019; Eversberg and Holz, 2020). A lack of public acceptance of bioeconomy products has been reported in the literature (Sijtsema et al., 2016, Stern et al., 2018; Bröring and Vanacker, 2022; Ruf et al., 2022; Macht et al., 2023).

Knowledge is an important factor in the acceptance, appreciation, and promotion of bioeconomy (Mukhtarov et al., 2017; Dallendörfer et al., 2022; Harrahill et al., 2022). It is recognized as a positive predictor of public acceptance of bio-based technological innovations (Zografakis et al., 2010; Herbes et al., 2018; Zander et al., 2022), and consumer knowledge is a determining factor in the purchase of bio-products (Lynch et al., 2017; Dilkes-Hoffman et al., 2019; Ende et al., 2023; Skouloudis et al., 2023). Attitude influences the acceptance of bioeconomy products (Russo et al., 2019; Macht et al., 2023). Studies found a link between environmental attitudes and choice-based behavior with regard to bioeconomy products (Rumm et al., 2013; Scherer et al., 2017; Tran and Cheng, 2017; Scherer et al., 2018b; Zander et al., 2022). Product acceptance intentions in the bioeconomy are influenced by perceived usefulness (Soland et al., 2013; Wurster and Schulze, 2020; Bagheri et al., 2021).

2.3 The bioeconomy landscape in Africa

^Due to political obscurity just a mere decade ago, governments and businesses all over the world are currently promoting the idea of a bioeconomy as a new paradigm for a sustainable economy, with several countries and jurisdictions formulating dedicated wholesome bioeconomy policies, initiatives, or strategies (Vogelpohl, 2021; Dietz et al., 2023; Gardossi et al., 2023). However, bioeconomy is not popular in Africa yet (Rosa and Martius, 2021) and is not governed by any explicit bioeconomy strategy in most African countries. On the continent, only South Africa has a well-defined bioeconomy strategy.

There are some bioeconomy-related policies and initiatives in place in nations such as Democratic Republic of the Congo, Nigeria, Ghana, Namibia, Uganda, Ethiopia, Kenya, Senegal, Mozambique, Mali, Mauritius, Malawi, Rwanda, Congo, Tanzania, and Zimbabwe, but there is no evidence that these have had a particularly positive effect on the continent's economy or society as a whole (Oguntuase, 2018; Rosa and Martius, 2021). Comparing African countries' bioeconomy potential to those of nations with dedicated bioeconomy policies or strategies, the former have lower potential. The only nation on the continent with a defined bioeconomy strategy is South Africa, which has the highest potential for a bioeconomy. This has policy implications in that developing a national bioeconomy strategy is the first step toward implementing bioeconomy in Africa (Oguntuase and Adu, 2021).

2.4 Bioeconomy as climate-friendly, low-carbon technological innovation

By substituting renewable biological resources for fossil fuels in the bioeconomy, greenhouse gas emissions are prevented or reduced, and the effects of global climate change are mitigated (Lima, 2022; Perišic et al., 2022; Dees et al., 2023). The main way the bioeconomy mitigates climate change is by lowering the net flow of CO2 into the atmosphere by replacing carbon-intensive fossil fuels and products with less carbon-intensive bioeconomy products. Contrary to carbon-intensive fossil fuels, biomass produces the same amount of CO_2 ingested during its growth, which is addressed as 'carbon neutral' in scientific terms (Timmons et al., 2016; Martínez et al., 2020). In addition to the literature on the role of bioeconomy in mitigating climate change, the important role of bioeconomy in supporting countries to reach the goals of the agreement as reflected in their Nationally Determined Contributions (NDCs) has also been discussed in the literature (Machado et al., 2019; von Braun and Mirzabaev, 2019; Boyarov et al., 2021; Fava et al., 2021).

The bioeconomy offers numerous opportunities for carbon removal and management by incorporating biological carbon fixation into a wide range of different end bioeconomy products, with biofuels, bioplastics, biochar, and wood products offering near-term carbon removal potentials (Dees et al., 2023). Almost all intergovernmental panel on climate change (IPCC) mitigation scenarios that are consistent with the 1.5–2°C target and that constrain end-of-century atmospheric CO_2 to 450 parts per million rely on a large-scale contribution from biofuels (Daioglou et al., 2017; Sebos, 2022; Usmani, 2023). According to Bang et al. (2009), industrial biotechnology, biofuels, and bioenergy could cut greenhouse gas emissions worldwide by 1.0–2.5 billion tonnes of CO2 equivalent annually by 2030. Because they have smaller carbon footprints than petro-plastics, bioplastics derived from second-generation biomass considerably lessen the effects of climate change (de Paula et al., 2018; Lamberti et al., 2020; Rosenboom et al., 2022). By 2050, bioplastics could eliminate more than 1 billion tonnes of CO2 annually (Meys et al., 2021). The use of biochar has demonstrated a major impact on the total greenhouse gas emissions' global warming potential (GWP) (Ashiq et al., 2020; Shakoor et al., 2021). Globally, biochar systems could deliver emissions reductions of 3.4–6.3 Pg CO_2e, half of which constitutes CO_2 removal (Lehmann et al., 2021). Wood products help mitigate climate change in addition to storing carbon in forest ecosystems and harvesting wood products. This is especially true if they are used to replace more fossil-intensive products such as steel and concrete (Leskinen et al., 2018; Himes and Busby, 2020; Hurmekoski et al., 2023). Beyond reducing the effects of climate change, the bioeconomy and climate change adaptation has a lot of potential to work together to improve people's quality of life and provide energy and food security (Mukhtarov et al., 2017; Yang et al., 2021).

3 Methodology

Descriptive cross-sectional survey research design was used in this study. When it comes to describing and exploring variables and constructs of interest quickly and affordably, survey research is a valid and helpful method of conducting research (Coughlan et al., 2009; Ponto, 2015). Survey research has been used to accomplish somewhat similar goals in the past with success (van Winkle et al., 2013; Liu et al., 2018; Stahl et al., 2021).

3.1 Development of research instrument

There are two sections to the questionnaire. The demographic data of the respondents are surveyed in Part 1. Subjective knowledge of the bioeconomy (SK), environmental attitude (measured by the New Environmental Paradigm, NEP), belief about climate change (BCC), perceived usefulness from climate change (PU), and intention to accept the bioeconomy (INT) are the five individual-level factors about which data are collected in Part 2. Based on a review of the literature, a total of 19 items were created for the five constructs. A 5-point Likert scale was used to rate the items used to measure the five constructs: strongly agree = 5, agree = 4, not sure = 3, disagree = 2, and strongly disagree = 1. Reverse coding was used for the subjective knowledge (SK) items, SK1, SK2, and SK3.

The draft test instrument was reviewed for readability, clarity, content relevance, and comprehensiveness by eight reviewers comprising academics, teacher scientists, environmental scientists, business scientists, and policy scientists. The eight reviewers are sufficient to validate the questionnaire items (Faris and Ahmad Ramli, 2016; Boateng et al., 2018). The reviewers commented on the format, wording of questions, order/flow of the questions, made corrections, and wrote comments and suggestions on the items. The three major amendments made to the questionnaire based on the reviewers' opinions were the removal of two variables—household size and household income—from Section A and the rephrasing of five items in Section B for better understanding.

A pilot survey was carried out between 4th October 2021 and 30th October 2021 among 50 residents of Lagos, Nigeria, who would not be part of the main study in line with the submission by Treece and Treece (1982) as well as Connelly (2008) that a pilot study sample should be 10% of the sample projected for the larger parent study. The questionnaires were re-administered, and 46 valid questionnaires were collected for analysis. A time of 6 weeks was the only source of variance in the test–retest reliability. The calculated test–retest reliability coefficient in this study was 0.81, which was reliable for a developing questionnaire (Matheson, 2019). The computed Cronbach's alpha coefficients for the constructs based on the pilot study findings are shown in Table 1. All the coefficients exceed the conventional lower limit of 0.70 (Taber, 2017).

The pilot study provided the following insights into how the actual process of data collection should proceed: (1) To make certain questionnaire items easier for respondents to understand, simple and easily understood words were used in place of terminologies; (2) The need to reformat the location of tick boxes under the section; (3) The rephrasing and substitution of some items in the questionnaire; and (4) The length of the questionnaire was found appropriate considering that the time taken to answer the questionnaire was an average of 5 min. Table 2 displays the final measures for each construct.

3.2 Ethical consideration

While ethical approval was not required for this study, critical ethical principles of freely given consent, deception, debriefing, withdrawal from the survey, confidentiality, and protection of participants were observed. The nature and purpose of the survey were explained to all the respondents so they could make an informed decision about whether they wanted to participate or not. Respondents were asked for verbal consent before the questionnaires were administered. Anonymity and confidentiality, which are crucial, were also made clear to the respondents, and clearly informed that their participation is voluntary and re-negotiable. Each questionnaire contained a reference code that ensured the anonymity of all the respondents so that their identity would never be linked to their responses and that no personal details would be made public.

3.3 Data collection

The sample size of the survey research was calculated using the simplified formula by Yamane (1967). The Yamane formula is $n = N/1 + N\ (e)^2$, where n is the sample size, N is the population size, and e is the margin of error. This formula assumes a level of precision of 0.05 and a confidence level of 95%.

The sample size was estimated to be 400, based on estimates of the population in Lagos (Famuyiwa et al., 2022). However, to overcome the risks of non-responses or poorly answered questionnaires, the number obtained was divided by the expected response of 80%, which is considered acceptable (see Fincham, 2008; Ewing et al., 2018) to get 500 as the study population. Proportional stratified random sampling was employed to distribute 500 questionnaires among the accessible population—the residents of Ikeja, Ikorodu, and Badagry local government areas based on their populations (Lagos State Government, 2019). Ikeja, Ikorodu, and Badagry local government areas are urban (Afolabi et al., 2017), peri-urban (Adedire, 2017), and rural (Otekhile and Verter, 2017) areas, respectively. The survey was carried out between February 2022 and July 2022. A face-to-face administration of the questionnaires was done by the researcher and three trained field assistants.

Of the 500 questionnaires distributed, 35 contained missing data. To prevent the study variables and constructs from being artificially correlated, the 35 incomplete questionnaires were removed. Therefore, 465 valid questionnaires with a 93% response rate were analyzed for interpretation.

3.4 Validity and reliability of the measurement model

Table 3 displays the calculated Cronbach's alpha values for the study's constructs: SK, NEP, BCC, PU, and INT have values of 0.87, 0.77, 0.87, 0.71, and 0.70, respectively. Every one of them exceeds or equals the widely accepted lower bound of 0.70 (Taber, 2017).

To evaluate the measurement model's validity and reliability, confirmatory factor analysis was performed; the results are displayed in Table 4. The study's standardized factor loadings are all higher than the 0.50 threshold for acceptable loading, supporting the constructs' validity as appropriate indicators for measuring the variables (Chen and Tsai, 2007; Truong and McColl, 2011). The construct variables' average variance extracted (AVE) values are greater than the generally accepted threshold of 0.50, which indicates that the instrument variables are valid and the tested model does not have a convergent validity issue (Bagozzi and Yi, 1988; Gangwal and Bansal, 2016). The squared multiple correlations (R-squared) were well defined by the measure items; most R-squared values were higher than the 0.50 threshold (Bryne, 2001; Al-Hawari et al., 2005). All of the composite construct reliabilities were above the acceptable threshold of 0.70, implying that every item consistently measures the same latent factor (Hair et al., 2010; Raykov and Marcoulides, 2016).

4 Results

4.1 Demographic data of survey respondents

We recruited participants with heterogeneous demographic backgrounds to ensure fair representation. The sample included 237 male

TABLE 1 Result of the pilot study.

Constructs	Original questionnaire		Refined questionnaire	
	Number of items	Cronbach's alpha	Number of items	Cronbach's alpha
Subjective knowledge	4	0.614	3	0.752
Environmental attitude (NEP)	5	0.727	5	0.757
Belief about climate change	4	0.110	4	0.739
Perceived usefulness	4	0.359	4	0.827
Intention	4	0.673	3	0.833

TABLE 2 Constructs, their items, and sources.

Variable/Item	Statements	Sources	Definition/ Measurement	Possible answers
Location			As Urban, Peri-urban, Rural	1 = Ikeja LGA 2 = Ikorodu LGA 3 = Badagry LGA
Gender	What is your gender?			1 = Female 2 = Male
Age	What is your age?		As Generation Z, Millennials, Generation X, Boomers, Silent, Greatest	1 = 25 and below 2 = 26-41 yrs. 3 = 42-57 yrs. 4 = 58-76 yrs. 5 = 77 and above
	What is your marital status?			1 = Single 2 = Married 3 = Divorced 4 = Separated 5 = Widowed
	What is your highest qualification?			1 = SSCE 2 = ND/NCE 3 = Degree or equivalent 4 = Postgraduate
Subjective knowledge (SK)	I do not feel very knowledgeable about bioeconomy (SK1) Compared to most other people, I know less about bioeconomy products (SK2) When it comes to bioeconomy products, I really do not know a lot (SK3)	Činjarević et al. (2018) Manika et al. (2021)	5-point Likert scale	1 = Strongly Agree 2 = Agree 3 = Unsure 4 = Disagree 5 = Strongly disagree
Environmental attitude (NEP)	Humans are severely abusing the environment (NEP1) Plants and animals have as much right as humans to exist (NEP2) The Earth is like a spaceship with very limited room and resources (NEP3) The balance of nature is very delicate and easily upset (NEP4) If things continue on their present course, we will soon experience a major ecological catastrophe (NEP5)	Liu et al. (2018)	5-point Likert scale	1 = Strongly disagree 2 = Disagree 3 = Unsure 4 = Agree 5 = Strongly Agree
Belief about climate change (BCC)	I am quite sure that climate change is happening right now (BCC1) I believe human activities are responsible for climate change (BCC2) I think the temperature is hotter now than in previous years (BCC3) I think recent harmattan was not as cold as last year (BCC4)	Ballew et al. (2019); Hidalgo and Pisano (2010); Zobeidi et al. (2020)	5-point Likert scale	1 = Strongly disagree 2 = Disagree 3 = Unsure 4 = Agree 5 = Strongly Agree
Perceived usefulness (PU)	Using bioeconomy products would be useful for me (PU1) Using bioeconomy products would be convenient for me (PU2) Using biofuels would be advantageous for me (PU3) I support the use of bio-based fertilizers as a way to combat climate change (PU4)	Tran and Cheng (2017)	5-point Likert scale	1 = Strongly disagree 2 = Disagree 3 = Unsure 4 = Agree 5 = Strongly Agree
Intention (INT)	I intend to use biofuels if it is available (INT1) I would go out of my way to find bioeconomy products to purchase (INT2) I would like to recommend bioeconomy products to my family and friends (INT3)	Tran and Cheng (2017); Liu et al. (2018); Han (2019)	5-point Likert scale	1 = Strongly disagree 2 = Disagree 3 = Unsure 4 = Agree 5 = Strongly Agree

TABLE 3 Result of constructs validity tests.

Constructs	Number of items	Cronbach's alpha
Subjective knowledge (SK)	3	0.87
Environmental attitude (NEP)	5	0.77
Belief about climate change (BCC)	4	0.84
Perceived usefulness (PU)	4	0.71
Behavioral intention (INT)	3	0.70

TABLE 4 Result of confirmatory factor analysis test.

Constructs	Items	Standardized loadings	Squared multiple correlations	Composite construct reliabilities	Average variances extracted
Subjective knowledge (SK)	SK1	0.839	0.89	0.86	0.67
	SK2	0.835	0.53		
	SK3	0.779	0.66		
Environmental attitude (NEP)	NEP1	0.629	0.55	0.73	0.53
	NEP2	0.655	0.50		
	NEP3	0.634	0.46		
	NEP4	0.645	0.45		
	NEP5	0.548	0.51		
Belief about climate change (BCC)	BCC1	0.845	0.66	0.92	0.73
	BCC2	0.844	0.64		
	BCC3	0.859	0.62		
	BCC4	0.869	0.55		
Perceived usefulness (PU)	PU1	0.903	0.67	0.91	0.71
	PU2	0.818	0.84		
	PU3	0.807	0.50		
	PU4	0.832	0.52		
Behavioral intention (INT)	INT1	0.838	0.54	0.83	0.61
	INT2	0.775	0.56		
	INT3	0.734	0.51		

SPSS and MSexcel, value of $p < 0.01$.

(50.97%) respondents and 228 female (49.03%) respondents. There is not much gap between the male respondents and the female respondents. This shows that there is a fairly even gender distribution among the respondents. Nearly a quarter of the respondents (24.73%) were 25 years old and below, followed by those aged between 26 and 41 years (23.65%), between 42 and 57 years (22.37%), between 58 and 76 years (16.56%), and ≥77 years old (12.69%). Furthermore, 38.50% of the respondents were single (n=179), 35.70% were married (n=166), and approximately one-tenth were separated (n=48), while the remaining respondents were equally divorced or widowed (n=36). The respondents had different levels of education, beginning with secondary school (21.94%), followed by Nigeria Certificate in Education (NCE) and equivalent National Diploma (ND) (23.01%), bachelor's degree and its equivalents (40.00%), and master's and above (15.05%). The places of residence of the respondents were urban (n=182), peri-urban (n=183), and rural (n=100).

4.2 Descriptive statistics

The level of residents' perception of the studied constructs was reflected in the mean of the construct. In contrast to perceived usefulness (mean = 12.61) and intention (mean = 9.56), subjective knowledge (mean = 8.43), environmental attitude (mean = 11.71), and belief about climate change (mean = 11.23) showed comparatively smaller mean scores.

To gain a comprehensive understanding of the respondents' perceptions, the responses to each of the measures were further categorized into three groups: positive (agree + strongly agree), neutral (not sure), and negative (strongly disagree + disagree), as illustrated in Figure 1. The respondents who expressed poor subjective knowledge of the bioeconomy were 44.5%, with 216 respondents indicating they feel knowledgeable about it (SK1), 193 respondents claiming they know less about it than most other people (SK2), and 211 respondents stating they do not really know a lot about it (SK3); 53.0% of respondents indicated low belief in climate change, and 65.0% of respondents also had a negative attitude toward the environment. Using bioeconomy products would be useful (PU1) and convenient (PU2) for 44.52% of the respondents. Residents' opinions toward using biofuels, if they are available, were favorable in 46.5% of cases (INT1). Individuals who will make an effort to find bioeconomy products (INT2) and encourage their friends and family to purchase bioeconomy products (INT3) made up 48.6 and 44.3% of the sample, respectively. The survey participants generally exhibited favorable opinions regarding the perceived usefulness of the bioeconomy and the intention to accept it.

4.3 Structural model analysis

A standard path coefficients analysis was conducted to investigate potential relationships between individual-level psychological factors, perceived usefulness from the bioeconomy, and intention to accept the bioeconomy. The results of the relationships between the variables are shown in Table 5.

All three of the study's hypotheses were supported at the significance level of 0.05 in each scenario that was investigated. Subjective knowledge ($\beta = 0.29$, $p = <0.01$) and belief about climate change ($\beta = 0.25$, $p = <0.01$) both have a positive influence on perceived usefulness. Perceived usefulness is less strongly predicted by environmental attitude (NEP) ($\beta = 0.13$, $p = 0.04$). Additionally, environmental attitude ($\beta = 0.07$, $p = 0.04$) and subjective knowledge ($\beta = 0.09$, $p = 0.01$) have a positive influence on the intention to adopt the bioeconomy. Belief in climate change is a strong and positive predictor of intention to accept bioeconomy ($\beta = 0.68$, $p = <0.01$). Perceived usefulness and intention to accept the bioeconomy had a strong and statistically significant relationship ($\beta = 0.76$, $p = <0.01$). As seen in Figure 2, the analysis revealed that four of the seven path relationships in the structural model are positively significant and supported.

4.4 The fit of the developed model

The Bioeconomy Technology Acceptance Model (BTAM) was developed, and its fit was assessed using five measures. The metrics included were the goodness-of-fit index (GFI), root mean square error of approximation (RMSEA), standardized root mean square residual (SRMSR), comparative fit index (CFI), and Tucker–Lewis index (TLI). Overall, the model has an acceptable fit. Table 6 presents the findings of the model's fitness used in this study. The model has an acceptable fit with a goodness-of-fit index (GFI) of 0.92 and an adjusted goodness-of-fit index (AGFI) of 0.90, both of which are approximately 1 (Schermelleh-Engel and Moosbrugger, 2003). The root mean square error of approximation (RMSEA) is 0.06, and the root mean square residual (SRMR) of the model is 0.04. A good fit is indicated by the small RMSEA and SRMR values (Hoe, 2008; Cangur and Ercan,

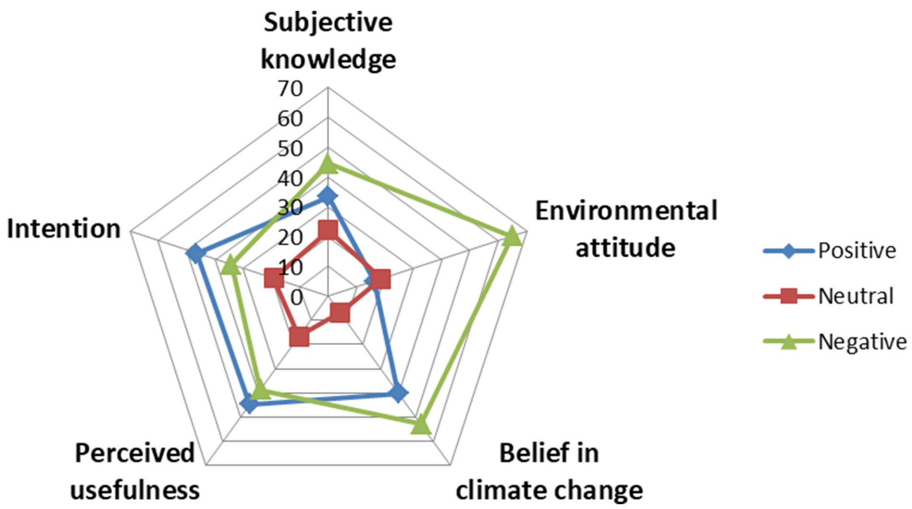

FIGURE 1
Classification of survey results.

TABLE 5 Relationship between individual-level factors and the outcomes of hypothesis tests.

Relationship scenario	Standard coefficient β	value of p	Explanation
Subjective knowledge and perceived usefulness	0.29	<0.01	Good and significant relationship
Subjective knowledge and intention	0.09	0.01	Weak but significant relationship
Environmental attitude and perceived usefulness	0.13	0.04	Weak but significant relationship
Environmental attitude and intention	0.07	0.04	Weak but significant relationship
Belief about climate change and perceived usefulness	0.25	<0.01	Good and significant relationship
Belief about climate change and intention	0.68	<0.01	Strong and significant relationship
Perceived usefulness and intention	0.76	<0.01	Strong and significant relationship

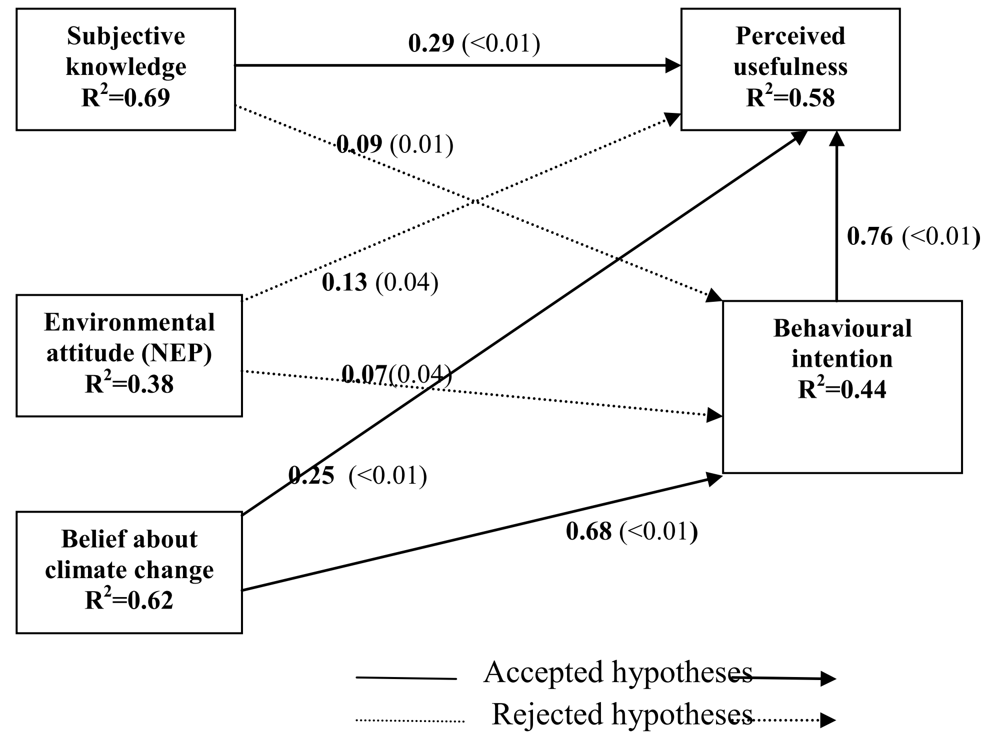

FIGURE 2
The developed model results.

TABLE 6 Model fit for the bioeconomy technology acceptance model (BTAM).

Model fit indices	Fit criteria	BTAM
Tucker–lewis index, TLI	> 0.95	0.96
Comparative fit index, CFI	≅ 0.95	0.97
Goodness of fit index, GFI	> 0.90	0.92
Adjusted Goodness of fit index, AGFI	> 0.90	0.90
Root square error of approximation, RMSEA	< 0.08	0.06
Standardized root mean square residuals, SRMSR	< 0.05	0.04

Adapted from Hu and Bentler (1999), Schermelleh-Engel and Moosbrugger (2003), Hoe (2008), and Cangur and Ercan (2015).

2015). The model has a perfect fit because the Tucker–Lewis index (TLI) value is 0.96 and the comparative fit index (CFI) value is 0.97, both of which are close to 1 (Hu and Bentler, 1999: Cangur and Ercan, 2015).

5 Discussion

This study was primarily conducted to address the identified knowledge gaps in relation to public acceptance of the circular economy in Nigeria. Circular bioeconomy represents the replacement of fossil resources with bio-based resources and fossil fuel-derived products with bioeconomy products to combat climate change. The survey research employed a 5-point Likert scale questionnaire and incorporated three individual-level psychological factors to extend and enhance the revised version of the Technology Acceptance Model (TAM) by Venkatesh and Davis (1996) to address the gap in the technology acceptance research in a new context, the acceptance of bioeconomy at the individual level among residents of Lagos metropolis in Nigeria. The study determined and clarified the relationships between the three individual-level psychological factors, namely subjective knowledge of bioeconomy, environmental attitude and belief about climate change, and influence perceived usefulness from bioeconomy and intention to accept bioeconomy.

The respondents attributed the highest proportions of positive attitudes to perceived usefulness and intention to accept the bioeconomy. However, their inadequate subjective knowledge, unfavorable attitude toward the environment, and moderate belief about climate change may make it more difficult for them to intend to adopt bioeconomy products. The study's low environmental attitude (as determined by NEP) is in line with a previous study by Ogunbode (2013), which found that Nigerians endorse pro-ecological ideologies less than similar samples from other countries. Nonetheless, the high percentage of perceived usefulness and intention to accept indicates that the respondents are open to accepting the bioeconomy.

Subjective knowledge of bioeconomy was a better predictor of perceived usefulness than belief about climate change, which is in turn a better predictor than environmental attitude. These findings were

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consistent with earlier TAM research showing that knowledge of low-carbon products or/and technologies has a positive influence on the perceived usefulness of the products or/and technologies (Liu et al., 2018; Masukujjaman et al., 2021; Zhang and Liu, 2022), and that environmental attitude positively influences the perceived usefulness of eco-friendly products or/and technologies like bioeconomy (Park et al., 2014; Hu et al., 2021; Zhang and Liu, 2022). Subjective knowledge and environmental attitude, two individual-level socio-psychological factors, were found to have weak but significant relationships with the intention to accept the bioeconomy. Belief about climate change has a strong influence on intention. The relationship was strong and significant. These findings are consistent with earlier research on the acceptance of bioeconomy products (Scherer et al., 2017; Hengboriboon et al., 2020; Notaro and Paletto, 2022). The null hypotheses, H1 and H2, were rejected since there were significant relationships between the three individual-level psychological factors and perceived usefulness and intention.

In this study, a positive and significant relationship between intention and perceived usefulness was found. The study's hypothesis—that perceived usefulness from bioeconomy is a positive predictor of intention to accept bioeconomy among residents of Lagos, Nigeria—was supported by the results, which demonstrated that the TAM applies to the bioeconomy. As a result, the null hypothesis—which held that Lagos residents' intention to accept bioeconomy is not influenced by their perceived usefulness from bioeconomy—was rejected. The present finding is consistent with previous research indicating that the perceived usefulness of bioeconomy products significantly influences their local acceptance (Soland et al., 2013; Golembiewski et al., 2015; Tran and Cheng, 2017; Bagheri et al., 2021).

The developed model, the Bioeconomy Technology Acceptance Model (BTAM), is the main novelty of this study. The BTAM demonstrated a good and acceptable fit. Calculated model fit indices show the high predictive validity of the BTAM, as shown in Table 6. The model successfully extended the TAM to illustrate the relationships between the TAM constructs (PU and INT) in the context of the bioeconomy.

5.1 Recommendations

The majority of African nations lack a dedicated circular bioeconomy policy, which is a prerequisite for the responsible advancement of the circular bioeconomy. It is imperative for national and sub-national governments to formulate cohesive bioeconomy policies to drive initiatives such as public enlightenment about the economy.

The identified factors that influence the acceptance of circular bioeconomy in this study include limited knowledge of bioeconomy and moderate belief in climate change. These underscore the need for initiatives to improve public knowledge of circular bioeconomy products and belief about climate change. Local governments and authorities should support communication campaigns that reinforce climate action attributable to bioeconomy. To improve the bioeconomy awareness and knowledge of students who may become future adopters and influencers of the circular economy, higher education universities and institutes can modify their curricula to include education and training programs in the circular economy.

Understanding pre-conditions for public use of circular bioeconomy products is crucial when embarking on product development and commercialization to prevent investment loss. The findings of this study implied that promotional activities by manufacturers of bioeconomy products should target individual psychological attributes of the target consumers. Collaboration between academia and business is essential to fully understand the psychological dynamics of consumer markets so that producers can introduce circular bioeconomy products to specific market niches.

5.2 Limitations

This study focused on circular bioeconomy, which is one of several low-carbon technologies. It also applied a theoretical lens, the Technology Acceptance Model (TAM), out of an array of such models. Due to the novelty of the study's objectives, the dearth of literature on public acceptance of circular bioeconomy in Africa, and the absence of literature on public acceptance of bioeconomy as climate action, related studies provide some guidance in this study. Furthermore, the lack of resources to undertake a longitudinal and country-wide study has restricted the collection of participants' and respondents' data to a single point and the accessible population to the adult population of three local government areas in Lagos Metropolis.

5.3 Suggestions for future research

This study exclusively examined the public acceptance of circular bioeconomy. Future researchers are encouraged to validate the thesis of this study with other low-carbon technologies such as green building, electric vehicle, and solar photovoltaic. It is also desirable to combine the TAM with other theoretical models, such as the Innovation Diffusion Theory (IDT), Technological-Personal-Environment Framework (TPE), Technology Readiness Index (TRI), and Unified Theory of Acceptance and Use of Technology (UTAUT), to study the acceptance of circular economy. Furthermore, the predictors involved in this study are not exhaustive for acceptance of new technology. Additional findings from more extensive studies in other contexts, such as organizational-level or social-level and larger populations, would contribute to efforts to ensure the adoption and diffusion of circular products in society.

6 Conclusion

The circular bioeconomy offers numerous advantages as a new economic structure for addressing and overcoming the sustainability issues that have defined the Anthropocene. The circular bioeconomy is the most notable manifestation of the circular economy. Bioeconomy products have been identified as a promising pathway to transition from a linear to a resilient bio-based circular economy. On the African continent, the circular economy is still relatively new. Like every other country in Africa, Nigeria must develop public policies that support circular transition. The findings of this study highlight the necessity of placing individual-focused approaches at the forefront of circular economy discourses and policies to promote public acceptance of bio-based circular products. Circular economy development initiatives should target the improvement of individuals' knowledge of circular bioeconomy and its products. It is imperative to encourage climate change education among Nigerians to foster acceptance of the circular economy in the nation, given the substantial influence that beliefs about climate change have on the perceived usefulness of bio-based circular products and intentions to embrace it.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

This article was part of an ongoing dissertation by OJO, a PhD candidate at the Centre for Environmental Studies and Sustainable Development (CESSED) at Lagos State University, Nigeria. OA and OSO are the supervisors. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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