**VOICE COMMERCE AND SUSTAINABILITY: HOW VOICE ASSISTANTS DRIVE SUSTAINABLE E-COMMERCE AND SDGs?**

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**Abstract**

The rapid growth of voice assistants (VAs) can transform the retail e-commerce sector by fostering sustainability and supporting the achievement of Sustainable Development Goals (SDGs). This study aims to explore the role of voice assistants powered by artificial intelligence in transforming the retail e-commerce sector making it more sustainable and attaining sustainable development goals. VAs promote sustainable products, educate consumers on environmental impacts, and support circular economy initiatives. They also support eco-friendly practices, reduce carbon footprints, and enhance inclusivity in e-commerce. They streamline operational efficiencies, contribute to SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure) and SDG 13 (Climate Action), and improve accessibility for diverse consumer groups, aligning with SDG 10 (Reduced Inequalities). This paper highlights the potential of Virtual Assistants (VAs) as a bridge between technology and environmental stewardship, highlighting their role in promoting responsible consumption, waste reduction, and sustainability awareness. The findings provide actionable insights for retailers, policymakers, and technology developers to leverage VAs for a greener and more inclusive e-commerce future.

**Keywords:** Voice assistants, Sustainability Development Goals, Sustainable e-commerce, industry innovation

**1. Introduction**

***1.1 Background and Context***

The global retail e-commerce market has witnessed remarkable growth, significantly shaping modern consumer behavior. In 2023, e-commerce sales were estimated at $5.8 trillion USD, with projections suggesting a 39% increase, surpassing $8 trillion USD by 2027 (Statista, 2024). This rapid expansion is particularly evident in emerging economies, where digitization and increasing consumer demand drive market transformation. India, for instance, has become a major e-commerce hub, with its industry valued at $123 billion USD in 2024 and expected to reach $300 billion USD by 2030, reinforcing its influence on global retail trends. Despite this growth, many consumers lack awareness of sustainable product choices, underscoring the need for solutions that promote eco-conscious shopping. Voice assistants (VAs) offer a compelling approach, leveraging artificial intelligence (AI) and natural language processing to provide tailored recommendations for sustainable purchases (Ahmad & Zhang, 2020; Sadiq et al., 2024). The rise of voice commerce, driven by voice-enabled smart devices, has revolutionized shopping by enabling hands-free, intuitive transactions (Mittal & Manocha, 2022; McLean & Osei-Frimpong, 2019). With global voice commerce projected to reach $151.39 billion by 2025 (Business Research Company, 2025), its potential to enhance consumer convenience and foster sustainable decision-making is substantial.

While e-commerce has transformed shopping habits, it has also introduced environmental challenges such as carbon emissions from packaging, transportation, and waste disposal (Hao & Huang, 2023). To mitigate these impacts, e-commerce platforms are increasingly adopting eco-friendly strategies, including biodegradable packaging, optimized logistics, and recycling initiatives (Wang et al., 2020). However, driving sustainable consumer behavior remains a key challenge, requiring innovative interventions (Falcão & Roseira, 2022).

The push for sustainable e-commerce aligns with the United Nations Sustainable Development Goals (SDGs). Introduced by the World Commission on Environment and Development (WCED) in 1987, sustainable development emphasizes balancing economic growth, social equity, and environmental responsibility (WCED, 1987). This vision was formalized in 2015 with 17 SDGs and 169 targets to guide global sustainability efforts by 2030 (UN, 2015). Information and communication technology (ICT) is integral to advancing these goals, directly impacting 70% of SDG targets while indirectly supporting the remainder (Dhahri, 2024; ITU & UNDP, 2023). Emerging AI technologies, particularly conversational AI, have demonstrated considerable potential in addressing SDG-related challenges (Singh et al., 2024; Vinuesa et al., 2020). For example, SDG 12 promotes sustainable consumption and production, while SDG 13 focuses on urgent climate action. E-commerce platforms can contribute to these goals by embedding sustainability into their operations, reducing environmental impact, and encouraging responsible consumer choices (UNDP, 2022). AI-driven voice assistants serve as a valuable tool in this transition, helping consumers discover eco-friendly products and raising awareness of sustainable practices (Ameen et al., 2023).

While sustainability in e-commerce is a growing priority, there is a lack of clarity regarding the specific role of voice assistants (VAs) in fostering sustainable practices in retail e-commerce. VAs, powered by artificial intelligence, are increasingly integrated into shopping experiences, offering personalized recommendations and streamlining transactions. However, their potential to promote sustainability—by educating consumers about eco-friendly products, encouraging green consumption, and enhancing awareness of environmental impact—remains underexplored. This gap highlights the need for further research into how VAs can be optimized to support the global sustainability agenda in the e-commerce sector. Therefore, the main objectives of the research are: (a) To analyze the transformative role of voice assistants (VAs) in promoting sustainable consumption and eco-conscious behavior in the e-commerce sector. (b) To investigate how VAs contribute to the achievement of specific United Nations Sustainable Development Goals (SDGs).

**2. Literature Review**

***2.1 Voice Assistants in E-Commerce***

Commerce has continually advanced by moving alongside and making use of technological developments such as the Internet (Steinicke, 2016). As a result, E-commerce evolves, which refers to the purchase and sale of goods and services online through fixed or mobile devices (Lee et al., 2007; Wareham et al., 2005). Over the period, Voice recognition technology has replaced the online point-and-click decision-making process with spoken command methods (De Regt, & Barnes, 2019). Artificial intelligence, cloud computing, and machine learning are some of the technological advancements that have contributed to this transition. Consumers are becoming more open to conversational user interfaces like smart speakers and virtual voice assistants. So, Voice commerce involves buying and selling of goods and services using voice assistants through digital channels (Mari et al., 2020; Sun et al., 2021). Voice commerce enables self-service transactions via mobile phones and other connected devices by using natural language speech recognition technology (Dennis & Harris, 2002). Voice commerce applications are relevant to all customer journey phases, such as making a shopping list, researching a product/service, looking for a product/service, comparing products/services, and pricing comparison (Olson & Kemery, 2019). Voice assistants act as trusted companions throughout these phases, answering queries, recommending products, and facilitating simple tasks like reordering previously purchased items. This personal touch revolutionizes online retailing, fostering deeper connections with customers (Piacenza et al., 2018).

***2.2 Sustainability in E-Commerce***

Sustainability is the ability to meet current needs without compromising future generations' needs and reducing negative impacts on the environment, social, and economic dimensions (Hajdukiewicz & Pera, 2023). Sustainable e-commerce involves environmentally friendly methods, such as eco-friendly shipping, durable, high-quality products, and social engagement. Companies should create awareness about the benefits of going green and associate with retailers advocating for green products. Transparent green manufacturing and shipping processes can also be implemented (Kiba-Janiak et al., 2021, Oláh et al., 2023). Online businesses are promoting a green environment through proper packaging, reducing returns and facilitating deliveries. This reduces greenhouse gas emissions and positively impacts global warming (Pålsson et al., 2017; Radonjič & Tompa; 2018). Companies must prioritize environmental conservation, considering consumers, social needs, employment, and environmental protection, as it is the duty of every party involved (Laudon, 2018). Technology is crucial in promoting sustainable consumption by promoting transparency, efficiency, and informed decision-making. AI-driven systems, blockchain-based supply chain tracking, voice assistants, AI chatbots, IoT, and big data analytics help consumers identify eco-friendly products, promote ethical sourcing, and simplify access to green products (Ameen et al., 2023). These tools align with global sustainability goals and address consumer demand for responsible consumption in the retail sector.

***2.3 Sustainable Development Goals and Retail***

Retail and e-commerce play a significant role in achieving several Sustainable Development Goals (SDGs) by addressing environmental, social, and economic challenges. SDG 12, which emphasizes responsible consumption and production, directly aligns with sustainable practices in retail, encouraging businesses to reduce waste, adopt eco-friendly supply chain processes, and promote sustainable products (United Nations, 2015). SDG 13, focusing on climate action, underscores the importance of reducing carbon emissions associated with logistics and packaging in e-commerce (Hajdukiewicz & Pera, 2023). Additionally, SDG 8, which promotes decent work and economic growth, and SDG 9, advocating for industry innovation and infrastructure, emphasize the need for inclusive growth and technological advancements in the retail sector (Ziemba et al., 2024). Through innovative solutions, the industry can address these goals while creating economic opportunities and minimizing environmental impacts. Moreover, Technology drives inclusivity and environmental stewardship in e-commerce through AI, IoT, and blockchain, enhancing supply chain transparency, reducing waste, and supporting ethical sourcing (Ameen et al., 2023). AI tools like voice assistants improve accessibility for diverse consumer groups, while data-driven innovations optimize logistics and energy use, minimizing environmental impacts and helps in achieving SDG 10 (Singh et al., 2024). This integration of technology, inclusivity, and sustainability fosters equitable and eco-conscious growth in the retail sector.

**3. The Role of Voice Assistants in Promoting Sustainability**

Voice assistants (VAs) have emerged as powerful tools in the e-commerce landscape, significantly contributing to the advancement of sustainability by influencing consumer behavior, enhancing operational efficiencies, and supporting circular economy initiatives. Their capacity to seamlessly integrate sustainability into the retail experience is a testament to the transformative potential of technology in fostering eco-conscious practices.

***3.1 Promoting Sustainable Products***

One of the primary roles of VAs in promoting sustainability lies in their ability to suggest eco-friendly alternatives. Equipped with advanced artificial intelligence (AI) and natural language processing capabilities, VAs can identify and recommend sustainable products based on user preferences, search patterns, and purchasing history (Sadiq et al., 2024). For instance, a VA might suggest reusable alternatives to single-use items or highlight products made from environmentally friendly materials. These mechanisms not only influence individual choices but also promote a culture of sustainability among consumers.

In addition to personalized recommendations, VAs play a pivotal role in educating consumers about the environmental impacts of their purchases. They can provide detailed information on aspects such as a product’s carbon footprint, production processes, or the environmental benefits of choosing eco-friendly options (Lin et al., 2020). This educational component empowers users to make informed decisions that align with their values, fostering greater accountability and environmental stewardship in the retail ecosystem.

***3.2 Supporting Circular Economy Initiatives***

VAs also contribute to sustainability by promoting the principles of a circular economy—reuse, recycling, and waste reduction. By integrating with e-commerce platforms and third-party services, VAs can encourage consumers to return used items for recycling or guide them toward local programs that support circularity. For instance, a VA might remind a user to return empty product containers or offer recommendations for purchasing refurbished or second-hand items, extending product lifecycles and reducing waste (Blythe, 2022). Moreover, VAs can facilitate the adoption of reusable products by creating user-friendly reminders and notifications. These functions encourage a shift away from disposable goods toward more sustainable consumption patterns, aligning with global efforts to reduce resource depletion and environmental impact (Sadiq et al., 2024).

***3.3 Reducing Carbon Footprints***

Another critical area where VAs contribute to sustainability is in reducing carbon footprints associated with retail operations. By streamlining supply chain processes, VAs enable businesses to optimize inventory management and logistics. For example, real-time inventory tracking powered by VAs can prevent overproduction and minimize waste, leading to more efficient resource utilization (Ramos, 2024).

In logistics, VAs can facilitate consolidated shipping strategies, ensuring that deliveries are optimized to reduce unnecessary transportation and emissions. This is particularly valuable in urban areas where carbon emissions from last-mile delivery are a growing concern (OZ virtual assistant, 2024). Through these efficiencies, VAs help retailers not only cut costs but also contribute to broader climate action goals, such as reducing greenhouse gas emissions. Additionally, VAs can incorporate sustainability insights into operational decision-making. For instance, they might identify energy-efficient shipping routes or recommend eco-friendly packaging solutions, further aligning retail practices with environmental sustainability targets (Ramos, 2024).

**4. Contribution of VAs to Sustainable Development Goals**

Voice assistants (VAs) have become integral to the evolving landscape of retail and e-commerce, offering technological solutions that align with the United Nations' Sustainable Development Goals (SDGs). By enhancing operational efficiency, promoting climate-conscious consumer habits, and fostering inclusivity, VAs contribute to multiple SDGs, including SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 13 (Climate Action), and SDG 10 (Reduced Inequalities).

***4.1 SDG 8:*** ***Decent Work and Economic Growth***

SDG 8 aims to foster sustained, inclusive, and sustainable economic growth while ensuring full and productive employment and decent work for all (UN, 2015). Voice assistants contribute to SDG 8 by improving productivity and efficiency in the retail sector, ultimately fostering economic growth and employment opportunities. By automating routine customer service functions, such as handling inquiries, processing orders, and managing returns, VAs enable businesses to allocate human resources more strategically, allowing employees to focus on higher-value tasks like personalized customer service and strategic decision-making (Ramos, 2024). For instance, Amazon's Alexa for Business helps companies streamline operations by managing schedules, automating administrative tasks, and providing instant responses to common queries, reducing the burden on human staff. Similarly, Walmart's voice-powered shopping assistant simplifies the purchasing process, enabling faster transactions while minimizing manual workload for employees.

Moreover, VAs play a crucial role in supporting small and medium-sized enterprises (SMEs) by offering cost-effective customer engagement solutions. Businesses can integrate AI-driven chatbots and voice assistants to handle customer interactions, reducing the need for large customer support teams while maintaining service quality (Ziemba et al., 2024). This reduction in operational costs allows SMEs to compete in the global market, increasing their scalability and economic viability.

Furthermore, VAs enhance workplace accessibility by assisting employees with disabilities. For example, visually impaired workers can use voice-activated systems to navigate digital interfaces, improving inclusivity in the workforce (Volochtchuk et al., 2024). By facilitating efficient business operations, reducing costs, and enabling broader workforce participation, VAs support sustainable business models that align with economic growth objectives.

***4.2 SDG 9: Industry, Innovation, and Infrastructure***

SDG 9 aims to develop resilient infrastructure, advance sustainable industrialization, and drive innovation, emphasizing that economic growth, social progress, and climate action rely significantly on investments in these sectors (UN, 2015). Innovation and infrastructure improvements are crucial in modern retail, and VAs play a significant role in advancing SDG 9. By utilizing artificial intelligence (AI) and machine learning, VAs enhance operational efficiency through real-time inventory tracking, predictive demand forecasting, and automated supply chain management (Plathottam et al., 2023). For instance, retailers like Amazon and Walmart integrate AI-powered voice assistants to optimize warehouse operations, ensuring timely stock replenishment and minimizing overproduction, which reduces both costs and waste.

Moreover, VAs play a crucial role in streamlining logistics coordination. Companies leverage AI-driven assistants to manage delivery schedules, monitor transportation routes, and optimize last-mile delivery, reducing fuel consumption and carbon emissions (Hsiao & Chang, 2019). For example, logistics companies such as UPS use AI-powered systems to determine the most efficient delivery routes, significantly cutting down environmental impact.

In addition to operational improvements, VAs drive consumer-centric innovation by offering highly personalized shopping experiences. AI-powered assistants like Alexa and Google Assistant analyze user preferences, browsing history, and purchase patterns to provide tailored product recommendations, enhancing customer engagement and satisfaction (Tabassum et al., 2019). This data-driven approach not only boosts sales but also ensures that consumers are directed toward relevant and sustainable product options, reinforcing responsible consumption patterns.

As businesses continue to integrate VAs into their e-commerce strategies, the retail industry benefits from increased resilience, efficiency, and sustainability, aligning with the broader goals of SDG 9 in fostering innovation and infrastructure development.

***4.3 SDG 10: Reduced Inequalities***

SDG 10 aims to reduce inequality within and among countries. This goal addresses disparities in income and those based on age, sex, disability, race, ethnicity, origin, religion, and economic or other (UN, 2015). Voice assistants (VAs) play a crucial role in enhancing accessibility and inclusivity, directly supporting SDG 10 (Reduced Inequalities). By enabling voice-based interactions, VAs make digital commerce more accessible to individuals with disabilities, the elderly, and those with limited digital literacy (Kumar et al., 2024). For instance, visually impaired users can navigate e-commerce platforms using voice commands through Amazon Alexa or Google Assistant, eliminating the need for screen-based interactions. These features help break down digital barriers, ensuring that a broader demographic can participate in e-commerce and reducing inequalities in access to online services.

Additionally, VAs support inclusivity through multilingual capabilities, allowing non-native speakers to shop and interact with platforms in their preferred language (Gunda et al., 2024). For example, Google Assistant supports over 40 languages, enabling users from diverse linguistic backgrounds to access e-commerce services more comfortably. This feature is particularly beneficial in regions where language barriers have traditionally hindered digital inclusion.

Moreover, VAs help bridge the gap for underserved communities by providing localized shopping recommendations tailored to specific cultural and economic contexts. AI-powered voice assistants can suggest regionally available sustainable products or highlight small businesses, fostering economic opportunities in less-developed areas. For instance, voice-enabled commerce platforms in India, such as JioMart’s AI assistant, provide recommendations in multiple regional languages, making e-commerce more accessible to rural consumers.

Another vital contribution of VAs is their role in facilitating financial inclusion. Voice-enabled payment solutions, such as Google Pay’s voice transactions and Amazon Pay’s voice authentication, allow users—especially those unfamiliar with digital banking—to complete transactions securely and conveniently (Nguyen et al., 2024). These advancements empower diverse consumer groups, fostering a more inclusive digital economy and reducing inequalities in access to online retail opportunities.

***4.4 SDG 13: Climate Action***

Voice assistants (VAs) contribute to SDG 13 (Climate Action) by fostering environmentally conscious shopping habits and reducing the carbon footprint of retail operations. Through AI-driven insights, VAs can guide consumers toward sustainable choices by recommending eco-friendly products, informing them about ethical sourcing, and encouraging greener purchasing decisions (Silver, 2024). For instance, Amazon’s Alexa and Google Assistant can suggest biodegradable household items, energy-efficient appliances, or fair-trade-certified products based on user preferences. These recommendations empower consumers to make responsible choices, aligning their purchases with environmental sustainability.

Additionally, VAs help optimize supply chain logistics by improving delivery efficiency and reducing unnecessary transportation. AI-powered systems can analyze real-time traffic data, consolidate shipments, and recommend the most eco-friendly delivery routes, minimizing fuel consumption and emissions (Hsiao & Chang, 2019). Companies like DHL and FedEx use AI-driven logistics solutions to enhance fleet efficiency, reducing their environmental impact. For example, AI-enabled route optimization in last-mile delivery has helped UPS reduce fuel usage and emissions through its ORION (On-Road Integrated Optimization and Navigation) system, which saves millions of miles annually.

Furthermore, VAs educate consumers on responsible consumption by providing real-time insights into the sustainability metrics of products. When users inquire about a product, VAs can display details such as energy efficiency ratings, recyclability, carbon footprint, and ethical sourcing certifications (He et al., 2022). Retailers like IKEA have integrated AI-driven tools to help customers choose sustainable furniture options by providing information on renewable materials and eco-friendly production methods. By raising awareness and facilitating informed decision-making, VAs drive a significant shift toward sustainable consumer behaviors, reinforcing global climate action efforts.

**5. Challenges and Barriers**

Despite the transformative potential of voice assistants (VAs) in promoting sustainability and inclusivity, several challenges and barriers hinder their widespread adoption and effectiveness.

***5.1 Digital Divide***

One of the major challenges in leveraging VAs for sustainable e-commerce is the digital divide. Limited access to internet infrastructure, smart devices, and digital literacy in underserved regions restricts the adoption of voice technologies (Baxter et al., 2025). Many rural and economically disadvantaged populations lack the necessary technological infrastructure to use VAs, preventing them from benefiting from AI-driven retail solutions. For example, in low-income regions of Africa and South Asia, the affordability of smart speakers and smartphones remains a significant barrier, limiting access to voice-enabled shopping experiences (Baxter et al., 2025). Addressing this issue requires investment in digital infrastructure, affordable devices, and localized VA solutions tailored to diverse linguistic and cultural contexts.

***5.2 Ethical and Privacy Concerns***

Another critical barrier is the ethical and privacy concerns surrounding VAs. As voice assistants collect and process vast amounts of personal data, users often express concerns about data security, surveillance, and potential misuse of their information (Bolton et al., 2021). Cases of unauthorized data access and voice recordings being stored without consent have led to distrust in voice technologies (Pal et al., 2020). For instance, reports of Amazon Alexa and Google Assistant inadvertently recording conversations have raised concerns about user privacy and data protection regulations. Addressing these issues requires stricter data governance policies, enhanced encryption techniques, and transparent data usage practices to build consumer trust.

***5.3 Algorithmic Biases***

Algorithmic biases in VA recommendations pose another challenge, particularly when promoting sustainable products. AI-driven voice assistants may unintentionally prioritize certain brands, favor large corporations over small sustainable businesses, or reinforce consumer biases due to limitations in training data (Rabassa et al., 2022). For example, if a VA’s recommendation algorithm is trained primarily on mainstream consumer preferences, it may overlook eco-friendly alternatives that are less popular but more sustainable. Ensuring unbiased and diverse recommendations requires continuous monitoring of AI training datasets, implementing fairness algorithms, and promoting inclusivity in product listings to support ethical and responsible consumption.

Overcoming these challenges is essential to maximize the potential of VAs in fostering sustainability, accessibility, and ethical AI-driven e-commerce. Addressing the digital divide, ensuring strong data privacy measures, and mitigating algorithmic biases will enable VAs to play a more impactful role in achieving Sustainable Development Goals (SDGs) in retail and beyond.

**6. Recommendations**

To maximize the role of voice assistants (VAs) in promoting sustainability and achieving Sustainable Development Goals (SDGs), stakeholders—including retailers, policymakers, and technology developers—must adopt strategic approaches to enhance their effectiveness, accessibility, and ethical implementation.

**6.1 For Retailers**

Retailers play a crucial role in integrating VAs into sustainable e-commerce strategies. They can:

* **Integrate VAs to promote sustainability:** Businesses should leverage VAs to recommend eco-friendly products, highlight sustainability certifications, and provide real-time insights into the environmental impact of purchases. For example, e-commerce platforms like Amazon and Walmart can enhance VA capabilities to prioritize sustainable alternatives in product recommendations.
* **Leverage VAs for consumer education and engagement:** Retailers should use VAs to educate consumers about sustainable consumption practices, such as recycling programs, carbon footprint reduction, and responsible purchasing decisions. Interactive voice-driven sustainability quizzes or personalized sustainability tips can further enhance consumer awareness and engagement.

**6.2 For Policymakers**

Governments and regulatory bodies must create policies that support sustainable retail through voice technology while ensuring inclusivity and accessibility. Key recommendations include:

* **Developing policies to support sustainable retail:** Policymakers should encourage businesses to integrate AI-driven VAs for sustainability by providing incentives such as tax benefits or grants for companies that use voice technology to promote green products.
* **Promoting accessibility and reducing the digital divide:** Governments should invest in digital infrastructure, affordable smart devices, and internet access in underserved regions to ensure equitable access to VA-driven e-commerce. Additionally, initiatives to support multilingual VA capabilities can improve inclusivity for diverse consumer groups.

**6.3 For Technology Developers**

Technology developers must focus on enhancing the capabilities, ethics, and security of VAs to ensure they effectively contribute to sustainability. This includes:

* **Innovating to enhance VA capabilities for sustainability:** AI developers should integrate advanced natural language processing (NLP) and machine learning models to improve VA recommendations for sustainable products, ethical sourcing, and energy-efficient logistics. For example, voice assistants could provide carbon footprint comparisons between similar products to help consumers make informed decisions.
* **Ensuring ethical design and data privacy:** Developers must address ethical concerns by implementing robust data privacy protocols, transparency in AI decision-making, and eliminating algorithmic biases in VA recommendations. Stricter adherence to global data protection standards, such as GDPR and CCPA, can help build consumer trust in voice technologies.

By implementing these recommendations, retailers, policymakers, and technology developers can ensure that VAs effectively contribute to sustainable retail, fostering environmental responsibility, economic inclusivity, and ethical AI adoption in the e-commerce sector.

**7. Conclusion and future research directions**

This study highlights the transformative role of voice assistants (VAs) in promoting sustainability and contributing to the achievement of Sustainable Development Goals (SDGs). VAs facilitate responsible consumption by recommending eco-friendly products, educating consumers about environmental impacts, and optimizing supply chain logistics to reduce carbon footprints. Their integration into retail e-commerce enhances operational efficiency, supports circular economy initiatives, and promotes inclusivity by improving accessibility for diverse consumer groups. Additionally, VAs drive innovation in the retail sector by streamlining business processes, reducing costs, and fostering economic growth. However, challenges such as the digital divide, ethical concerns, and algorithmic biases must be addressed to maximize their potential impact. Further studies on the role of VAs in sustainability can explore various opportunities and challenges associated with their adoption. Research can focus on improving VA capabilities for sustainability-driven consumer engagement, enhancing AI algorithms to eliminate biases, and ensuring data privacy and security. Additionally, examining regional and sectoral variations in VA adoption can provide insights into the specific barriers and enablers influencing their implementation across different markets. Comparative studies between developed and emerging economies can further highlight best practices for leveraging VAs in sustainable e-commerce. Future research should also explore interdisciplinary approaches, integrating AI advancements with policy frameworks and behavioral insights to optimize the role of VAs in promoting sustainability.

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