Exploring User Perceptions on Visual CO2 Representations as Eco-Feedback in Virtual Reality

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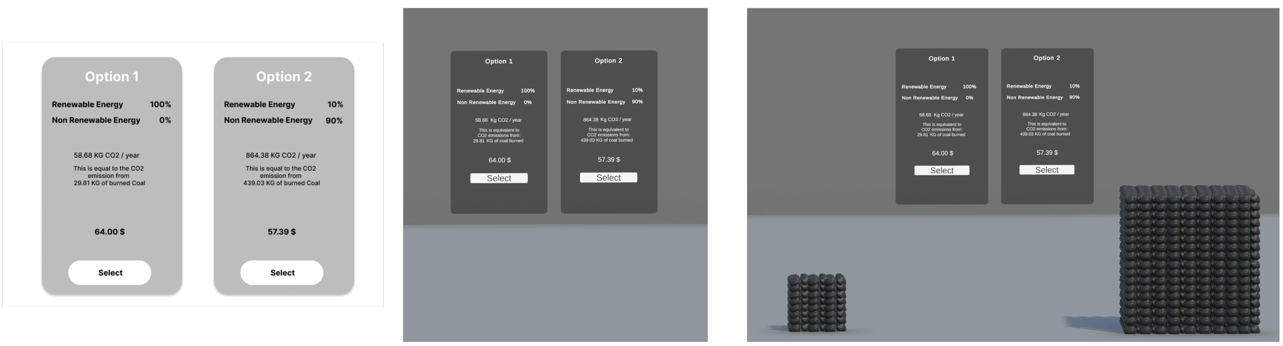

Figure 1: We explore the impact of visual CO2 representations on customers' perceptions when choosing an energy supplier in virtual reality. Thereby, we compare the following conditions: On the left the *Paper* as baseline; in the middle *PCAbstract* and *VRAbstract*; On the right *PCVisual* and *VRVisual*.

Abstract

Eco-feedback interventions primarily focus on lowering energy consumption behaviours instead of considering the impact of CO_2 emissions resulting from the overall energy mix of renewable and non-renewable energy sources. Although labelling products with CO_2 emission is an effective way for *green nudging*, consumers often perceive the information as intangible and incomprehensible. In this paper, we study the impact of the visual representation of CO_2 equivalences (VisualRepCO_2) on customers' perceptions when choosing an energy supplier in virtual reality (VR) compared to a paper baseline and desktop setup. Our findings indicate that a VisualRepCO_2 supports customers of electricity supplies in understanding their impact more comprehensibly and touches them more emotionally than a text label. We conclude by demonstrating lessons learned for future research and offering recommendations to support practitioners in enhancing customers' understanding of CO_2 emissions.

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CCS Concepts

• **Human-centered computing → Empirical studies in interaction design**.

Keywords

Carbon Emissions, CO2 Emissions, Eco-Feedback, Sustainability, Virtual Reality, Design Intervention

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1 Introduction

Facing wicked sustainability challenges, HCI researchers have investigated for more than a decade human behaviour to implement artefacts that support change, nudge and reflect on consumption patterns [27]. For example, labelling products and services with

CO_2 emissions and equivalents is an effective eco-feedback method to nudge consumers towards a more sustainable option [53]. However, consumers do not fully understand CO_2 information, which often limits their understanding of why it is a green choice [43]. Knowing that choosing an energy mix from renewable energy sources reduces households CO_2 emissions significantly [4], research on eco-feedback started to investigate beyond limiting to change human behaviour to reduce energy consumption [31, 32]. However, the consumer energy provider switching rate within the European Union remains low [14]. At the same time, with the technological advance of VR, the first virtual shopping experiences have been launched, as Peukert [47] identified in his research, allowing the assumption that contracts, like e.g with energy providers, can be concluded in VR in the near future as well. In this context, closing contracts in VR offers new design opportunities in terms of how CO2 equivalents can be presented and experienced in virtual space, potentially enabling consumers to make better-informed decisions. This paper presents insight into how consumers perceive a VisualRepCO_2 in the form of a coal pile as eco feedback in VR. To do so, we compared the VisualRepCO_2 in VR with a paper baseline and on a desktop interface. We found that a VisualRepCO_2 is easier to understand compared to raw numbers and that a VisualRepCO_2 in VR triggered participants emotionally. Further, we discuss participants' perceptions and opinions about VisualRepCO_2 and renewable energy after exposure. We conclude by discussing the results and formulating lessons learned for future research.

2 Related Work

We review research on eco-feedback design and how VR promotes sustainable behaviour.

2.1 Design of Eco-Feedback and Eco-Label

Even though this paper refers to Eco-Feedback Labels, there is a differentiation between Eco-Feedback and Eco-Labels. While the concept of *Eco-Feedback* provides the consumer usually feedback information about a certain pattern over or during a specific time [23, 31, 51], *Eco-Labels* are used mostly in a commercial context to nudge a consumer towards a sustainable choice [52, 53]. However, since the case presented in this research covers both concepts, we will refer to *Eco-Feedback* throughout this paper. Using eco-feedback intervention to nudge and persuade consumers towards a more sustainable choice has been explored over the last two decades [7, 19], including diverse application fields for instance, in the consumption of water [25], household energy [17], grocery [52, 57] and waste [39]. Thereby research showed different ways of representing resource consumption. Within the domain of water consumption, Kappel and Grechenig [35] investigated water conservation in showering, with a shower water meter prototyped with LEDs which indicates the amount of water used. Similarly, Laschke et al. [38] designed a shower calendar for behaviour change in water consumption through motivational aspects such as "goal setting, comparison, competition, and communication". Using a provocative design intervention that specifies when electricity is available for washing and when it is not, Jensen et al. [32] have elaborated the themes of adaptation, reflection, and formation of new routines and expectations in relation to energy-consuming practices in the field of washing. Others like Grönewald et al. [25] focused on new design possibilities within the interface of washing machines in order to nudge consumers towards the choice of energy-saving programs. Within the domain of grocery, Bohné et al. [6] prototyped and evaluated an Eco Panel, which enables reflection on consumers' food choices, aiming for sustainable grocery shopping practices. Lim et al. [39] focused in their research on eco-feedback for food waste reduction by creating a smart bin system that visualises the current domestic food waste to impact consumption patterns. To provide eco-feedback on waste, Assor et al. [3] designed an augmented reality prototype to embed the visualisation of waste data in an environment that the user is familiar with. Furthermore, there is research that does not focus on a specific context but rather on the entire household [22, 33, 37] and community energy consumption [30, 31, 34, 48]. In this regard, Day et al. [17] reviewed monitoring interfaces in order to understand how thoughtfully designed interfaces can result in both energy savings as well as increased occupant comfort. Others like Petkov et al. [46] focus rather on motivational design techniques to promote energy-saving behaviour. To improve the effectiveness of eco-feedback interventions, Sanguinetti et al. [51] investigated a design behaviour framework which puts the "behaviour mechanism of attention, learning, and motivation" in relation to the design dimensions of information, timing, and display. Taking the display dimension into consideration, current research investigated different artefacts to communicate eco-feedback information within households energy consumption e.g. conversational agents [24], building interfaces [17] and smartphones [36].

2.2 Promoting Sustainable Behaviour Using VR

Next to the design of eco-feedback interventions, there is also interest in using VR in the sustainability research domain. Cosio et al. [15] explored the domains of mixed reality technology within environmental subjects, including education and learning [2], crowdsourcing [16], decision making [11], environmental awareness [44], connection with nature [8], training [20] as well as environmental behaviour [18]. As a result of their literature review, Cosio et al. [15] appealed that future research should focus on *"pro-environmental behaviour and connection with nature by exploring how XR can be used to increase individuals' sense of self-efficacy and their perceived locus of control over environmental problems"*. In order to promote sustainable behaviour, research has shown that experiencing a replication of nature in VR can be as effective as a self-guided hike in nature [18].

Others, such as Turchet and Hueller [55], prototyped an AR-based, audio-visual system that conveys messages about the urgency of addressing environmental threats such as pollution, climate change, and biodiversity loss. Similarly, Hofman et al. [28] explored the effectiveness of virtual vs. real-life marine tourism experiences in encouraging conservation behaviour. They found that a nature-based VR marine tourism experience can influence conservation behaviours and that VR simulations are promising for prompting widespread behavioural changes [28]. Several additional works highlight the benefits of VR to, for example, teach underwater sustainability while diving [12], promote climate change awareness [21], and use VR in education for sustainable development [50].

Overall, the message here is that many works investigated the effectiveness of eco-feedback designs and utilised VR to promote sustainable behaviour. However, limited research has investigated users' perception of eco-feedback labels and augmented visual representations of CO_2 emission in VR. We aim to fill this gap by investigating the users' perception of a 2D representation of CO_2 emission and a 3D representation of CO_2 emission using VR.

3 Concept and values for visual CO_2-equivalent representation

Following, we describe our approach of representing a realistic visual equivalent representation for potentially caused CO_2 emission by selecting an energy mix.

3.1 Concept for visual CO_2-equivalent representation

We decided to implement two options to simulate the selection of an energy supplier in VR. One option obtains energy exclusively from renewable sources, referred to in the following as the *green option*. The second option obtains energy from both renewable and non-renewable sources, referred in the following as the *conventional option*. Both options show the respective energy mix, followed by the CO_2 emissions generated per year when selected. To enable customers to relate to the CO_2 values, a corresponding equivalent for the emissions caused is given. We decided to represent CO_2 equivalents as coal piles, as these are the most effective in terms of nudging compared to other equivalents [43]. The coal piles are shown next to the corresponding option in each case, as seen in Figure 1. Consequently, the coal pile will be smaller for the green option than the conventional one. The basis on which we determined the values and the size of the coal piles is outlined in section 3.2. Underneath, the price is displayed as the monthly payment for the option, followed by a select button to confirm the selection.

3.2 Values for visual CO_2-equivalent representation

To explore the scenario of the choice of the electricity mix in VR, we aimed to be as close as possible to a real-world scenario. For the green option, we limited the mix to hydropower, solar and wind energy generation types. Non-renewable energy sources include the generation types of nuclear power, oil, gas, brown coal, hard coal and waste. To ensure that we present realistic emission values for the elected electricity supply technologies, we refer to the technology-specific cost and performance parameters report of the IPCC [49]. In our case, we distributed the shares of generation type within the renewable source group as well as within the non-renewable source group equally. We then predefined a list of conventional options where we distributed the shares of renewable and non-renewable sources as outlined in Table 1 in Appendix A. To convert the CO_2 emissions in coal values we used the Greenhouse Gas Equivalencies Calculator from the Environmental Protection Agency [1]. Finally, we used the volume to illustrate the coal piles in cube form in VR accordingly.

4 Study

To investigate the impact different representations of CO_2 equivalents have on customers' decision-making process, we implemented a prototype that visualises the energy mix in an abstract form using labels and in a more visual form using 3D coal blocks that represent CO_2 equivalents in VR and in a 2D desktop setting. We added a paper-based version with labels as a baseline, as this represents the current state-of-the-art in-person experience in real-world settings. Figure 1 shows the different representations of CO_2 , which we describe in more detail below. We conducted a within-subjects design study whereby each participant performed all conditions, counterbalanced using a Latin Square.

- The ***Paper* (baseline)** condition represents the raw number of CO_2 emission and the number of coal equivalences as labels on a paper. This represents the situation in which customers decide about the energy mix solely based on printed material. This represents the current state of the art in real-world settings.
- With ***PCAbstract*** the raw number of CO_2 emissions and the amount of coal equivalences are displayed as a label within a two-dimensional desktop interface. Here, we were interested in seeing how transferring the information from paper to a screen impacts the users' perception.
- ***PCVisual*** incorporates a VisualRepCO_2 displayed within a desktop interface. Here, we were interested in a corresponding coal representation of the CO_2 emission impacting the participant's perception.
- With ***VRAbstract*** we moved the raw number of CO_2 emissions and the number of coal equivalences as a label into a VR environment to investigate whether or not there are differences between presenting abstract information about energy combinations on a paper, on a desktop screen, and in VR.
- ***VRVisual*** represents the scenario where coal equivalences are rendered in VR. This allows us to investigate how the combination of VR and a VisualRepCO_2 emission impacts the perception of CO_2-equivalent representation of our participants when choosing their energy mix.

4.1 Participants & Ethics

We recruited 20 participants (9 female, 11 male), who were on average 26.7 years (SD= 2.79 years, min= 23 years, max= 32 years). One participant had used VR several times a week, 14 participants used it on occasion, four participants used it once, and one participant had never tried it all. In the initial assessment, 11 participants stated that they currently buy a basic energy mix of non-renewable and renewable energy. Three participants mentioned that they buy a fully green renewable energy source, while six did not know what kind of energy mix they buy at all.

4.2 Apparatus & Study Setup

The conditions *Paper*, *PCAbstract* and *PCVisual* where performed on a desk. While the *Paper* condition was performed by pen and paper, the conditions *PCAbstract* and *PCVisual* where performed on a PC. For the conditions *VRAbstract* and *VRVisual* the participant was sitting on a chair wearing the Meta Quest 2 head-mounted display and holding both haptic controller devices. The desktop, as well as the VR conditions, were implemented in Unity 2022.6.f1 LTS.

4.3 Tasks & Procedure

Upon conducting an initial assessment of general information as well as their attitudes towards their choice of energy supplier, each participant completed all five conditions in a counterbalanced order using a Latin Square. Within each condition, the participant had to make a sequence of nine decisions between two options. As described in section 3, one option was based on renewable energy sources, always displaying the same numbers in each decision, while the second option always consisted of different weightings of renewable and non-renewable sources. After completing all five conditions a semi-structured interview based on their reflection of the representations was conducted.

4.4 Data Collection & Analysis

We followed a qualitative research approach where we asked participants about their experiences and perceptions after being exposed to the different visual representations of CO_2 consumption. The interviews were literally transcribed and then translated, if necessary. One author went through the transcript by open-coding. After that two researchers discussed and clustered the codes into themes using an affinity diagram [29] for reflexive thematic analysis [10].

5 Results

We report the main findings of the interviews, covering participants' reflection on (1) the VisualRepCO_2; (2) the different exposures using paper, desktop and VR; and (3) their perceptions and opinions of renewable energy after exposure.

5.1 Theme 1: Visual Representation of CO_2 Equivalencies

Regarding CO_2 emissions, as well as carbon equivalents, most participants stated that *"when we had 100 and 0, renewable versus non-renewable, and then we were comparing something with 70 and 30, I would not have expected that the difference in CO_2 emissions is so big"* (P14). The participants were surprised that even *"if it is only 20 percent non-renewable energies, [that it is such a] striking difference. But now, especially in the illustrated example, it has become clear that it can also make a big difference"* (P14). Regarding the VisualRepCO_2 in coal, participants stated it was easier to understand compared to a simple number because *"of course, you see the numbers and you know like that 500 is way more than 50. But I think the blocks there reinforce that feeling of, oh wow, this is so much bigger than the other one"* (P14). Similarly, P10 described that *"if you only see numbers, it's hard to imagine something"*, highlighting that if you *"bring in this visual component, it hooks people"* (P10). Participants, for example, P8 and P9, voiced that the VisualRepCO_2 in VR had immersive effects on them, as *"in virtual reality these piles of coal seem even more real, bigger, handy, more tangible"* (P8). P9 further described that *"on the sheet of paper it seems the least brutal, the differences that exist sometimes, in the choice of the electricity mix"* (P9). P12 described with regard to the *VRVisual* that:

> *"When I see that one [coal] pile is like this and the other pile is so big, it makes something emotional happen with me."* **P12**

Similarly, P13 argued that in comparison to the desktop version, they found the VisualRepCO_2 *"more threatening in VR"* (P13) and that *"especially with this big block, when it was on the left, [they] came very close to it, [so that] at the very beginning [they] moved back a bit"* (P13).

In contrast to the perceptual realism of the CO_2 representation in the VR environment, where participants stated that the VisualRepCO_2 was *"more tangible"* and *"better understood"*, P17 argued that it was *"just a stack of coal [where] you don't really feel the gravity of it, so it didn't play too much of an effect"* (P17). While the piles of coal were a visual illustration for many participants, P4, for example, did not understand what the coal pile was related to:

> *"I don't know if a pile of coal with six pieces is so much bigger than a pile with three pieces. I know the number is bigger, but I don't know what it refers to. Can you heat a house with three pieces of coal or do you need ten? For driving hours, I could already imagine how far you could get with that"* **P4**

Other participants, such as P17, suggested that *"if you show them the supply chain, I think they start to realise, okay, that's a lot of work to get that much coal"* (P17) and that the price differences between the green and mixed energy could be represented with equivalents, i.e., *"[...] to kind of make a story out of it that you can have the green option and then you only have to drink one less coffee a month"* (P17).

5.2 Theme 2: Paper vs Desktop vs VR

There were various comments regarding the differences between the paper, desktop and VR in the exposures to the CO_2 representations. While P1 voiced to have experienced no noticeable differences between *Desktop* and *VR*, i.e., *"The visual information you can get from it is pretty similar for me, whether it's desktop or VR"* (P1), P17 argued to have experienced some differences across the exposures, particularly when using VR:

> *"I don't think regardless of desktop or paper would have made a difference, but with the VR, I do see the coal and I kind of feel it a bit more, you see it a bit more, but at the same time, the price at the end wins."* **P17**

Similarly, P19 perceived the visualisations on the PC as less tangible compared to the VR exposure. Regarding the advantages of the exposures on the PC, P12 argued that the PC setting provided them with the most straightforward option to comprehend all necessary information to make an informed decision:

> *"I was most comfortable with the desktop because I could quickly grasp everything. For example, for coal, I was able to make the decision faster because I could grasp and see everything more quickly."* **P12**

Both P18 and P12 voiced that the PC setting most accurately represented their real-world experience as this is how they are currently making informed decisions about the energy mix they are planning to order.

5.3 Theme 3: Perceptions and Opinions About Renewable Energy After Exposure

The interviews revealed additional elements that contribute towards consumers' perceptions, opinions, and final decision-making regarding when to choose a renewable energy mix. For example, P2 stated they are not limiting themself on the options but also to the provider itself, meaning that *"if they focus solely on green and renewable energy and don't sell oil or anything else in the meantime, [they] would even prefer them, even if they were even more expensive"* (P2). Other participants described that in reality their decision would have taken longer and would have been more informed:

> *"Sometimes I don't just rely on the facts and figures, but also try to understand the background better because I don't know the subject very well myself, and perhaps I'm a bit dependent on it being explained to me [...] I don't know enough about the subject to be able to make that statement in a standing circle. That means I would probably first find out what criteria would be important to me."* **P18**

P4 and P19 further described that their influence on the actual energy mix is too small, implying that the selection of the energy mix is often a political and not an individual decision: *"I'm from a country where we have a lot of oil but we also have a lot of reusable energy so I think it's kind of stupid that we don't use it and we sell it which I think is stupid because I don't know where I get my energy from because I don't get the energy from my country it's imported so if I could choose I would choose to get my energy from [my country] and from a source that were reusable"* (P4). P19 commented that *"Yes, now I'm reflecting on it, I'm also noticing that in this case I'm abstracting and dismissing my guilt, that it's the companies and the government that have to do this"* (P19).

6 Discussion

We first discuss the results by contrasting them with the literature and then present lessons learned for future research.

6.1 Visual Representation of CO_2 Equivalencies

Our results show that the energy mix and the resulting CO_2 emissions were important to the participants when choosing an electricity supplier but that they were surprised by the extent to which sources from non-renewable sources impact the CO_2 emission, especially through the comparison of the VisualRepCO_2 of the two options. Participants mentioned the VisualRepCO_2 in VR was easier to understand compared to numerical numbers, which confirms previous work by Chirico et al. [13], where consumption of plastic bottles was visualised in VR. Additionally, participants mentioned that it was way easier to compare two blocks rather than a numerical number. However, they hardly understood what the coal pile relates to, which goes in line with Mohanty et al. [43], that CO_2 equivalencies do not always lead to a better understanding of CO_2 emission even though they are effective in nudging towards a more environmental friendly option [43]. One pathway for further research is to enable participants to choose their preferred equivalencies, which they feel mostly related to, in order to foster informed decisions. Since participants asked in the interviews for eco-feedback on a greater emotional level, we argue to investigate deeply into storytelling as a promising method for eco-feedback, as also identified in other contexts like in the underwater domain [45].

Lesson 1: A physical representation of CO_2 equivalencies can be easier to understand compared to raw numbers.

Several participants stated that with the VisualRepCO_2 they either had a better idea about the caused CO_2 or felt emotionally attached. On the other hand, participants stated that they just compared two piles, similar to how they would compare two numbers. A future pathway might include personalised equivalencies that are comprehensible for each individually. While some prefer raw numbers, others might benefit from specific equivalencies that they understand best.

6.2 Visual Eco-Feedback in VR compared to Paper and Dekstop

Participants stated perceiving the VisualRepCO_2 as "more tangible" and "easier to understand" than the abstract information. Furthermore, participants highlighted that the VisualRepCO_2 of the coal in *VRVisual* triggered emotional feelings with them while this was not mentioned for *Paper*. This finding goes in line with the results obtained in other VR studies that highlight various benefits of using VR to immerse users into environments that are closer to reality than traditional lab studies [40, 41] and are even capable of eliciting emotions [42, 54]. However, particularly the experiences during *PCAbstract* as well as *PCVisual* where perceived as more accessible and straightforward as it allows comprehension of all the necessary information quicker and it was perceived as most similar to current real-world experiences where energy mix selection is performed on a desktop PC. Future work is required to investigate how VisualRepCO_2 in *PCVisual* and *VRVisual* can support or even ethically nudge people into positively contributing towards the environment. Since some participants stated that the VisualRepCO_2 of the coal touched them emotionally, we believe that future work is required to identify the "sweet spot" between price and energy mix in combination with different representations of CO_2 equivalencies, including tangible 3D-representations of CO_2.

Lesson 2: Results suggest that visual representation of CO_2 equivalencies in VR can trigger emotions.

Participants stated that seeing the coal pile as a representation of CO_2 equivalencies directly in front of them triggered them in an emotional way since the raw numbers became tangible and understandable. We suggest further investigating the effect of different VisualRepCO_2 in more detail on consumers' perception and choice.

6.3 Participants Critical Reflection and Future Work

Reflecting on future work, our findings reveal that besides the VisualRepCO_2 in VR other factors influence participants perception and opinion about the adoption of a renewable energy mix. First, consumers are not only concerned by the energy mix but also about the practices of the energy provider itself. This goes in line with previous research that although the factor price remains one of the most important choice criteria, the importance of corporate social responsibility (CSR) in decision-making is growing and consumers start reflecting even beyond their individual CO_2 consumption and price benefits [5, 26]. This resonates with another finding, that an informed decision-making process is more time-consuming and complex than it might appear, especially when consumers feel inadequately informed [58] and seek to understand the background information better. Furthermore, although some participants stated that they the VisualRepCO_2 supported them in their decision, they expressed concerns about the impact of their individual energy mix, attributing the responsibility on a political level. Having the perception that their action is inconsequential in a larger systemic picture, causes consumers may neclecting to make an eco-friendly choice [56]. This goes in line with research highlighting the need to embrace HCI research beyond the individual consumption [7, 9, 19]. Therefore, we argue to embrace research on eco-feedback mechanisms by placing it in real real-world setting, acknowledging that a sustainable choice involves various factors which go beyond consumers' energy consumption.

Lesson 3: Real-world observations and larger systemic information are needed to evaluate customer decisions.

Even though the qualitative results reveal that the VisualRepCO_2 are easier to understand and trigger emotions compared to raw numbers, further research in real-world settings is needed to understand how VisualRepCO_2 influences customers' decisions. Besides offering renewable energy options and marking them with an eco-feedback label, the results highlight also the need to communicate organisations' commitment to sustainability to appeal to consumers.

7 Conclusion

This study addressed eco-feedback intervention at the critical point of choosing an energy mix since the choice significantly impacts households CO_2 emission. Existing research has shown that labelling products with CO_2 emissions is an effective way to nudge consumers towards a more environmentally friendly choice. However, consumers can hardly relate to CO_2 emissions. Inspired by previous research that highlighted the benefits of VR for user-centred investigations, this study contributes to the growing body of eco-feedback interventions and sustainability in VR by investigating consumers' perception of VisualRepCO_2 in VR compared to a desktop and paper baseline. Our results show that a VisualRepCO_2 equivalencies using coal blocks were perceived as more comprehensible and touched some participants emotionally. Based on our discussion of the results, we hope to support future research in eco-feedback in VR to investigate storytelling methods and customisation of CO_2 equivalencies to support individuals' decision-making processes. Furthermore, we argue to situate research on eco-feedback in real-world settings, allowing the consideration of diverse customers' choice criteria beyond their energy consumption.

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In this paper, we used Overleaf's built-in spell checker, Grammarly, and the current version of ChatGPT (GPT-4o). These tools helped us fix spelling mistakes and get suggestions to improve the writing of the paper. If not noted otherwise in a specific section, these tools were not used in other forms.

References

[1] Environmental Protection Agency. 2024. *Greenshouse Gas Equivalencies Calculator.* Retrieved August 21, 2024 from https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
[2] Masaki Akaike, Yuko Takishita, Li Wenjun, and Junichi Hoshino. 2021. Marine Biology VR Learning Support System Using Fish Swimming Simulation. In *2021 (NicoInt).* IEEE.
[3] Ambre Assor, Arnaud Prouzeau, Pierre Dragicevic, and Martin Hachet. 2023. Exploring Augmented Reality Waste Data Representations for Eco Feedback.. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems.* ACM.
[4] Shui Bin and Hadi Dowlatabadi. 2005. Consumer lifestyle approach to US energy use and the related CO2 emissions. *Energy Policy* 33, 2 (Jan. 2005), 197–208.
[5] Flavio Boccia, Rosa Malgeri Manzo, and Daniela Covino. 2018. Consumer behavior and corporate social responsibility: An evaluation by a choice experiment. *Corporate Social Responsibility and Environmental Management* 26, 1 (Sept. 2018), 97–105. https://doi.org/10.1002/csr.1661
[6] Ulrica Bohné, Jorge Luis Zapico, and Cecilia Katzeff. 2015/09. The EcoPanel - designing for reflection on greener grocery shopping practices. In *Proc. of EnviroInfo and ICT for Sustainability 2015.* Atlantis Press, 221–228.
[7] Christina Bremer, Bran Knowles, and Adrian Friday. 2022. Have We Taken On Too Much?: A Critical Review of the Sustainable HCI Landscape. In *Proc. of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22).* ACM, New York, NY, USA, Article 41, 11 pages. https://doi.org/10.1145/3491102.3517609
[8] Priska Breves and Holger Schramm. 2021. Bridging psychological distance: The impact of immersive media on distant and proximal environmental issues. *Computers in Human Behavior* 115 (Feb. 2021).
[9] Hronn Brynjarsdottir, Maria Håkansson, James Pierce, Eric Baumer, Carl DiSalvo, and Phoebe Sengers. 2012. Sustainably unpersuaded: how persuasion narrows our vision of sustainability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12).* ACM. https://doi.org/10.1145/2207676.2208539
[10] David Byrne. 2021. A worked example of Braun and Clarke's approach to reflexive thematic analysis. *Quality & Quantity* 56, 3 (June 2021), 1391–1412. https://doi.org/10.1007/s11135-021-01182-y
[11] Juliano Calil, Geraldine Fauville, Anna Queiroz, Kelly Leo, Alyssa Mann, Tiffany Wise-West, Paulo Salvatore, and Jeremy Bailenson. 2021. Using Virtual Reality in Sea Level Rise Planning and Community Engagement—An Overview. *Water* 13, 9 (April 2021).
[12] Licia Calvi, Carlos P. Santos, Joey Relouw, Bojan Endrovski, Chris Rothwell, Antonio Sarà, Serena Lucrezi, Marco Palma, and Ubaldo Pantaleo. 2017. A VR game to teach underwater sustainability while diving. In *2017 Sustainable Internet and ICT for Sustainability (SustainIT).* 1–4.
[13] Alice Chirico, Giulia Wally Scurati, Chiara Maffi, Siyuan Huang, Serena Graziosi, Francesco Ferrise, and Andrea Gaggioli. 2020. Designing virtual environments for attitudes and behavioral change in plastic consumption: a comparison between concrete and numerical information. *Virtual Reality* 25, 1 (May 2020), 107–121.
[14] European Commision. 2016. *Second Consumer Market Study of the Functioning Retail Electricity Market for Consumers in the EU, Final Report; European Commision: Brussels, Belgium.*
[15] Laura D Cosio, Oğuz 'Oz' Buruk, Daniel Fernández Galeote, Isak De Villiers Bosman, and Juho Hamari. 2023. Virtual and Augmented Reality for Environmental Sustainability: A Systematic Review. In *Proc. of the 2023 CHI Conference on Human Factors in Computing Systems.* ACM.
[16] Michael F. Curran, Kyle Summerfield, Emma-Jane Alexander, Shawn G. Lanning, Anna R. Schwyter, Melanie L. Torres, Scott Schell, Karen Vaughan, Timothy J. Robinson, and Douglas I. Smith. 2020. Use of 3-Dimensional Videography as a Non-Lethal Way to Improve Visual Insect Sampling. *Land* 9, 10 (Sept. 2020).
[17] Julia K. Day, Claire McIlvennie, Connor Brackley, Mariantonietta Tarantini, Cristina Piselli, Jakob Hahn, William O'Brien, Vinu Subashini Rajus, Marilena De Simone, Mikkel Baun Kjærgaard, Marco Pritoni, Arno Schlüter, Yuzhen Peng, Marcel Schweiker, Gianmarco Fajilla, Cristina Becchio, Valentina Fabi, Giorgia Spigliantini, Ghadeer Derbas, and Anna Laura Pisello. 2020. A review of select human-building interfaces and their relationship to human behavior, energy use and occupant comfort. *Building and Environment* 178 (July 2020), 106920.
[18] S. Anthony Deringer and Adam Hanley. 2021. Virtual Reality of Nature Can Be as Effective as Actual Nature in Promoting Ecological Behavior. *Ecopsychology* 13, 3 (Sept. 2021), 219–226.

[19] Carl DiSalvo, Phoebe Sengers, and Hrönn Brynjarsdóttir. 2010. Mapping the landscape of sustainable HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM. https://doi.org/10.1145/1753326.1753625

[20] Marek Fabrika, Peter Valent, and Ľubomír Scheer. 2018. Thinning trainer based on forest-growth model, virtual reality and computer-aided virtual environment. *Environmental Modelling & Software* 100 (Feb. 2018), 11–23. https://doi.org/10.1016/j.envsoft.2017.11.015

[21] Géraldine Fauville, Anna Carolina Muller Queiroz, and Jeremy N. Bailenson. 2020. Virtual reality as a promising tool to promote climate change awareness. In *Technology and Health*. Elsevier.

[22] Corinna Fischer. 2008. Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency* 1, 1 (Feb. 2008), 79–104.

[23] Derek Foster, Shaun Lawson, Mark Blythe, and Paul Cairns. 2010. Wattsup?: motivating reductions in domestic energy consumption using social networks. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries (NordiCHI '10)*. ACM. https://doi.org/10.1145/1868914.1868938

[24] Ulrich Gnewuch, Stefan Morana, Carl Heckmann, and Alexander Maedche. 2018. Designing Conversational Agents for Energy Feedback. In *Designing for a Digital and Globalized World*. Springer International Publishing, 18–33.

[25] Laura Grönewald, Julian Weiblen, Matthias Laschke, Lara Christoforakos, and Marc Hassenzahl. 2023. Sustainability by Design. How to Encourage Users to Choose Energy-Saving Programs and Settings when Washing Laundry. In *Proc. of the 2023 CHI Conference on Human Factors in Computing Systems*. ACM.

[26] Heesup Han, Jongsik Yu, Kyung-Sik Lee, and Hyungshin Baek. 2020. Impact of corporate social responsibilities on customer responses and brand choices. *Journal of Travel & Tourism Marketing* 37, 3 (March 2020), 302–316. https://doi.org/10.1080/10548408.2020.1746731

[27] Lon Åke Erni Johannes Hansson, Teresa Cerratto Pargman, and Daniel Sapiens Pargman. 2021. A Decade of Sustainable HCI: Connecting SHCI to the Sustainable Development Goals. In *Proc. of the 2021 CHI Conference on Human Factors in Computing Systems* (, Yokohama, Japan,) *(CHI '21)*. ACM, New York, NY, USA, Article 300, 19 pages.

[28] Karen Hofman, Gabby Walters, and Karen Hughes. 2021. The effectiveness of virtual vs real-life marine tourism experiences in encouraging conservation behaviour. *Journal of Sustainable Tourism* 30, 4 (Feb. 2021), 742–766.

[29] Karen Holtzblatt and Hugh Beyer. 2017. 6 - The Affinity Diagram. In *Contextual Design (Second Edition)* (second edition ed.), Karen Holtzblatt and Hugh Beyer (Eds.). Morgan Kaufmann, Boston, 127–146.

[30] Mine Islar and Henner Busch. 2016. "We are not in this to save the polar bears!" – the link between community renewable energy development and ecological citizenship. *Innovation: The European Journal of Social Science Research* 29, 3 (June 2016), 303–319. https://doi.org/10.1080/13511610.2016.1188684

[31] Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2016. HeatDial: Beyond User Scheduling in Eco-Interaction. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction (NordiCHI '16)*. ACM. https://doi.org/10.1145/2971485.2971525

[32] Rikke Hagensby Jensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B. Skov. 2018. Washing with the Wind: A Study of Scripting towards Sustainability. In *Proc. of the 2018 Designing Interactive Systems Conference* (Hong Kong, China) *(DIS '18)*. ACM, 14 pages.

[33] Rikke Hagensby Jensen, Dimitrios Raptis, Laurynas Siksnys, Torben Pedersen, and Mikael B. Skov. 2022. Design Visions for Future Energy Systems: Towards Aligning Developers' Assumptions and Householders' Expectations. In *Nordic Human-Computer Interaction Conference (NordiCHI '22)*. ACM. https://doi.org/10.1145/3546155.3546655

[34] Rikke Hagensby Jensen, Maurizio Teli, Simon Bjerre Jensen, Mikkel Gram, and Mikkel Harboe Sørensen. 2021. Designing Eco-Feedback Systems for Communities: Interrogating a Techno-solutionist Vision for Sustainable Communal Energy. In *C&T '21: Proceedings of the 10th International Conference on Communities & Technologies - Wicked Problems in the Age of Tech (C&T '21)*. ACM. https://doi.org/10.1145/3461564.3461581

[35] Karin Kappel and Thomas Grechenig. 2009. "show-Me": Water Consumption at a Glance to Promote Water Conservation in the Shower. In *Proc. of the 4th International Conference on Persuasive Technology* (Claremont, California, USA) *(Persuasive '09)*. ACM, New York, NY, USA, Article 26, 6 pages.

[36] Hyun Bae Kim, Toshiya Iwamatsu, Ken ichiro Nishio, Hidenori Komatsu, Toshihiro Mukai, Yoko Odate, and Masanobu Sasaki. 2020. Field experiment of smartphone-based energy efficiency services for households: Impact of advice through push notifications. *Energy and Buildings* 223 (Sept. 2020), 110151.

[37] Jesper Kjeldskov, Mikael B. Skov, Jeni Paay, and Rahuvaran Pathmanathan. 2012. Using mobile phones to support sustainability: a field study of residential electricity consumption. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM. https://doi.org/10.1145/2207676.2208395

[38] Matthias Laschke, Marc Hassenzahl, Sarah Diefenbach, and Marius Tippkämper. 2011. With a Little Help from a Friend: A Shower Calendar to Save Water. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI EA '11)*. ACM, New York, NY, USA, 633–646.

[39] Veranika Lim, Lyn Bartram, Mathias Funk, and Matthias Rauterberg. 2021. Eco-Feedback for Food Waste Reduction in a Student Residence. *Frontiers in Sustainable Food Systems* 5 (May 2021).

[40] Ville Mäkelä, Rivu Radiah, Saleh Alsherif, Mohamed Khamis, Chong Xiao, Lisa Borchert, Albrecht Schmidt, and Florian Alt. 2020. Virtual Field Studies: Conducting Studies on Public Displays in Virtual Reality. In *Proc. of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. ACM, New York, NY, USA, 1–15.

[41] Florian Mathis, Kami Vaniea, and Mohamed Khamis. 2022. Can I Borrow Your ATM? Using Virtual Reality for (Simulated) In Situ Authentication Research. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 301–310.

[42] Noah Miller, Ekaterina R. Stepanova, John Desnoyers-Stewart, Ashu Adhikari, Alexandra Kitson, Patrick Pennefather, Denise Quesnel, Katharina Brauns, Anika Friedl-Werner, Alexander Stahn, and Bernhard E. Riecke. 2023. Awedyssey: Design Tensions in Eliciting Self-Transcendent Emotions in Virtual Reality to Support Mental Well-Being and Connection. In *Proc. of the 2023 ACM Designing Interactive Systems Conference* (Pittsburgh, PA, USA) *(DIS '23)*. ACM, New York, NY, USA, 189–211.

[43] Vikram Mohanty, Alexandre L. S. Filipowicz, Nayeli Suseth Bravo, Scott Carter, and David A. Shamma. 2023. Save A Tree or 6 Kg of CO2? Understanding Effective Carbon Footprint Interventions for Eco-Friendly Vehicular Choices. In *Proc. of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. ACM, New York, NY, USA, Article 238.

[44] Jeeyun Oh, Eunjoo Jin, Sabitha Sudarshan, Soya Nah, and Na Yu. 2021. Does 360-degree Video Enhance Engagement with Global Warming?: The Mediating Role of Spatial Presence and Emotions. *Environmental Communication* 15, 6 (April 2021), 731–748.

[45] Laura J Perovich, Catherine Titcomb, Tad Hirsch, Brian Helmuth, and Casper Harteveld. 2023. Sustainable HCI Under Water: Opportunities for Research with Oceans, Coastal Communities, and Marine Systems. In *Proc. of the 2023 CHI Conference on Human Factors in Computing Systems*. ACM.

[46] Petromil Petkov, Suparna Goswami, Felix Köbler, and Helmut Krcmar. 2012. Personalised Eco-Feedback as a Design Technique for Motivating Energy Saving Behaviour at Home *(NordiCHI '12)*. ACM, New York, NY, USA, 587–596.

[47] Christian Daniel Peukert. 2020. Next Generation Shopping: Experimental Studies on the Adoption and Design of Virtual Reality Shopping Environments. (2020).

[48] Èlia Gil Peña and Rikke Hagensby Jensen. 2023. The Character of Eco-feedback Systems for Energy Communities. In *The 11th International Conference on Communities and Technologies (C&T) (C&T '23)*. ACM. https://doi.org/10.1145/3593743.3593783

[49] Schlömer S., T. Bruckner, L. Fulton, E. Hertwich, A. McKinnon, D. Perczyk, J. Roy, R. Schaeffer, R. Sims, P. Smith, and R. Wiser. 2014. Annex III: Technology-specific cost and performance parameters. *In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA* (2014). https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf

[50] Raziye Sancar, Deniz Atal, and Hüseyin Ateş. 2023. The Use of Virtual Reality in Education for Sustainable Development. In *Designing Context-Rich Learning by Extending Reality*. IGI Global, 298–318.

[51] Angela Sanguinetti, Kelsea Dombrovski, and Suhaila Sikand. 2018. Information, timing, and display: A design-behavior framework for improving the effectiveness of eco-feedback. *Energy Research & Social Science* 39 (May 2018), 55–68. https://doi.org/10.1016/j.erss.2017.10.001

[52] Gözel Shakeri, Frederike Jung, Ferran Altarriba Bertran, Adrian Friday, and Daniel Fernández Galeote. 2022. Eco-Joy: Imagining Sustainable and Joyful Food Eco-label Futures. In *Adjunct Proceedings of the 2022 Nordic Human-Computer Interaction Conference (NordiCHI '22)*. ACM. https://doi.org/10.1145/3547522.3547694

[53] Paul E. Stillman, Anna Gavrieli, Jane Upritchard, Chavanne Hanson, Treeny Ahmed, Jonathan Kaplan, Ravi Dhar, and Michiel Bakker. 2023. Driving Sustainable Food Choices: How to Craft an Effective Sustainability Labeling System. *Journal of the Association for Consumer Research* 8, 3 (July 2023), 301–313.

[54] Sahinya Susindar, Mahnoosh Sadeghi, Lea Huntington, Andrew Singer, and Thomas K Ferris. 2019. The feeling is real: Emotion elicitation in virtual reality. In *Proc. of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 63. SAGE Publications Sage CA: Los Angeles, CA, 252–256.

[55] Luca Turchet and Jhonny Hueller. 2020. Promoting Awareness on Sustainable Behavior Through an AR-Based Art Gallery. In *Lecture Notes in Computer Science*. Springer International Publishing, 53–65.

[56] Rusitha Wijekoon and Mohamad Fazli Sabri. 2021. Determinants That Influence Green Product Purchase Intention and Behavior: A Literature Review and Guiding Framework. *Sustainability* 13, 11 (May 2021), 6219. https://doi.org/10.3390/su13116219

[57] Jorge Luis Zapico, Cecilia Katzeff, Ulrica Bohné, and Rebecka Milestad. 2016. Eco-Feedback Visualization for Closing the Gap of Organic Food Consumption *(NordiCHI '16)*. ACM, New York, NY, USA, Article 75, 9 pages.
[58] Albin Zeqiri, Pascal Jansen, Jan Ole Rixen, Michael Rietzler, and Enrico Rukzio. 2024. "Eco Is Just Marketing": Unraveling Everyday Barriers to the Adoption of Energy-Saving Features in Major Home Appliances. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 8, 1 (March 2024), 1–27. https://doi.org/10.1145/3643558

A Energy Mix used in the Study

Table 1: Overview of the energy mix used in the study, showing the distribution of renewable (R) and non-renewable (NR) in %, the price, KG of CO_2, and KG of coal that visualises the CO_2 emission. *EM1*, the fully renewable option, was used as a reference and compared to all other energy compositions (e.g., *EM1* vs. *EM2*, *EM1* vs. *EM3*).

Energy Mix	R / NR	Price	KG of CO_2	KG of coal
EM1	100 / 0	64,00	58,68	29,81
EM2	90 / 10	63,27	148,20	75,28
EM3	80 / 20	62,53	237,72	120,74
EM4	70 / 30	61,80	327,25	166,21
EM5	60 / 40	61,06	416,77	211,68
EM6	50 / 50	60,33	506,29	257,15
EM7	40 / 60	59,59	595,81	302,62
EM8	30 / 70	58,86	685,34	348,09
EM9	20 / 80	58,12	774,86	393,56
EM10	10 / 90	57,39	864,38	439,03