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When Pixels Turn Green: The role of virtual reality in the fight against climate change

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ABSTRACT

Nature has found a way to make itself heard. Disasters like floods, heatwaves, and the extinction of flora and wildlife should serve as a wake-up call for humanity to act more sustainable in the climate crisis. However, far-off occurrences in both space and time, along with disconnectedness from nature, appear to preclude effective responses. This review explores how Virtual Reality (VR) technology can be used to circumvent those limitations as a vital method to inspiring people. VR has the ability to enhance reality by allowing users to see their environmental impact, immerse themselves in different worlds, or change the passage of time. On the other hand, a paucity of longitudinal designs and energy-intensive online data storage may undermine its usefulness in fighting climate change. This narrative review therefore examines relevant approaches using VR, including self-efficacy and immersion, their impact on individuals, and potential implications for society.

Keywords: Virtual Reality, Environmental Communication, Embodied Experience, Climate Change, Connectedness with Nature

"The perennial cry to "Save Earth" is odd. Planet Earth survives massive asteroid strikes – it'll survive anything we throw at it. But Life on Earth will not." (deGrasse Tyson, 2018). Reports about flood disasters, wildfires, and increasing spreads of deadly diseases, are piling up in the news. Sadly enough, the unemotional nature with which people often are confronted with such is reminiscent of listening to the weather forecast. Strategies are needed that circumvent natural defense mechanisms of the human brain with which we cradle ourselves at the cost of our home planet. This review critically questions whether *Virtual Reality (VR)* technology can support the fight against climate change. VR can allow glimpses into the future to discover impacts on the environment by offering vivid, dangerous, or simply impossible scenarios. The current work reviews empirical studies that used VR setups to estimate whether VR can enhance the motivation for and the execution of pro-environmental behavior. The outcomes will be discussed in the light of relevant theories to evaluate their usefulness and implications for future research. Finally, drawbacks and blind spots of VR technology will be discussed to enhance the sustainability and safety of the method.

1. Part One: Open Your Eyes

Humanity's interference with climate is flooding families out of their houses, acidifying the oceans, and is destroying essential forests. For the longest time, governments silently observed how the global West is polluting the atmosphere, without having to carry the final consequences. Lower levels of income and infrastructural disadvantages due to dark histories of colonialism provide less chances for vulnerable populations in the Global South to protect themselves against the tremendous consequences of climate change (Ngcamu, 2023). Nonetheless, impactful behavioral and lifestyle changes are still missing as one passive climate discussion moves on to the next. After the Intergovernmental Panel on Climate (IPCC) revealed that human activity is responsible for the majority of greenhouse gas emissions, human inactivity cannot be the answer (Calvin et al., 2023). Albeit an implementation of economic and governmental changes is pivotal for the reduction of large-scale impacts on the climate (Nielsen et al., 2020), individual behaviors must be considered as one dimension through which we can collectively contribute to reaching the goal of limiting global warming to 1.5 degrees Celsius (IPCC et al., 2018). A lack of engagement, knowledge, and imagination, impedes international energy agreements (Huang et al., 2021) and reduces public pressure that can motivate the prioritization of environmental protective measurements (Agnone, 2007).

1.1 How to Push Pro-Environmental Action?

Perceiving the immediate character of the problems at hand drives motivations to address pro-environmental choices (Raja & Carrico, 2021). Sheppard (2012) further identified three major principles to foster engagement with climate change. He proposed the use of localized instead of geographically distant scenarios, visualizations instead of abstract graphs, and the connection between past and

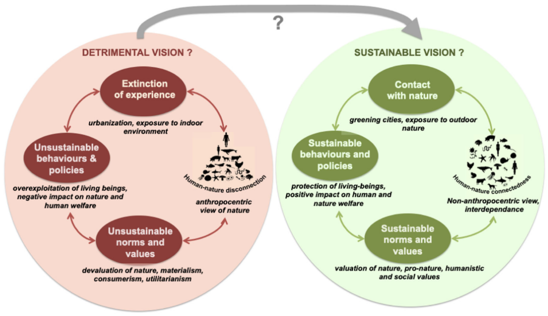

Figure 1: Effects of Detrimental and Sustainable Visions of Human-Nature Relationships. Figure depicts Barragan-Jason et al.'s (2022) illustrated reflection on the consequence of a worldview in which humans are separated from nature. A vicious circle is initiated on the left (detrimental vision) side impacting individual and societal levels.

future. In reality, urbanization is increasing globally, which is expected to separate 55 to 68% of the world's population from living in nature-rich environments by 2050 (The World's Cities in 2018). Figure 1 (adapted from Barragan-Jason et al., 2022) underlines the detachment between humans and nature. The rigid dualist notion of this separation fuels a detrimental vision ultimately impeding sustainable developments (Braidotti, 2019; Giaccardi et al., 2024). Western ontologies reinforced this narrative by ignoring alternative, indigenous human-nature relations (Dema et al., 2019). One rather counterintuitive method of moving towards an interconnected, non-anthropocentric view is the use of virtual environments.

1.2 What 'Virtual' Adds to Reality

VR encompasses computer-generated 3D-environments in which individuals or groups can interact. Besides a field of view covering 360 degrees as perceived through head-mounted displays (HMD), VR comes with accurate stereoscopic sound. These, and other optional features, e.g., haptic feedback in form of vibrating controls, create immersive, multisensory, thus create vivid experiences (Fox et al., 2009). People frequently claim to forget about the experience's mediated nature, which is known as *presence* (feeling of *being there*; Markowitz et al., 2018). Albeit the impact of VR on individuals cannot be fully explained by the level of realism (e.g., Thoma et al., 2023; see also Gisbergen et al., 2019), it has the potential to meet Sheppard's (2012) engagement principles by providing localized experiences at chosen moments in time.

1.3 Ways in Which VR Affects Individuals

Rather than just provoking imagination, VR can alter bodily perceptions. Participants who experienced a virtual earthquake scenario dropped to their knees to hide underneath a virtual table (Bailenson, 2018). In a simulation to overcome vertigo (*Richie's Plank Experience*), people lose balance when standing on a plank that exceeds a skyscraper without safety precautions. They breath heavily, vocalize fear, show increased heartrate levels, and eventually, are likely to fall over while jumping off the fictitious plank (Aspiotis et al., 2022).

VR exhibits memory benefits in comparison to traditional media. Memories are reconstructed (i.e., autobiographical recall) for which the brain uses spatially and temporally bound information (Spreng et al., 2009). This process can elicit strong emotions, enable self-projection, and influence them in the future, which is referred to as prospection. When presenting a two- dimensional video depicting a motorcycle ride vs. a 360-degree VR experience of the same, participants show significantly greater memory retrieval in the VR condition two days after exposure (Schöne et al., 2019). The authors concluded these findings to evidence an integration of the experience into the autobiographical associative network, and thus, a memory benefit for encoding sensory stimuli in VR. Adding other sensory information to the experience (e.g., scent) can enhance recognition memory even further (Tortell et al., 2007). Virtual experiences, therefore, appear to impact individuals in a way that resembles real-life processing.

2. Part Two: VR for Change

One goal of VR applications used in social or environmental psychology is to heighten environmental literacy (see Fauville et al., 2020). This encompasses the dimensions: *knowledge* (about physical and economical systems), *competencies* (identifying, analyzing, evaluating), *dispositions*, and *environmentally responsible behavior*. Investigating all of those dimensions is crucial for the implementation of pro-environmental behaviors. In the here reported narrative review, I therefore focused on the disposition and behavioral dimension to highlight how VR is implemented to enhance pro-environmental self-efficacy, attitudes, motivation, and behaviors. A list of the reviewed literature, including sample and effect sizes, can be found in Appendix A.

2.1 Self-Efficacy and Pro-Environmental Outcomes

Work suggests that one's perceptions of self-efficacy cannot be changed through cognitive processes (Hornsey et al., 2021). Rather, to heighten environmental self-efficacy ("I am able to exert certain behaviors."), and response efficacy ("My actions have an impact!"), emotionally engaging experiences are needed which are assumed to drive pro- environmental behaviors (Bandura, 1977; Van Valkengoed & Steg, 2019). Putting this to test, Ahn and colleagues (2014) compared cutting a tree in a virtual environment with watching the same in video format. Participants in the VR condition used less napkins directly after the study and reported greater perceptions of an internal locus of control, which is associated with higher levels of self-efficacy (Bandura, 1977). No changes in self-reported toilet paper consumption were found after one week. As the food industry is responsible for up to 35% of the annual greenhouse gas emissions, including land use, agricultural production, and transport (Crippa et al., 2021), related work tested pop-up messages in virtual supermarkets. Learning about the impacts of their decisions, participants in the virtual supermarket shopped more local and avoided products containing palm oil, which was explained by perceived *personal response efficacy* (Meijers et al., 2022). A follow-up study disentangled response and self-efficacy by showing that only self-efficacy significantly explained the relationship between impact messages and behavioral intentions (Plechatá et al., 2022).

VR can be used to increase self-efficacy in creative ways. One method is to present the passage of time in time machine scenarios. A recent work used this to illuminate the impact of shopping plastic-packed products (Sungur et al., 2022). After selecting items in a shopping simulation, participants were sent into the future where piles of plastic corresponded to the selected items. A subsequent training to change shopping behavior increased behavioral intentions to act more sustainable at the follow-up measurement. Interviews with 6 to 13 years old children, who participated in a virtual supermarket scenario, revealed that personal environmental impacts and negative reactions to unsustainable food choices begin around the age of ten (Smit et al., 2021). Given that food preferences are learned throughout childhood (Berridge, 1996), this finding may drive the development of ecological guilt leading to pro- environmental behaviors (Moore & Yang, 2019).

2.2 How Immersive is Enough?

How immersive an application is considered to be depends on the quality of the hardware that is used. Usually, the more sensory stimuli, the higher the immersion and perceived presence. This leads people to perceive the experience as continuous, personal, and immediate (Cummings & Bailenson, 2016). An investigation on energy consumption revealed that participants in immersive scenarios used colder water as compared to a non-vivid condition (Bailey et al., 2014). Similarly, immersive emotional video material, such as VR vs. desktop videos, resulted in higher selections of a vegetarian pizza option over meat in the laboratory (Fonseca & Kraus, 2016). Meijers et al. (2023) presented video material of a wildfire in VR (vs. desktop, vs. control: written text) with higher *feelings* of immersion elevating participants' sense of presence including reports of bodily feelings. Although, VR and desktop video condition showed no differences in how they affected pro-environmental behavior, higher immersion was accompanied by higher risk perception and intentions for reducing meat and dairy consumption. In addition, the authors showed that higher perceived risk and emotional responses explained increased NGO donations.

In conclusion, the reported findings underline previous inconclusive reports about how much immersion is needed to stimulate feelings of immersion and behaviors in general, which points to an interaction between individual differences and medium (see Cummings & Bailenson, 2016).

2.3 Changing Your Self Can Change Behaviour

Designing VR for change can put people in the shoes of another person, the hooves of another animal, or the trunk of another plant. This technique is called *embodiment illusion* (Slater, 2017) and was shown to increase the connectedness with the embodied entity.

Participants that embodied a virtual cow (but not coral) reported greater self-nature overlap on a pictorial scale as compared to a control video condition (Ahn et al., 2016). Hence, breaching the dissimilarity between mental representations (schemas) of a coral and a human may be more effortful as compared to a cow. Even though nature connectedness is supposed to influence behavior, self-reported intentions to reduce meat consumption did not reach significant levels. Similarly, participants who embodied a coral or scuba diver indicated more positive attitudes towards the environment after the experience, acknowledging the disruptive nature of humans (Markowitz et al., 2018). Interestingly, there was no difference between the two embodiment conditions. The sense of connectedness between a person and the avatar rather than the quality of the avatar could thus lead to positive pro-environmental outcomes. This points to the importance of a felt sense of agency (or self-efficacy) in virtual environments. To strengthen the illusion, both studies included haptic feedback in the form of touching the participant's body concurrently in the real and virtual environment to strengthen the illusion. In contrast, Spangenberger et al. (2022) embodied participants as rainforest tree without the inclusion of haptic feedback. Higher levels of perceived immersion led to higher nature connectedness. However, this was reported irrespective of the condition. Only reflections on the relationship between humanity and nature surfaced after the VR but not video condition, indicating higher levels of closeness to the subject when embodying the tree. Experiencing an overlap between the self and another entity has been shown to induce closeness and empathy, leading to subsequent positive outcomes. Therefore, this mechanism may be pivotal to enhance the feeling nature connectedness, which, in turn, can positively influence pro-environmental intentions (Ahn et al., 2016; Spangenberger et al., 2022).

3. Discussion: VR for Change

Research using VR as method covers a variety of climate change related contents wherefore it can be used to educate about scientific insights, enhance feelings of self-efficacy, and enhance emotional responses and higher nature connectedness. The results are higher pro- environmental attitudes and immediate sustainable behaviors. Such VR exposures might be most effective starting at an age of ten when preferences can still be shaped, and habits are not yet safeguarded by complex defense mechanisms (Berridge, 1996; Smit et al., 2021). Educational settings like project days or field trips to museums would be cost-effective examples of feasibility. It is important to reflect on consequences of mediated nature encounters and their potential to reduce playful explorations of nature. As a consequence, children may fail to create an environmental identity (Cumbo & Iversen, 2020). The co-creation of such VR experiences with artists and community members would mitigate those risks (e.g., Liu, 2017).

Approaches to heighten the motivation to address climate change elicited through VR designs include ecological guilt, the perception of risk and related emotions, but also the extent to which people feel connected to their virtual self-representation (avatar). All of which seems to impact how individuals perceive their relation to climate change.

3.1 It Happens Here and Now: Psychological Distance

Psychological Distance (PD), more accurately its reduction, played a striking role in a majority of the reviewed literature. Originally derived from *Construal Level Theory* (Liberman et al., 2007), it encompasses multiple dimensions according to which individuals have difficulties in imagining future scenarios, and vary in their general perception of environmental issues. PD dimensions cover spatial, social, temporal, and hypothetical ("How likely will this happen to me?") distance (Jones et al., 2017). They are assumed to contribute to the public lack of engagement in environmental issues and behavioral change (Jones et al., 2016; Raja & Carrico, 2021). Its relation to VR is matches the principles Sheppard (2012) raised to foster greater involvement in climate change (i.e., localized scenarios, use of visualizations, and connecting past to future). VR may thus be one of the more effective ways for making the abstract and distant consequences of climate change more concrete and tangible. For instance, carbon emissions, or general degradation, are invisible to the naked eye. A sense of psychological disconnectedness is often a consequence which leads to the underestimation of situation.

More importantly, first-hand experiences are crucial in developing a sense of nature connectedness and subsequently an upsurge in pro-environmental behaviors (Klaniecki et al., 2018). Although more investigations are needed to see which dimensions are indeed affected by virtual experiences, PD combats climate change from different angles and should be focused on in future investigations.

3.2 What is Missing?

A lack of longitudinal designs may be a consequence of a technology that is still too young to be particularly user-friendly. Those are important to show that presenting an immersive video of how an animal is slaughtered, which can be expected to reduce immediate reductions of meat preferences, can be prolonged. In other words, short-term effects might merely reveal the inability to suppress feelings and thoughts following exposure to uncomfortable topics. I therefore suggest the inclusion of moderators such as 'mentalized affectivity', or 'emotion regulation ability'. This should be coupled with longitudinal designs to assess the dissipation of effects. The reviewed studies, moreover, did a poor job in distinguishing between agency and self- and response-efficacy. This is understandable given that their causal relation is still insufficiently investigated (Alsaleh et al., 2023). Finally, feelings of immersion did not differ between video and VR conditions in embodiment illusions that did not employ haptic feedback. It should be scrutinized whether bodily perceptions drive VR's effectiveness the most, or if immersion assessments are not yet sensitive enough.

4. General Discussion

This work reviewed empirical studies using VR designs for the enhancement of pro- environmental motivations, attitudes, and behaviors. The primary goal was to infer the utility of such designs as one strategy to reinforce the fight against climate change. Using dimensions of environmental literacy provided a structured framework by offering tangible starting points for research and improvements. The reviewed studies revealed designs to enhance self-efficacy, the level of immersion, and embodiment, as effective means to tackle climate change in VR. In addition, the reduction of PD proved to be a major driver for circumventing peoples' abstract perceptions on the topic to eventually elicit pro-climate action. Accordingly, VR can expose people to dangerous scenarios that illustrate consequences of climate change not only vividly but without wasting fossil fuels for traveling or on demonstrations. Through these, and the increase of ecological validity (more realistic scenarios) and replicability (higher control), VR clearly advances traditional research designs. Whether this field has the potential to inspire perpetuated climate activism, or shape more sustainable habits, however, cannot be inferred due to the lack of longitudinal designs.

5. Future Direction: I See What You Do

People have a strong desire to belong (Baumeister & Leary, 1995). This can result in an unconscious alignment of attitudes and behaviors with close friends and people we admire. Social norms may therefore be an avenue to focus on when assessing long-term effects of VR experiences or trainings. It was shown that existing social norms are maintained in virtual museum environments (Parker & Saker, 2020), whereas an experience designed for prevention against E-Cigarette use did not find adjustments of existing social norms (Weser et al., 2021). It is thus more likely that VR affects social norms through engaging in content discussions after the experience. In a similar vein, Gifford (2011) suggested 11 psychological barriers to address climate change: one of them being interpersonal relations. The fear of exclusion that is inherent to every human being can direct attention to comparisons and social norms (Williams, 2009). Future research is advised to assess whether individuals tend to share VR experiences with close others, which may instantiate social pressures. Due to the paucity of literature regarding the formation of social norms following VR experiences, I suggest designing for group settings in public spaces for examining the extent to which they entail emotional debates.

5.1 Still a Long Way to Go

Despite the importance of understanding the feasibility and sustainability of VR for widespread adoption, only a small proportion of the reviewed papers addressed VR's technological limitations such as production, cloud storage of data and accessibility. Efforts to raise VR usability revolve around standardization (Timmerer, 2017). That is, the majority of applications cannot be transferred between different types of headsets (known developers are Meta, HTC, or Pico), because developers have to struggle with user interface specifications.

This complicates the designing of scientific studies leading to purchases of multiple headsets that are replaced by newer models almost twice a year (VRcompare, 2023). Not only is this confining the accessibility of already expensive VR equipment, it also contributes to the increasing carbon footprint of the industry. In addition, not all headsets function without a computer but require devices that come with high-end graphic cards and microprocessors, for which essential resources are mined (Hamad & Jia, 2022). Recent work calls for more sustainable VR-design creations by using game engines that demand less energy such as Unreal Engine (Kattakinda et al., 2024). VR can further directly affect the wellbeing of individuals. Some of the more frequently discussed consequences are back and neck pain (Kaplan et al., 2021), or cybersickness including nausea and dizziness (LaViola, 2000).

6. Concluding Remarks

Paradoxically, virtual environments seem to reinforce connections with the world around us by presenting versions of reality that are free of physical boundaries. Individual pro- environmental actions can be influenced more profoundly than with traditional, less immersive designs, and processes such as PD reductions may be essential in explaining and predicting comparable findings. The method's broader applications could be explored by looking into how social norms influence the propagation of beneficial impacts after VR encounters. Although VR advances behavioral science approaches to tackle climate change, we also need to focus on group dynamics and systemic challenges, for which VR seems to only play one small part in the whole problem-solving process.

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Table 1: Overview of the reviewed literature and relevant effect sizes. Not significant results are marked as ns and lacking effect sizes with n/a (not available). If provided, effect sizes were transformed into eta square ($\eta 2$) or kept as partial eta square ($\eta 2p$).

Reference	Purpose	Research Method	Sample Size [N]	Effect Size
Ahn et al., 2014	Investigated short- and long-term effects of embodied experiences in VR on environmental locus of control and behavior.	Experiment	60	$\eta 2 = .11$
Ahn et al., 2016	Examined in experiment 1 the impact of embodying a cow VR on the inclusion of nature in self.	Experiment	49	$\eta 2 = .156$
Aspiotis et al., 2022	Assessed stress induced by VR high-altitude scenario using EEG and ECG measurements.	Experiment w/ physiological measures	16	n/a
Bailey et al., 2014	Studied effect of vivid messages in reducing energy consumption.	Field experiment	70	$\eta 2p = .10$
Fonseca and Kraus, 2016	Compared HMD and hand-held displays for 360° videos focusing on attitude and behavior change.	Experiment	52	n/a
Markowitz et al., 2018	Investigated VR embodiment illusions for climate education and attitude change.	Experiment	47	$\eta 2p = .63$
Meijers et al., 2022	Explored VR's role in sustainable food choices; effects mediated by response efficacy.	Experiment	229	$\eta 2 = .053$
Meijers et al., 2023	Analyzed VR's effects on climate-related cognition, emotion, and behavior.	Experiment	277	Spatial presence: $\eta 2p = .46$; Behavior: ns
Parker & Saker, 2020	Examined VR's impact on spatial and social norms in art museums.	Interviews	19	n/a
Plechatá et al., 2022	Investigated VR's effect on pro-environmental food choices.	Experiment	90	$\eta 2p = .024$; ns
Schöne et al., 2019	Explored VR experiences as triggers for autobiographical memory.	Experiment	43	$\eta 2p = .113$
Smit et al., 2021	Studied VR's influence on eco-friendly food consumption in children.	Interview	22	n/a
Spangenberger et al., 2022	Examined tree embodiment in VR on nature relatedness.	Experiment	28	$\eta 2p = .176$
Sungur et al. (2022)	Designed VR experiences aimed at enhancing self-efficacy.	Experiment	n/a	n/a
Weser et al., 2021	Tested VR game prototype for e-cigarette prevention in teens.	Quasi-experiment	285	ns