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Nudging Into the Future of Immersive Reality: A Systematic Review of Sustainability-Orientated Nudges in Policy and the Future Role of Extended Reality (XR)

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ABSTRACT

Sustainability issues are highly complex and constantly evolving, posing significant challenges for effective management. Addressing these challenges requires innovative policies, such as digital innovations like extended reality (XR) and the application of psychological insights through nudges. This paper examines the intersection of social and behavioral sciences, focusing on how immersive technologies can be used to design and implement nudges for sustainable behavior. We conduct a review and meta-analysis of nudge effectiveness to better understand sustainability behavior, categorizing nudges as cognitive, affective, or behavior-oriented. Cognitive nudges are the most studied (*n*: 99) but have mixed results (54% positive), while behavioral nudges (*n*: 50) are more effective (70% positive). XR studies testing cognitive (*n*: 3) and behavioral (*n*: 4) nudges generally show positive outcomes, but research on affective nudges is limited (overall *n*: 15, XR *n*: 0), likely due to difficulties in testing emotional interventions. XR can enhance cognitive nudges by reducing information processing barriers and expand behavioral nudges by offering convenience not possible in the physical world. Immersive technologies also present new opportunities to test affective nudges by creating virtual scenarios that evoke empathy and social connections. We conclude by emphasizing the need to prioritize ethical considerations in using immersive technologies.

1 | Introduction

Climate change, ecosystem conversion, biodiversity loss, and water scarcity (Foley et al. 2005; IPCC 2014; Wada and Bierkens 2014), among many of the planet's numerous and pressing environmental threats, can be directly attributed to human behavior. As populations grow and purchasing power increases, these issues are projected to worsen (Ferrara and Serrat 2008), making it imperative to change such behaviors and reverse environmental decline (Cowling 2014; Fischer et al. 2012). Recent studies have argued that policies for incremental changes are insufficient and that innovative policies (Falcone and Tutore 2025), and digital innovations (John et al. 2025) are needed for systemic transformations in hopes of achieving the sustainable development goals (SDGs). This area requires development as there remains a gap in understanding the influence of social and behavioral sciences in adopting innovation policies (Falcone and Tutore 2025). We look to address this gap through providing an exploration between a behavioral policy tool, nudges, and an emerging digital innovation that can act as a vehicle for shifting individual's perspectives and priorities, namely the use of extended reality (XR) (Scurati et al. 2021). XR encompasses different types of immersive technologies including augmented reality (AR),

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virtual reality (VR), and mixed reality (MR). These technologies "enable the display of computer-generated objects onto the real environment or the integration of real-world elements into computer generated virtual environments" (Bekaroo 2024, 216). While this technology has received much interest in fields such as medicine, marketing, education, and skills training (Bulearca and Tamarjan 2010), the implications for policy and sustainability are less well understood. Here, we contribute to informing policy making by exploring how digital (XR) and behavioral interventions (nudges) can be brought together and operationalized to comprise more effective policy interventions in the field of sustainability.

In a real-world setting, one can conduct experiments on a confined set of environmental behaviors at one time, for example, waste disposal or sustainable consumption at supermarkets. The introduction of XR technology means that researchers are no longer limited by the physical setting for the experiment (Thomas et al. 2013). XR makes different modalities available to researchers, such as immersive experiences (Breves and Heber 2020; Chirico et al. 2021), computer games (Fletcher 2017; Schott 2017), simulations (Barbalios et al. 2013; Khashe et al. 2019), and single and multiuser applications (Breves and Heber 2020; Chirico et al. 2021; Larson and Edsall 2010). Such modalities allow for the manipulation of the environment and for the possibility of diversifying experiences (Scurati et al. 2021), accentuating the key ingredients of a scenario, improving its viability for application in the real world.

New applications of XR technology create substantial value for not only private companies but the wider society. While others are working to bring together XR start-ups and developers to unlock economic and social impact opportunities, there is also immense potential to draw upon such technologies to formulate effective behavioral policy tools. This moves the adoption of XR beyond its use as a commercial marketing tool for improved customer experiences (Bulearca and Tamarjan 2010) to a tool for exploring how to encourage sustainability-friendly behavior. Gaining a better understanding of how behavioral policy tools could be applied through XR to influence people's sustainability behaviors would inform the future development and opportunities to make use of the metaverse to contribute toward a more sustainable society.

Traditionally, policies and programs targeted at influencing decision making have been guided by the economic perception of the rational actor. This conceives individuals as having limitless cognitive capacity for evaluating decisions, making cost–benefit analyses based on personal loss/gains, and responding to information and incentives (Byerly et al. 2018). The concept of humans being entirely rational overlooks the influence of emotions, context, or the environment in which decisions are made (Kahneman 2011; Thaler and Sunstein 2008). People have been found to be sensitive to the behavior of others and so not entirely self-interested (Nyborg et al. 2016; Ostrom 2000). Consequently, insights from psychology, economics, and neuroscience indicate that people make use of heuristics and biases to simplify decision making, which can result in predictable systematic biases and errors (Simon 1955; Thaler and Sunstein 2009; Tversky and Kahneman 1974; Vlaev et al. 2016).

These behavioral insights can be incorporated into policy making alongside traditional policy forms; a prominent technique, which will be focused on here, is that of nudging (Thaler and Sunstein 2009). In particular, nudges to encourage sustainability-orientated behavior (Evans et al. 2017; Michalek et al. 2016; Vlaev et al. 2016) aim to encourage people to voluntarily contribute to environmental protection (Schubert 2016). Research into this area of behavioral policy is growing, but there is a need to build coherent and comprehensive understandings regarding the actual application of sustainability-orientated nudges within policies, particularly regarding their success in real-world settings (Bryan et al. 2021; Chater and Loewenstein 2022; Michalek et al. 2016; Zhang et al. 2023).

Ultimately, the aim of this paper is to provide a better understanding of how XR could be used to inform and enhance the design and implementation of nudges. To do so, we must first find out which type of nudges are more effective in motivating sustainability behavior, as this will inform subsequent discussions on how XR can enhance nudge effectiveness in this field. As such, we start by considering the behavioral foundations and policy implications of sustainability-oriented nudges to better understand their functioning and, later, how XR can leverage these behavioral underpinnings. We then conduct a review and meta-analysis to provide insights into nudge effectiveness, to explore which nudges (and associated behavioral underpinnings) may be more susceptible to XR application and which behaviors to target. This research builds on previous review studies investigating the effectiveness of nudging for pro-environmental behavior (Byerly et al. 2018; Ferrari et al. 2019) and to answer the call for improved understanding of how new technologies can provide promising vehicles for wider systemic change and enable sustainability transitions (Scurati et al. 2021).

2 | Nudging for Sustainability: Behavioral Underpinnings and Policy Implications

Thaler and Sunstein (2009) introduce the original definition and categorization of nudges. Accordingly, nudges are modifications to the choice architectures that keep all incentives and information unchanged in the decision context. These include how the availability, accessibility, and representation of information are perceived by individuals as well as how framing, the perception of gains and losses, and overconfidence can bias decision making (Thaler and Sunstein 2009). Various authors have explored these cognitive shortcuts and preconceptions to identify an extensive range of factors that influence decision making (e.g., Battaglio Jr et al. 2019; Kahneman 2011; Korteling et al. 2023; thedecisionlab 2024; Tversky and Kahneman 1974). Nudges make strategic use of these biases and heuristics by making small adjustments in the choice architecture that stimulate a certain choice. Importantly, nudges do not make alternative options less available, forbidden, or financially less attractive (Van Gestel et al. 2020). They include techniques such as defaults, campaigns, commitments, information mechanisms, transaction shortcuts, improved design strategies, and warnings and reminders (Thaler and Sunstein 2009).

Multiple studies have sought to refine and develop categorizations of nudges. These include categorizations based on

meta-analysis (Battaglio Jr et al. 2019; Wee et al. 2021), brain systems and psychological processes involved (Vlaev et al. 2016), dual process theory (Hansen and Jespersen 2013; House and Lyons 2013), how they alter the target individual's perception of utility (Fischer and Lotz 2014), or a combination of approaches (Evans et al. 2017). Many of these approaches can create fuzzy categories, with many nudges falling into more than one category as nudges generally rely on a mix of biases or provide too many options to give meaningful understandings.

In this study, we adopt the categorization of nudges that follow the trilogy of the mind, which is based on the cognitive influence they seek to affect (Barry and Howard 1990; Breckler 1984; Hanssens et al. 2014; Oliver 1999; Srinivasan et al. 2010). Subsequently, nudges can be divided into whether they seek to influence what is known (cognitive orientated interventions), what is felt (affective orientated interventions), and what is done (behavior orientated interventions) (Cadario and Chandon 2020). Nudges within these different categories can then exploit various heuristics and biases to shift individuals toward a more desirable behavior.

Nudging has come to be recognized as an effective policy tool in inducing behavioral change among the public (Momsen and Stoerk 2014). Consequently, several government organizations have been established to provide insights into the adoption of nudging into public policies in fields such as health, education, and tax (Behavioural Insights Team 2021; Holz et al. 2020). While comparatively less prominent in the study of public policy (e.g., Carlsson et al. 2021; Lehner et al. 2016), the body of literature providing evidence for utilizing nudges in implementing pro-environmental behavioral change has rapidly expanded (e.g., Karlsen and Anderson 2019; Sunstein 2014; Wee et al. 2021). Nudges are considered necessary as part of the environmental policy toolkit due to the complexities embedded in sustainability issues (Evans et al. 2017). At the same time, such complexities mean that there is no straightforward recipe for the effective implementation of nudges. Studies confirm that biases and heuristics are found to have the potential to impede behavioral and policy practices that seek to address sustainability challenges (Korteling et al. 2023).

While a large number of biases have been identified, biases that are more likely to occur in the domain of public decision making, and within different policy domains, are expected. Subsequently, certain biases have been identified to be more likely to occur in individuals' decision making processes within the sustainability domain (Korteling et al. 2023). This is based partly on common psychological barriers which influence people's decision making in general, such as limited access to relevant information and limited capacity to compare choice options (Mertens et al. 2022), but also as certain characteristics embedded with sustainability issues complicate related decisions. For example, issue complexity, experiential vagueness, or the long-term nature of the phenomenon are at odds with the biases and heuristics built into human thinking. Resistance to change or consumption-based lifestyles as well as the pursuit of individual benefit over the collective are also common psychological characteristics that may impede pro-sustainability choices (e.g., Green and Myerson 2004; Hardin 1968; Kahneman 2011; Kahneman and Tversky 1979; Korteling et al. 2023; Sunstein 2002).

Several specific biases have been identified to be more likely to impede sustainability decision making and behaviors due to these characteristics of sustainability (Korteling et al. 2023). These are summarized in Table 1, with examples of nudges that may be effective in counteracting or utilizing these biases. Although all three categories of nudges (cognitive, behavior, and affective) have been identified to be applicable for overcoming one or more psychological sustainability characteristics, cognitive nudges were considered to be relevant for all of the identified characteristics. This suggests that more attention should be paid to better understand ways to employ cognitive nudges to overcome psychological barriers for sustainable consumption.

2.1 | Nudge Policies for Sustainability

Studies in this area often provide insights into a specific domain of sustainability (e.g., Ferrari et al. 2019; Pandey et al. 2023) or others a specific functioning or design of nudges (e.g., Mertens et al. 2022); more limited is literature specifically reviewing nudging techniques in a pro-environment context (Wee et al. 2021). Byerly et al. (2018) investigated the effectiveness of nudges in promoting pro-environmental behavior in six domains where individuals can affect a large environmental impact. Interestingly, nudges in the investigated domains were found to outperform education interventions, although the relationship with financial incentives was less clear. The performance of different nudges was also found to vary, with some being more successful in generating pro-environmental behavior than others. Similarly, a comprehensive review is supplied by Wee et al. (2021), who review the status of the environmental context where nudges have been applied and the techniques available. While these studies provide important insights into the overall performance of nudging in encouraging pro-environmental behavior, they do not offer many insights into the practical or political application of nudging.

In terms of policy, Lehner et al. (2016) consider the policy potential for nudges across three domains: food, energy, and transportation, highlighting the potential for nudges to be incorporated alongside traditional policy tools. A review was also conducted by Carlsson et al. (2021), who differentiate between different types of nudges and theorize when nudges may form part of a policy mix. They conclude that when considering green nudges, policymakers need to compare the distributional effects, the potential to crowd out intrinsic motivation, the implementation cost, and the external validity of experimental findings of such nudges compared to more traditional policy instruments, such as taxes. These studies highlight an increasing recognition of the role of nudges within policymaking, but more direction is required in terms of practical application in designing policy mixes.

Evaluating the effectiveness of policy tools is not an easy exercise, especially in terms of nudge policies. Methodological issues and variations in study design, particularly related to the characteristics of participants and experimental settings, can substantially influence the final result, making it difficult to reliably induce general factors that contribute to effective nudge policies (Michalek et al. 2016; Zhang et al. 2023). The inconsistency of nudge tools in environmental and social policy

TABLE 1 | Psychological characteristics of sustainability challenges and strategies to overcome them.

Psychological sustainability characteristic	Commonly associated biases and heuristics	Strategy to overcome	Example of what can be targeted	Example of nudge type
Experiential vagueness	Experience effect	Make consequences tangible	Cognitive	Feedback
	Contrast effect			Framing
	Story bias			
Long-term effects and future risks	Hyperbolic time discounting	Bring rewards to the present	Cognitive	Feedback
	Normalcy bias			Reminders
	Optimism bias			
Complexity and uncertainty	Conformation bias	Information and education	Cognitive	Information
	Neglect of probability			Feedback
	Zero risk bias			Decoy effect
	Anchoring bias			Framing
	Availability bias			
	Focusing illusion			
	Affect heuristic			
	Framing bias			
	Knowledge illusion			
	Surrogation (means-goal)			
	Ambiguity effect			
Threat of the status quo	Status quo bias	Make sustainability the easy choice and present as gains	Behavior	Convenience enhancement
	Default effect			Convenience reduction
	Sunk cost fallacy			Visibility enhancement
	System justification			Sizing
	Cognitive dissonance			Priming
	Fear of regret		Cognitive	Information
	Loss aversion			Framing
	Endowment effect		Affective	Hedonic enhancement
Threat of social status	Affective forecasting (hedonic forecasting/ impact bias)	Connect sustainable decisions with higher social status	Affective	Morality calls
	Hedonic adaptation		Cognitive	Social norm
	Social comparison bias			
	Scarcity bias			
Personal vs. community interest	Tragedy of the Commons	Sustainability as favorable and profitable	Cognitive	Egoistic appeal
	Perverse incentive effect			Social norm
	Anthropocentrism			Framing

(Continues)

TABLE 1 | (Continued)

Psychological sustainability characteristic	Commonly associated biases and heuristics	Strategy to overcome	Example of what can be targeted	Example of nudge type
Group pressure	Bandwagon effect Conformity bias In-group (outgroup) bias Authority bias Liking bias Reciprocity Social proof	Social norms and peer pressure	Cognitive	Social norm Framing

Source: Adapted from Korteling et al. (2023).

domains, as well as across different contexts, has led to concerns regarding their overall effectiveness (Baldwin 2014; Bao and Ho 2015; Bryan et al. 2021; Chater and Loewenstein 2022) and has created challenges for policymakers (Ferraro and Shukla 2020; Zhang et al. 2023). Studies have scrutinized the effectiveness of nudges with conflicting results, the most severe case being Maier et al. (2022), which concluded that no evidence of nudge effectiveness remains after adjusting for publication bias. Moving from the field, experimental tests are not able to accurately predict how individuals will behave in real-world conditions (Alemanno and Spina 2014; Michalek et al. 2016), creating further inconsistencies when attempting to evaluate and break down the effectiveness of nudges as policy tools.

A comparison was made by DellaVigna and Linos (2022), who analyzed results from RCTs run across two large Nudge Units in the United States, and so not subject to publication bias, and published meta-analyses. They found nudge interventions in both the RCTs and the published meta-analyses have a meaningful and statistically significant impact on behavior. Even when nudges are held to have a significant impact, the reason for this remains unclear. Studies here have taken an ethical stance to the question, investigating if altering the transparency of a nudge to avoid subjects feeling manipulated impacts effectiveness (Weijers et al. 2021), finding that in certain circumstances making a nudge transparent may increase its effectiveness (Congiu and Moscati 2021). Others have investigated nudge effectiveness from a psychological perspective, utilizing the dual process theory to consider the differences between nudge effectiveness based on if they engage System 1 processes (intuitive and automatic) or also evoke a response from System 2 (reflective) thinking (Bruns 2019; Congiu and Moscati 2021; Dijkstra et al. 2013; Evans et al. 2017; Michalek et al. 2016; Van Gestel et al. 2020) with mixed results. In a similar vein, authors have considered the effectiveness of nudges using the tripartite understanding (Cadario and Chandon 2020; Zhang et al. 2023) or by considering the impact of nudges on habits or persistent behavioral change (Venema et al. 2020; Weijers et al. 2021). Studies have also incorporated characteristics of the participants being targeted, such as nationality, age, and BMI, contextual factors, including public/private settings, and the design of the study (Cadario and Chandon 2020; Dolgopolova et al. 2021; Ingendahl et al. 2020; Zhang et al. 2023). Taking a different approach, Sunstein (2017) identifies three reasons why nudges may fail, namely that they may be nudging against what is acceptable or known, the wrong nudge has been chosen as it is misaligned with the underlying psychological processes, or a stronger policy option is required.

Further, while previous reviews and studies are influential and advance understandings as to the different forms of green nudges and their operation, they do not provide many insights into the wider public policy debate that surrounds such nudges. Specifically, how policies incorporate nudges when aiming to effect pro-environmental behavioral change and their effectiveness. Research in this area will improve understandings of how sustainability-oriented nudges operate and perform in the public policy context and help address wider concerns regarding the ethics of nudging (Schubert 2016). This is significant as there is a need to understand how sustainability nudges fit and interact with public policies to reduce unintended consequences and maximize effectiveness.

2.2 | The Role of XR in Changing Behavior

XR and its applications are a growing field of interest; in terms of public policy, most studies are concerned with the governance of such technology to ensure best practice and prevent misuses (e.g., Egliston et al. 2024; Hine et al. 2024), rather than on how XR can be used to enhance policy and decision making. In terms of sustainability, focus can range from smart manufacturing and supply chains (Cao et al. 2025; Kumar et al. 2025), industry in general (Cárdenas-Robledo et al. 2022), retail (Schnack et al. 2021; Xi and Hamari 2021), and plastics consumption (Strassmann et al. 2020). The majority of environmental/XR literature appears to be in the field of education and learning (e.g., Cosio et al. 2023; Guo et al. 2021; Newton et al. 2024); this includes development of applications for classroom use or educational tools aimed at the public (Cosio et al. 2023). Other studies have also considered environmental behavior in terms of awareness raising or communication strategies (Breves and Greussing 2021). These studies employ techniques such as the

creation of digital worlds (Breves and Greussing 2021; Chirico et al. 2021), often containing gameplay or narratives (Breves and Greussing 2021; Cosio et al. 2023) or overlapping artificial scenarios on top of the real world (AR) (Newton et al. 2024). The fields focused on education or technical applications demonstrate that despite research engaging in novel technologies, it still does not go far enough in providing innovative approaches to mitigate environmental issues at the individual level (Cosio et al. 2023).

The most comprehensive assessment of the use of VR for changing behavior is conducted by Scurati et al. (2021). They highlight that VR is unique in its ability to impact human behavior and decision making through its ability to display collective and long-term consequences, provide a journey in space and time, create a symbolic and concrete representation, present and evaluate future solutions, and in its ability to test future solutions with users. These possibilities will also be available for a vast number of users, having the potential to reach people across the world and so having the potential to generating a large impact. Scurati and colleagues' study focuses on VR, and so does not include other types of XR, such as AR (although it does differentiate between immersive and non-immersive technology), to build a framework for designing VR experiences for pro-environmental behavioral change. Their study, however, provides limited information on the policy implications of the current and potential uses of VR.

Another notable contribution in this area is the Behavioral Framework for immersive Technologies (BehaveFIT), which has been developed to map why and how immersive technologies can help to overcome the intention-behavior gap, including in the areas of health and environmental and social behavior (Wienrich et al. 2021). This framework is based on a review of research on psychological barriers for the intention-behavior gap and behavioral models explaining how behavioral interventions can overcome the gap. Four key features of immersive technologies are highlighted to explain why and how they can help bridge the gap. The study's findings have yet to be extended to discuss their implications for policy.

XR can be both the vehicle through which nudges occur and a platform that decision makers and users can employ to test nudges in certain scenarios and contexts (Scurati et al. 2021). By bringing together and broadening conceptual understandings related to pro-environmental nudges, public policy, and the role of XR, this study indicates the potential utility and practicalities involved with incorporating XR into sustainability-orientated nudge policies as well as avenues for policymakers, practitioners, and academics to further explore. More specifically, this study addresses how XR can be applied to inform policies that utilize nudges to encourage pro-environmental behavior. This includes reviewing what has already been done in this area and the effectiveness of such approaches, followed by identifying any gaps in understandings and applications where further research could be beneficial.

Firstly, a systematic review of the current knowledge and application of sustainability-oriented nudges in the public policy context is conducted to take stock and help provide clarity into the effectiveness of nudges. Next, we conduct an in-depth and targeted review of the literature covering XR and sustainability-based nudges to better understand the role of XR in relation to behavioral policies and sustainability behavior.

3 | Methodology

A systematic review was conducted between January and February 2023 to identify studies examining nudges in a sustainability context. Three sets of search terms—"nudg*" "sustainab*" "experiment," "nudg*" "environment*" "experiment," and "nudg*" "green" "experiment" were used to search the Web of Science database. These search terms were chosen to capture all studies dealing with sustainability-related behavior, even if they used terms such as "green" nudges. We also included the term "experiment" to screen out contributions that are purely theoretical in nature, as these do not contain empirical research. The term instead allowed for studies that conducted experiments either in a controlled environment or in a field setting to be incorporated. Figure 1 describes the screening process that took place. The papers returned were first screened to exclude those that were conference/meeting papers, review papers, or duplicates and then skimmed to remove any that were considered to be irrelevant to the current study (e.g., those focused on financial incentives or related to geophysics).

After screening, we were left with 84 papers. This was considered sufficient to conduct a review[1] while ensuring the feasibility of an in-depth manual analysis to be performed. While we did not set a limit on the publication year to avoid narrowing the search, the review period covered papers published between 2012 and 2022. These were sorted and organized based on five key features: the type of nudge being examined, the policy domain of the targeted behavior, the effectiveness of the nudge, if nudges were tested alone or in combination (with other nudges or policy tools), and if they were tested in a laboratory or field environment (Table 2). This initial sorting was done by one of the coauthors and then confirmed by a second. Where disagreements arose, a consultation between two or more of the coauthors was held to determine how to best sort the paper.

This initial organization of data was used to inform further coding. The papers were coded based on the variables they considered and experiment outcomes to look more deeply into the issue of nudge effectiveness. Researchers agreed on the coding procedure based on what the nudge sought to influence and what outcome they were trying to achieve. Following, nudges, as the independent variable being considered, can be said to work to influence what is known (have a cognitive effect), what is felt (affective), or to influence what is done (behavioral) (Cadario and Chandon 2020; Zhang et al. 2023). These categories were chosen due to their conceptual clarity, there are multiple categorizations of nudges and understandings as to their functioning so broad, and easily understandable categories were selected to ensure more reliable results. Further details about the type of nudge are included alongside this variable to provide richer understandings, again these are categorized broadly to aid clarity.

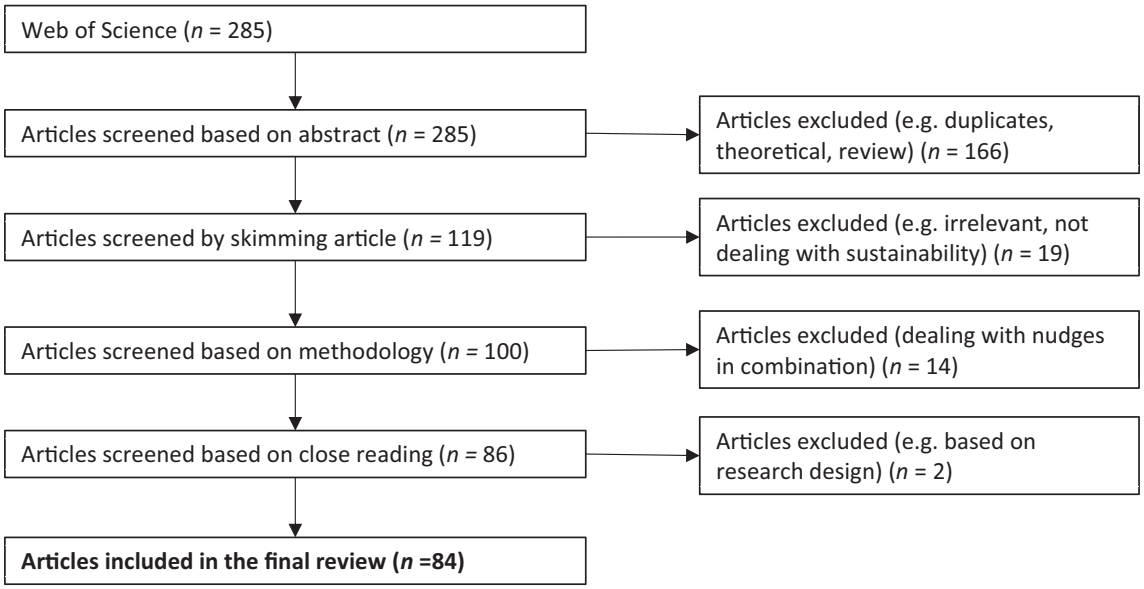

FIGURE 1 | Screening process.

TABLE 2 | Overview of entries returned for the review of nudges and sustainability.

Search terms	No. of entries returned	No. of papers post screening*
"nudg*" "sustainab*" "experiment"	64	20
"nudg*" "environment*" "experiment"	178	44
"nudg*" "green" "experiment"	43	20
Total	285	84

TABLE 3 | Overview of entries returned for the review of nudges, sustainability, and XR.

Search term	Number of papers returned	Papers after screening
"nudg*" "sustainab*" "virtual reality"	2	1
"nudg*" "environment*" "virtual reality"	9	1
"nudg*" "green" "virtual reality"	1	0
"nudg*" "sustainab*" "augmented reality"	1	0
"nudg*" "environment*" "augmented reality"	4	0
"nudg*" "green" "augmented reality"	1	0
Total	18	2

The outcome variable is coded according to the type of behavior being sought, behavioral or psychological change, and, again, more detail as to the specific behavior sought is also provided.

Three authors undertook the coding. The first policy area, "recycling and waste" was coded by two of the authors and then sent to a third author to ensure agreement. Nudges that were applied in combination were excluded from coding due to the increased uncertainty over which variable could be attributed to certain outcomes. Where papers considered multiple nudges individually, each nudge was coded separately. Any paper that could not be coded, for example if the outcome is unclear, were excluded. Once the authors agreed, the rest of the coding was carried out by a single author and then cross-checked by the other two. Areas of confusion and disagreement were marked and in the rare cases where consensus could not be reached regarding the relevance of the paper to this study, the paper was excluded.

Finally, a second, separate review targeting XR and nudges was also conducted in May 2023. The initial search of the Web of Science database, using the terms "nudg*" "sustainab*" "virtual reality," "nudg*" "environment*" "virtual reality," "nudg*" "green" "virtual reality," followed by a search using the terms "nudg*" "sustainab*" "augmented reality," "nudg*" "environment*" "augmented reality," "nudg*" "green" "augmented reality," returned only 18 papers, which were screened in the same manner as the first review (Table 3). To make sure we covered the literature, an exploratory search was also conducted to identify any papers that examined nudges and XR in the sustainable development context. This returned a further 9 papers (Table 4) making a total of 11 papers (Tables 3 and 4). A close reading of these papers was then conducted to understand the application

of the nudge and its relationship with XR (Table 6). An overview of the methodology is provided in Figure 2.

4 | Results

From the review on sustainability-oriented nudges, we found that the majority of papers considered resource use or food-related sustainability issues (16 papers each), with willingness to pay/donate (13 papers) and energy consumption (12 papers) also being popular topics of investigation. Sustainability-related nudges in relation to public transport had the least returns in our search, unearthing only two papers. In total, we coded 164 individual nudges; the majority of the nudges investigated were cognitive in nature (99 instances of cognitive nudges were recorded), followed by behavioral nudges (50). Very few papers investigated affective nudges; only 15 were found in our review. For full results, by nudge type, please see Supporting Information: Table X.

In terms of effectiveness, overall, all types of nudges were generally reported to have had a positive impact on the desired behavior, with behavior and affective-based nudges being reported to have the highest instances of positive impacts (70% and 60%, respectively) (see Table 5). Given the low number of affective nudges reported in the reviewed literature (15), and the issue of positive reporting bias, these numbers should be taken with caution. Cognitive nudges, the most researched category, were only found to be effective in just over half of the instances (54.5%).

Nudges seeking to influence how we behave, notably convenience enhancements, were reported to have a higher success rate (79%), which supports current literature on the effectiveness of default nudges (Ebeling and Lotz 2015; Ghesla et al. 2019; Pichert and Katsikopoulos 2008). Please see Supporting Information: Table Y for an overview of the effectiveness of nudges toward influencing behavior, which is broken down into different kinds of behavior. In terms of specific nudges and the behavior being influenced, convenience enhancements were most often reported to have a positive effect on increasing consumptive behavior (11 counts) while social norms were most frequently reported to have a positive impact on decreasing consumptive behavior (10 counts); but there were nearly as many instances (7 counts) where the social norm nudge had no effect or a negative impact. Convenience enhancements were also found to be more likely to increase the amount people are willing to pay/donate to sustainability causes (6 counts), followed by information (5 counts).

TABLE 4 | Papers returned via manual search.

Search area	Papers identified
Search for sustainability-based nudges and VR	4
Search for sustainability-based nudges and AR	4
Total	8

The review of XR literature revealed a paucity of studies investigating the application of XR for nudges in the domain of sustainability policy (10 papers). An overview of these papers can be found in Table 6. As with conventional nudge studies in this area, the majority of papers explored the application of XR to nudges in relation to food choice (6 papers).

The majority of studies consider the XR itself as the treatment, using it as the medium through which to convey the nudge, or using XR to test a particular type of nudge. Two studies were theory papers, these included a review paper to build a framework for immersive tech application and a theoretical discussion on how VR can reduce the difficulty of processing information. The papers employed a range of nudges, the majority focused on novel presentation of information or manipulating the environment through behavioral nudges.

This is reflected when we looked further into these papers to broadly discern which psychological limitation of sustainability they were seeking to address. Overlaps exist due to papers dealing with more than one nudge treatment or as the treatments were aimed at tackling several issues. Most of the papers (6) employed nudges aimed at simplifying the complexities and uncertainties involved with sustainability issues. Papers exploring how nudges could be used to manipulate the environment and challenge status quo biases (5 papers) were also relatively prominent. Less explored are how XR can utilize nudges to overcome personal interests in favor of the communities and in making long-term impacts apparent (3 papers each). Of interest is that none of the papers in our review focused on overcoming the socially based psychological barriers to sustainability

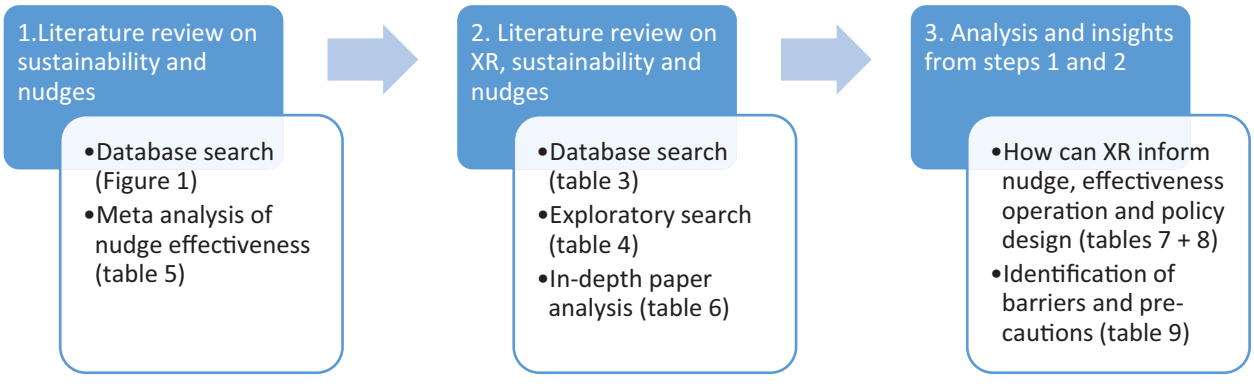

FIGURE 2 | An overview of the methodology.

TABLE 5 | Overview of results of nudge effectiveness.

Independent variable	Positive effect (%)	Negative effect (%)	No effect (%)	Total (count)
Results by nudge variable				
Cognitive				
Framing	41.7	33.3	25	12
Social norms	55.9	14.7	29.4	34
Information	55.3	14.9	29.8	47
Total cognitive	**54.5**	**16.2**	**29.3**	**99**
Behavior				
Priming	40	13.3	46.7	15
Convenience enhancements	79.3	10.3	10.3	29
Total behavior	**70**	**10**	**20**	**50**
Affective				
Morality calls	71.4	14	14	7
Total affective	**60**	**13**	**26.7**	**15**
Results by behavior				
Decreasing consumption	68.3	7.3	24.3	41
Increasing consumption	50	16.7	33.3	30
Different consumption	61.1	11.1	27.8	18
WTP	52.3	18.2	29.5	44
Intention	60	30	10	10

(threat of social status or group pressure). A table is provided in Supporting Information: Table Z listing the papers in each category.

5 | Discussion

Overall, our findings underscore the evolving landscape of behavioral policy tools, especially nudges, in the context of sustainability and the emergent role of XR technologies. Looking across the three categories of nudges, both the review of sustainability-oriented nudge research and the review of XR studies reveal a similar pattern. For both bodies of literature, the most popular research subjects are cognitive nudges, followed by behavior; interest then drops significantly for affective nudges.

While our nudge review is consistent with previous nudge-related reviews (e.g., Byerly et al. 2018; Wee et al. 2021) in finding that cognitive nudges are the most researched, we found them to be the least consistent in producing effective change (54.5%). The mixed success of cognitive nudges, particularly in the sustainability policy domain, suggests that simply increasing information or reframing messages is often insufficient to overcome ingrained psychological barriers to sustainable action (Korteling et al. 2023; Sunstein 2017). Results from the nudge review demonstrate that there is substantial room to enhance the effectiveness of cognitive nudges for the sustainability policy domain. This highlights the need for greater sophistication in designing and deploying nudges, ensuring that the targeted heuristic or bias is appropriately matched to the policy context and intended outcome.

Equally, the XR review suggests that its application has potential for enhancing the effectiveness of cognitive nudges and highlights areas for future research to capitalize on the potential of XR to extend the effectiveness of nudges for policy formulation, testing, and implementation. Important here, and a factor that may explain the inconsistencies found with the effectiveness of cognitive nudges, is the issue of cognitive overload. XR environments, while engaging, have been found to overwhelm students in educational settings with too much information or overly complex interactions, hindering rather than helping the learning process (Crogman et al. 2025). The user interface and experience design need careful consideration to ensure that learners can navigate and utilize XR environments effectively without becoming distracted or confused.

Behavioral nudges, such as convenience enhancements, were found to be the most effective (70%); this is in line with the general literature finding for the effectiveness of nudges such as defaults (e.g., Liebe et al. 2021; Radnitz et al. 2023). Social norm-based nudges were found to achieve mixed success in our review, with just over half being found to be effective. This supports

TABLE 6 | Overview of papers investigating the application of XR for nudges in terms of sustainability.

Paper	Nudge	Overview/summary	Purpose of XR	Effective/ outcome
Buljat (2022)	AR-based green artifact to communicate the problem of plastic pollution [Affective]	Social connection and empathy toward interactive and "real" AR will change behavior. AR of endangered animals suffering from plastic on mobile phone/ Focus group discussions suggests that this can potentially enhance green interventions, especially if they are immersive, interactive, accessible to a wide audience, enable social interactions, encourage users to take concrete actions, and are launched at the right time and place so that users can easily consume AR content	As the nudge (design and implementation explored with target group but not experimented)	Potential/ unknown or uncertain
Todd et al. (2011)	Color of shopping trolley handle [Cognitive (information)]	Ecological rationality, emphasizes the importance of the environmental information structures and how they fit to mental decision structures—simplify and amalgamate information	As the nudge (not experimented)	N/A
Ahn et al. (2015)	Food color codes in supermarkets—provides info when selected [Cognitive (information) Behavioral (visibility enhancement)]	Aid locating and selection of better food choices when shopping. Elements of consideration when designing the application were explored and evaluated from a video demonstration to online and in person participants, such as speed and usability	As the nudge (experimented)	Yes (in reducing time taken to find and choose healthier options)/ unknown or uncertain
Plechatá et al. (2024)	Impact messages linked to personal food choice—loss/ gain framings to increase efficacy beliefs. Shows future impact of choice made [Cognitive (framing, feedback)]	Experiential vs. informational based VR re pro-environmental behavior VR experience group consumed less meat in real life buffet experiment than VR information group. Important to show people that their behavior can make a difference	As the nudge (experimented)	Yes/decrease consumption
Blom et al. (2021)	Time pressure on nudge effectiveness Immersive virtual supermarket [Behavioral (visibility enhancement)]	Nudging increased no. of healthy food choices, even on the non-nudged healthier products Time pressure did not make a difference Effectiveness of nudge irrespective of impulsive or reflective decision making	To test nudge (experimented)	Yes/different consumption and increase consumption (or N/A)

(Continues)

TABLE 6 | (Continued)

Paper	Nudge	Overview/summary	Purpose of XR	Effective/ outcome
Melendrez-Ruiz et al. (2021)	Virtual supermarket, eye tracking [Behavioral (visibility enhancement, convenience enhancement)]	Position of groceries Pulses considered differently on each shelf depending on composition and organization of the shelf	To test nudge (experimented)	Yes (in consumer gaze behavior)/ uncertain (or N/A)
Scurati et al. (2021)		Review and framework to develop VR experience (considering aspects such as emotional, rational, immersive, and interactive) to support sustainable behavior change	Theme for review (not experimented)	N/A
Wan et al. (2022)	Color contrast between dish and table Position of dish in relation to the diner [Behavioral (convenience and visibility)]	Participants ate less meat when it was presented on a red table as dishes looked less attractive and green vegetable dishes more attractive Proximity made no difference	To test nudge (experimented)	Yes/decrease consumption (or N/A)
Laukkanen et al. (2022)	Cognitive role of VR, reducing the cost and difficulty of information processing Ability to induce empathy [Cognitive (information, framing) Affective (morality calls)]	Sensory marketing and the role of VR technology for sustainable consumption Theoretical discussion	Theory (not experimented)	N/A
Ong and Araral (2022)	Virtual simulation to mimic household conditions (water consumption) [Cognitive (framing, social norms)]	Serious game relating to drought risk. Both message framings were effective at reducing water consumption Participants were not found to have a greater consideration of future consequences or a stronger sense of environmental identity—problem of psychological distance regarding climate change effects Water rationing simulation reduced overall water consumption	As the nudge and to test nudge (experimented)	Yes (when used to test nudge), but No (when XR is used as the nudge)

TABLE 7 | Areas where XR is shown to be beneficial/strong.

Context factors	Description	XR dimension	Explanation
Location and timeframe	Nudge can be dependent on location where the behavior occurs (e.g., public vs. private), the time of day, etc. or the nudge itself can be the physical placement/manipulation of the environment There are many distractions in real life that can limit the effectiveness of nudging Different nudges can have different impacts in specific environments	Immersive nature	Ability to immerse participants in (almost) any geography/time period. Ability to manipulate environment Closest way of testing real-world conditions

Psychological sustainability characteristics	Nudges used	Description	XR dimension	Explanation/utility
Complexity and uncertainty	Cognitive (information) Behavior (convenience enhancements)	Individuals differ in their need for cognition—some deliberate more Too much information, need to simplify so people can understand key messages	Rational Immersive nature	Virtual reality can reduce the total cost and difficulty of information processing. Richer mediums of communication can lead to a better understanding of messages and tasks with greater ambiguity. VR has the potential to increase the depth of information processing. Can shape how we feel about complex issues and problems, their causes and consequences.
Experiential vagueness	Cognitive (feedback)	Psychological distance is a subjective perception of how far away an object or event is from the here and now—when, where, to whom, and whether an event occurs. When we do not directly experience something, we perceive such an event as psychologically distant. We do not always see the consequences of our actions or they may not be easily observable	Immersive nature	Allows the manipulation of space and time to show cause–effect relationships. Can reduce "abstractness" of phenomenon

(Continues)

TABLE 7 | (Continued)

Psychological sustainability characteristics	Nudges used	Description	XR dimension	Explanation/utility
Long-term effects and future risks	Cognitive (reminders, framing)	People are loss averse and consider losing something twice as painful as the happiness experienced from gaining the same thing. As a result, inertia occurs, which causes people to have strong desires to stick with their possessions and holdings, even though there might be more beneficial alternatives. Without visceral reactions to many environmental risks (if they are considered "natural" and well known) people may not be motivated to take corrective or evasive actions.	Emotional Rational Immersive simulation Perception of benefits Sense of time and space	Can show cause and effect relationships, both positive (so makes benefits more obvious) or negative. Can implement loss and gain scenarios depending on actions. People can experience events Can visualize invisible impacts/phenomenon
Personal vs. community interest	Cognitive (feedback)	Self-efficacy can give consumers an internal incentive to make decisions, and increase decision-making confidence and satisfaction.	Immersive Interaction (game play) Manipulation of self-perception/ability	Messages can increase respondent's belief in their ability to respond effectively Can "show" people that their behavior can make a difference—provide feedback on their actions
	Affective Cognitive	Emotional associations can trigger a sense of empathy and social connection with others in the community which can strongly shape our actions	Immersive Emotional Interactivity Sense of others	Computer has certain physical or psychological characteristics, it can trigger the same instincts as humans and create relationships. Thus, if the object AR is interactive and appears sufficiently real, a user may feel empathy and a social connection to it. VR technologies enable consumers to embody others and be placed in other cultural or socioeconomic surroundings—therefore, VR has also been aptly referred to as the "empathy machine" Increased spatial presence can elicit higher emotions

(Continues)

TABLE 7 | (Continued)

Psychological sustainability characteristics	Nudges used	Description	XR dimension	Explanation/utility
Threat of status quo	Behavior (visibility enhancement, size)	Individuals assess the likelihood of risks by considering how easily relevant examples come to mind. Systematic biases originate from accessibility when elements of the decision environment make some mental contents, instead of others, come to mind more easily and spontaneously. Accessibility is a continuum of the ease with which information is recalled rather than a dichotomy (Higgins 1996; Kahneman 2002). Determinants of the degree of accessibility of mental contents include availability, confirmation, anchoring and halo, bureauphobia, misconceptions of probabilities, and recall. Availability is the tendency to estimate the numerosity of a class or the chance of an event by the ease with which instances are available from memory. However, said instances tend to be systematically biased by such factors as familiarity or saliency, ease of imaginability, and illusory correlation of events. When availability is likely to generate predictably biased assessments, "decisions may be improved if judgments can be nudged back in the direction of true probabilities"	Motivation to repeat behavior Information design Rational behavior Game play	Motivating repetitions by modified environments and gamification elements (e.g., a beach instead of the hospital), and increasing the feeling of relatedness by virtual companions are examples of approaching the distance to persistence by immersive technologies

TABLE 8 | Areas where XR has potential.

Context factors	Description	XR dimension	Explanation/utility
Messengers	Who gives the message can be influential	Perception of others	Can create different messengers
Personal attributes	Attributes of the participant can make them more or less susceptible to nudges/certain factors To enhance the effectiveness of the nudging, the characteristics of the targeted group are necessary to be studied and considered in order to determine the suitable nudging for the targeted group	Manipulation of context/scenarios Perception of self Testing of decision making styles	Can tailor make experience to suit participant—insights into how to match nudges with different decision making styles, influence of preexisting preferences, etc.
Combinations of tools/nudges	One nudging alone may not be sufficient to encourage changes among individuals. Instead, multiple concurrent nudging interventions may be needed. Nudges may be more effective when supported with other instruments	Immersive Manipulative	Ability to create and manipulate multiple scenarios and contexts in a relatively short space of time to test multiple combinations of policy tools
Impact over time	May become "immune" to nudge (Michalek et al. 2016)	Serious game play Interaction Eye tracking Sense of space and time	Can require repetitive actions Can analyze over a period of time (game play) to test stickiness of nudge Can use tracking software to see what draws users attention and how it changes over time
Unintended consequences	Indirect rebound effect—"savings" etc. may be offset by undesirable behavior in other domains (Michalek et al. 2016)	Immersive Game play	Allows exploration of range of actions and activities in response to nudges
Bounded rationality (systems thinking)	Exploration of type 1 and type 2 systems thinking—are nudges more impactful when they only target type 1? What happens when type 2 is inhibited etc.	Immersion, control	Allows for different scenarios to be run quickly, can easily apply time pressure/cognitive fatigue exercises to target different systems
Ethics	Transparency of nudge: may evoke psychological reactance, leading perhaps to an intentional countervailing action that is undertaken in an attempt to preserve one's own "perceived freedom of choice" in response to a restrictive regulation Some studies suggest transparency makes nudge more impactful	Immersion, salience, eye tracking, control	Allows for interaction with nudge on different levels. Can track when individuals' awareness of nudges/how the transparency of nudges can be revealed and associated impact on behavior.

(Continues)

TABLE 8 | (Continued)

Context factors	Description	XR dimension	Explanation/utility
Changes in physical environment	Salience	Manipulation, immersion	Allows environment to be changed easily and relatively cheaply New environments can be created and tested

Psychological sustainability characteristic	Potential nudges	Description	XR dimension	Explanation/utility
Threat of social status	Affective (morality calls) Cognitive (social norms)	The desire for status, to follow norms or to have a positive self-image. The nudge rewards "doing the right thing" by providing the individual with moral (dis) utility. Moral nudges do not rely on bounded rationality or inattention; instead, they work through direct effects on utility	Game play Sense of time and space	Allows individuals to witness the impact/consequences of their actions
Group pressure	Cognitive (social norms, framing)	Outcomes obtained by others provide a salient reference point for relative comparisons Don't want to be left out etc.	Immersion, sense of self, sense of others Game play Social interaction	Can experiment with the impact of social norms beyond message framing—through ability to manipulate other characters etc. Could be particularly useful when considering the boomerang effect Can also interact with different users through XR

Policy	Description	XR dimension	Explanation/utility
Gauge public support	Can assess the acceptability/ popularity of proposals	Interactive Feedback	Allows immersive trials and interactions between different users and policymakers
Cost comparison	Can get a better idea of what nudges are required and allows more accurate comparison with conventional policy tools regarding the cost and resources required	Game play	Can run scenarios comparing different policy tools

TABLE 9 | Areas where XR may not be appropriate.

Context factors	Description	Explanation/utility
Situations where strong/deep seated feelings are involved	May not be appropriate where there are heated social debates, especially those involving politics or religion	Risk of distress
Where sensitive information is involved	Personal data protection	Risk of hacking
Where vulnerable groups are involved	Maybe more sensitive to certain topics or depictions	Risk of distress
Nudge design basis	**Description**	**Explanation/utility**
Ethics	Need to preserve choice and respect mental integrity of individuals. The XR experience must be designed to allow users to exercise their free will	"Too" realistic, may cause distress May feel coerced/overly manipulated
Target of nudge	Need to ensure that the nudge is morally justified	

literature cautioning of the "boomerang" effect, which is particularly prevalent with nudges utilizing social norms (Zorell 2020). Social norm-based nudges are largely absent from the XR literature, which is unfortunate as the use of such technology may help to unpack the phenomena.

The limited representation of affective nudges in both the general sustainability review and XR literature suggests a significant gap in harnessing emotional and empathetic engagement for pro-environmental behavior change. Given that affective experiences, such as empathy toward affected species or future generations, are powerful motivators of behavior (Laukkanen et al. 2022; Scurati et al. 2021), XR's capacity to create immersive, emotionally salient scenarios could offer a unique pathway to amplify these effects. For instance, XR can make distant or abstract sustainability challenges tangible, reduce psychological distance, and foster a sense of agency and personal relevance, as demonstrated in studies using VR to visualize future impacts of present-day choices (Plechatá et al. 2024).

The XR review finds a total of 10 papers where 8 tested the application of XR for sustainability nudges (Table 6), out of which 3 experimented with cognitive nudges, and 4 experimented with behavioral nudges, and all found a positive outcome in at least one of the experiments conducted in the study. In terms of empirical evidence of the effectiveness of XR as nudges, our review reveals that this is limited to Blom et al. (2021) and Plechatá et al. (2024). This means that there is substantial room for further research to develop more empirical evidence to better inform policymakers in their decisions of whether and how to incorporate XR as nudges.

Our review also goes further in providing insights into which nudges may be more effective in achieving certain types of behavior. Notably, social norms are likely to be more effective at decreasing consumption than other nudges. It was also found that convenience enhancements may be more effective at increasing an individual's willingness to pay. Such findings allow policymakers to better match nudge tools to desired outcomes.

Overall, research on affective nudges for both bodies of literature is severely limited and has the greatest potential for future research. Revealed by the few XR studies that utilize affective-oriented nudges, one potential aspect for future research could relate to the use of XR to induce empathy to encourage sustainability decision making. We can also see that XR has not yet explored the application of nudges to counteract perceived threats to social status or group pressures that impede sustainability decisions. Cognitive nudges, in particular those that utilize social norms, are likely to be particularly effective in addressing these barriers and so could be further explored through XR. The potential for XR to facilitate and support social interactions also means it could act as a medium through which the social influences, biases, and barriers to sustainability decisions can be explored and leveraged.

5.1 | Application of XR for Sustainability Nudges and Policymaking

While an emerging phenomenon, our qualitative review has shown that XR is an exciting avenue to explore the application and functioning of nudges in the field of sustainability (Table 7). Studies in this area have shown how the virtual environment can be manipulated to overcome biases and confront psychological barriers to sustainability or experimented with novel ways of presenting information, but there is huge potential for the technology to inform our understandings further. XR provides a means to overcome methodological or study design barriers as nudges can be explored in different settings or circumstances in a relatively accessible and quick manner. This will allow nudges that yield more ambiguous results in the physical environment, such as social norms and the boomerang effect or the nuances involved with framing, to be systematically dismantled and tested across a range of settings and circumstances.

The uses and gaps of nudging within XR are mapped out in detail based on the reviews and broader literature (Table 7). Literature on behavioral economics regarding the functioning of nudges, especially literature that considers nudge effectiveness (e.g., Battaglio Jr et al. 2019; Congiu and Moscati 2021; Michalek et al. 2016; Sunstein 2017; Vlaev et al. 2016; Weijers et al. 2021) as well as literature on psychology and cognitive biases (e.g., Battaglio Jr et al. 2019, Korteling et al. 2023; Tversky and Kahneman 1974), are drawn on to provide insights into the current and future relationship between nudges for sustainability, XR, and policies. From this, it is hypothesized where there is potential for XR to be used in this area (Table 8), as well as situations where it may not be appropriate (Table 9).

Better understandings of human decision making can be gained through using XR to create environments and scenarios that hinder or inhibit mental decision making processes (De Ridder et al. 2022; Hansen and Jespersen 2013; Marchiori et al. 2017). Insights into how different people or groups make decisions in different areas means nudges can be better selected or personalized, tailoring nudge interventions to individual decision-making styles, cultural backgrounds, or demographic groups (Peer et al. 2020), which is increasingly recognized as a critical factor for nudge effectiveness (Bryan et al. 2021; Dolgopolova et al. 2021). This will ensure policymakers are able to select the correct nudge for the group being targeted by the policy and ensuring the best chance for the nudge to be effective (Sunstein 2017).

From a methodological perspective, XR environments offer notable advantages for both research and policy design. They enable rapid prototyping and testing of a range of nudges under controlled yet realistic conditions, overcoming the logistical and ethical limitations of field experiments (Scurati et al. 2021). This allows politicians to test how the public may receive certain policy tool kits, garner feedback regarding public acceptance of the policy mix, and be aware of any unintended outcomes of the potential implementation of policies involving nudges. This is especially important when involving policies that employ behavioral economics due to the risk of people feeling manipulated. It can also ensure the most cost-effective measures are employed by providing realistic accounts of people's behavior under certain policy mixes. XR can also facilitate the exploration of combinatorial effects—testing how different nudges interact with each other or with traditional policy instruments such as taxes or regulations (Carlsson et al. 2021).

Ethics are particularly important to be aware of and take into consideration when dealing with both nudges and XR. As with all nudges, such tools should not be used where there is the potential for outcomes that are adverse to the individual or certain groups or where there may be strong religious or political sentiments attached to an issue (Table 9). The addition of XR inevitably involves privacy and concerns over hacking. Steps must be taken to ensure proper data management and protection. Additionally, the potential for XR to provide realistic and immersive scenarios must be treated with care to ensure that participants do not suffer any physiological or emotional distress. Research into XR ethics and the development of policies and guidelines for best practice are being rapidly developed by both researchers and practitioners (Cox et al. 2025) and, given the public dimension and risk of manipulation or potential for emotional distress, are particularly relevant here so should be referred to when engaging with such technology.

Given the paucity of empirical studies on XR-enabled nudges for sustainability, especially those leveraging affective and social norm-based interventions, there is a clear research agenda for future work. XR provides a promising platform for exploring how nudges can be designed, personalized, and implemented at scale, but more robust evidence is needed to inform best practices for policymakers. Collaboration between behavioral scientists, technologists, and policymakers will be crucial to unlock the full potential of these emerging approaches.

6 | Conclusions

This review has provided a comprehensive synthesis of the current state of research on sustainability-oriented nudges and the emergent application of XR technologies as vehicles for behavioral policy tools. Our findings highlight that while behavioral nudges, such as convenience enhancements, tend to be the most effective, cognitive nudges remain the focus of most research, despite their relatively modest success rates. The limited exploration of affective nudges provides significant opportunity for future inquiry, particularly given XR's capacity for immersive, emotionally engaging experiences.

XR technologies offer significant methodological and practical advantages for both researching and implementing nudges. Their ability to simulate real-world environments, manipulate contextual variables, and provide personalized, interactive experiences positions them as powerful tools for both policy experimentation and public engagement. XR can facilitate the testing and refinement of nudge interventions, support the ethical evaluation of behavioral policies, and enhance public understanding and acceptance of sustainability initiatives.

To maximize the societal benefits of these approaches, future research should focus on empirically testing the effectiveness of different types of nudges within XR environments, exploring the role of affective and social norm interventions, and developing best practice frameworks for ethical and equitable implementation. Caution is still required when developing and deploying XR-based nudging in policy practice. Policymakers and researchers must pay attention to ethical considerations, ensure inclusivity, and safeguard against potential adverse impacts. Additionally, the cost, accessibility, and digital literacy required for XR adoption remain practical barriers, particularly in diverse policy contexts.

This study sheds light on the several dimensions of behavioral policy tools and technology in relation to encouraging sustainability behavior. It is, however, limited by the sample size. As mentioned, few papers investigating affective nudges were returned in the initial review; for the XR review, a manual search had to be conducted to compensate for the limited number of papers recovered. These deficits, however, do highlight important gaps where further research is required. The paucity of XR

papers dealing with nudges and sustainability-oriented behavior is unsurprising given the relatively novel nature of the technology. Nonetheless, our findings provide insights into both the effectiveness of nudges in the field of sustainability, allowing the potential to better match nudges with the desired behavior being sought, and the appropriate application of XR to this field.

Endnotes

[1] The number of papers reviewed in similar relevant studies in this body of literature are 82 (Grilli and Curtis 2021), 72 (Byerly et al. 2018), and 37 (Wee et al. 2021).

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** Supplementary materials.