HAL open science

An Interdisciplinary Approach to Designing and Evaluating Data-Driven Interactive Experiences for Sustainable Decision-Making

Yvonne Jansen, Ambre Assor, Pierre Dragicevic, Aymeric Ferron, Arnaud Prouzeau, Martin Hachet, Thomas Le Gallic, Ivan Ajdukovic, Eleonora Montagner, Eli Spiegelman, et al.

To cite this version:

Yvonne Jansen, Ambre Assor, Pierre Dragicevic, Aymeric Ferron, Arnaud Prouzeau, et al.. An Interdisciplinary Approach to Designing and Evaluating Data-Driven Interactive Experiences for Sustainable Decision-Making. Workshop on HCI for Climate Change at CHI 2023, Apr 2023, Hamburg, Germany. 10.5281/zenodo.7961762 . hal-04103414

HAL Id: hal-04103414

https://inria.hal.science/hal-04103414v1

Submitted on 23 May 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution 4.0 International License

An Interdisciplinary Approach to Designing and Evaluating Data-Driven Interactive Experiences for Sustainable Decision-Making

YVONNE JANSEN, AMBRE ASSOR, PIERRE DRAGICEVIC, AYMERIC FERRON, ARNAUD PROUZEAU, and MARTIN HACHET, Univ. Bordeaux, CNRS, Inria, LaBRI, France

THOMAS LE GALLIC, CIRED – Centre International de Recherche sur l'Environnement et le Développement, France

IVAN AJDUKOVIC, ELEONORA MONTAGNER, ELI SPIEGELMAN, and ANGELA SUTAN, LESSAC – Laboratory for Experimentation in Social Sciences and Behavioral Analysis, Burgundy School of Business, France

Running long-term field studies is a valuable yet slow and costly approach to test the efficacy of interaction designs on people's everyday decision making and behavior. In this position paper we describe the rationale behind an interdisciplinary approach to designing and evaluating data-driven interactive experiences for sustainable decision-making. We are a group consisting of HCI and visualization researchers, energy-economy modeling experts who work on mitigation pathways, and behavioral economists who run controlled experiments to study how people make decisions in an incentivized context. The intent of this collaboration is two-fold: (1) we study how to design efficient data-driven experiences to help people build an intuition concerning the sustainability of daily choices and actions; (2) we explore the mutual benefit of working across disciplinary boundaries to go beyond the limits of our respective methodological toolboxes. We illustrate our approach through an example of a work-in-progress.

CCS Concepts: • **Human-centered computing → HCI design and evaluation methods**.

Additional Key Words and Phrases: Sustainable HCI, interdisciplinarity, evaluation, modeling

ACM Reference Format:
Yvonne Jansen, Ambre Assor, Pierre Dragicevic, Aymeric Ferron, Arnaud Prouzeau, Martin Hachet, Thomas Le Gallic, Ivan Ajdukovic, Eleonora Montagner, Eli Spiegelman, and Angela Sutan. 2023. An Interdisciplinary Approach to Designing and Evaluating Data-Driven Interactive Experiences for Sustainable Decision-Making. In *CHI'23 Workshop on HCI for Climate Change*. Hamburg, Germany, 8 pages. https://doi.org/10.5281/zenodo.7961762

1 INTRODUCTION

Providing information about the consequences of our actions and plans is fundamental to the various transition processes required by the crucial issue of reducing human pressures on the environment. This challenge occurs at many levels and with different actors, from individuals to governments, industry and finance. The information contained in the climate change mitigation scenarios put forward by the latest report of the IPCC [16] is a prominent example, intending to encourage and inform concerted actions by all relevant players. These scenarios set out the various sets of conditions, such as the speed with which we decarbonize our societies and the approach we plan to use to achieve that goal. However, by default the scenarios are abstract data, spit out by complex models with hundreds or even thousands of parameters and only comprehensible for experts. Furthermore, they cannot be readily used to make everyday decisions. Also, while carbon emissions have received much media attention, there are other planetary boundaries [24] – some of

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).
© 2023 Copyright held by the owner/author(s).

which we already exceeded – which have to be taken into account as well. For example, on an individual level, the difference between a decision to buy a new phone or a refurbished one is not just monetary but also differs on direct environmental consequences, such as required resource extraction [25]. Similarly, on the collective level, imposing regulations on the fast fashion industry would likely result in many different consequences along the production and use chain, such as driving up prices which reduces consumption and thus direct emissions, but also reducing water pollution during the creation and the disposal of currently short-lived items and on the many people working for that industry in low income countries [4]. Human-computer interfaces have a role to play in helping non-experts – that is most of humanity – to access and make sense of the available data and translate them into actionable decisions.

We describe here one possible interdisciplinary approach for working towards this goal: (1) we use modeling tools such as integrated assessment models to identify important levers (e.g., [20]) that people need to understand better to make informed decisions, be it as individuals or as policy makers; (2) we design data-driven, interactive experiences that aim to communicate the intricate interplay between these levers and relevant consequences, for example, concerning the interplay between different dietary choices and their respective consequences concerning land use, fresh water use, and direct emissions; (3) we evaluate these experiences to learn how different approaches affect people's decisions.

Evaluating such research in HCI is rarely straightforward, and some have argued that the evaluation of work in the area of sustainable HCI (SHCI) is particularly challenging [22, 23]: what we really want to know is if such work can have some form of positive impact in the long term, while making sure that bad usability is not hurting the intended purpose. HCI has a rich methodological toolbox to avoid the latter, but less so for determining lasting positive impact. There is no easy way out of this, but, as Remy and colleagues have argued [22], one may be able to identify new approaches by reflecting (among other things) on what one's goals and available methodologies are. Looking towards and collaborating with other disciplines can facilitate this process.

With this position paper we want to argue for an interdisciplinary approach to developing and evaluating data-driven interactive systems for sustainable decision-making that brings together experts from HCI, environmental modeling and behavioral economics. While such an approach will not magically solve all problems, it has valuable properties which we describe in this article.

The motivation for this collaboration is to overcome barriers inherent in each of the respective fields. Ecological modelers can determine the results of different behavioral patterns, but not what could encourage the behavior, nor how to communicate the relevant information to a wide audience; HCI researchers can validate the performance of information visualization tools, but require input about what exactly to visualize, and generally evaluate behavioral impact in a relatively observational manner; behavioral economists design experiments targeting the determinants of individual, strategic and collective choice, but generally lacks expertise in visualization and interaction design and in linking them to realistic ecological models. All three fields are therefore complementary to understanding complex environmental data and helping citizens engage in the concrete process of acting for change.

2 ENVIRONMENTAL MODELING

While it has not traditionally been the role of environmental scientists to determine how to *encourage* any particular kind of behavior, studies in environmental modeling clearly show that individual choice matters. For instance, changes in individual behavior and lifestyle have been recognized as a key factor to mitigating climate change [15]. Most importantly, models can provide guidance as to what specific behavioral changes may have the greatest impact. With

respect to carbon emissions, for instance, examples such as living car-free, reducing air travel, purchasing low-carbon-footprint durable and repairable products (and keeping them longer) or switching to a green electricity supplier have shown high mitigation potential consistent with high levels of well-being [6].

Research from environmental modeling provides reliable estimates of potential mitigation impacts, for example, through tools such as the carbon footprint [7], or material footprint, which covers a wider range of environmental issues [18]. Climate sciences have also developed downscaling methods [8] which could be of help to provide data-driven information about local impacts of climate change, or local implications of climate change mitigation scenarios. They do however lack expertise on how to design communication and visualization tools to convey their results to non-experts and on how to study if these tools are indeed effective.

3 BEHAVIORAL ECONOMICS

Behavioral economics use experiments to provide insight into the determinants of human behavior, and the management of common goods and associated dilemmas are one of the major research directions. The five basic principles of experimental economics research are (i) controlled variation; (ii) causality (not correlation); (iii) minimalistic settings validation; (iv) non-deception or common knowledge about the task (participants have information about known and unknown rules and parameters), and (v) incentivized choice: decisions in economic experiments have real-world consequences (usually monetary) in order to encourage participants to take their decisions seriously and align lab decisions with basic preferences that may appear outside the lab. Behavioral experiments have a relatively strong internal validity, based on game theoretical models and mathematical predictions [17].

Researchers in behavioral economics have been studying people's behavior in the context of environmental decision-making by abstracting such decisions using a variety of common experimental paradigms (see Table 1 for a summary

Public good game	Public good[1]games are a metaphor for modeling cooperative behavior in groups with opportunities for free riding. Participants have an endowment and the liberty to contribute to a public good that will be redistributed to all, irrespective of their contribution, which allows free riders to benefit from the efforts of the others.
Public bad game	Public bad[2]games are a variation of public good games where participants are instead endowed with "bads" of which they need to get rid.
Common pool resource game	Common pool resources games are extraction metaphors in which a resource that benefits all can be appropriated by self-optimizing individuals, which leads to over-extraction and a "tragedy of the commons" in the future (some individuals will not be able to benefit from the resource).
Learning-to-forecast experiment	Learning-to-forecast experiments are static or dynamic coordination games in which individuals learn the norm or predict the equilibrium or evolution path of an unknown parameter through repeated interaction or mental simulation. They learn either adaptively from the consequences of their actions or through eductive targeting "in the dark".

Table 1. Common experimental paradigms related to environmental issues

[1]Public goods are goods which are (1) non-excludable, that is, people who do not pay for such goods cannot be excluded, and (2) non-rivalrous, which means that use by one person does not prevent other people to use it as well nor does it reduce their ability to access the good. Examples include public parks or street lighting.

[2]Public bads are the symmetric opposite of public goods. They are non-excludable and non-rival, and negatively affect welfare. A prominent example is air pollution.

of particularly common ones). These basic game-forms (a) isolate and test pro- and anti-social behavior, (b) integrate both individual and institutional (managerial) decision making, and (c) simultaneously consider the behavior of many participants interacting with the context, but also among themselves (hence allowing analysis of aggregate behavior). All three are important dimensions of environmental decision making – i.e., making decisions that have an impact on the environment). The most relevant classes of paradigms include social dilemmas (public good games to model costly effort such as recycling, and common pool resource management problems as studied by Ajdukovic and colleagues [2] to model individualistic overexploitation of forests) and learning-to-forecast experiments (see Hanaki et al. [12], to model energy consumption for instance) – see Table 1.

While such experiments have a strict, principled methodology, they use very simple presentation formats – in most cases, the stimuli used are pure text and numbers shown on a computer screen. Experiments very rarely use interactive visualizations or experiences that involve more complex presentation formats or non-conventional media (e.g., virtual-reality displays). There have been a few attempts at using virtual representations to influence the salience of the consequences of participants' decisions. These experiments have used two classes of "virtual" humans: those controlled by algorithms (agents) and those controlled by other humans (avatars), and two classes of virtual environments: low-immersive virtual environments such as desktop renderings and (online) virtual worlds and highly-immersive 3D virtual environments [14]. More recently, Fujimi and Fujimura [11] and Mol et al. [21] tested VR interventions with environmental and social cues for evacuation decisions in case of natural disasters. Haruvy et al. [13] find that contributions to a public good increase when they are visible to other participants. Faralla et al. [9] examine connections with future selves in a VR environment. The use of VR in behavioral economics experiments is mainly justified by the need for ecological validity.

A major limitation of previous VR experiments in behavioral economics is that they are individual-choice experiments: an individual observes or interacts with a representation of the world and makes decisions alone. These studies miss the collaborative, competitive, and contagious dimensions of real human decisions, which are important, especially when those decisions impact a shared environment. Collective actions add a layer of complexity due to the unpredictability of others' behavior. They also add complexity concerning the design and implementation of interactive systems with which participants are asked to interact.

4 COMBINING OUR EXPERIMENTAL TOOLBOXES

Typical quantitative HCI methods measure people's performance when executing certain tasks using different user interface designs. Typical measures are time taken to complete a task and errors while doing so. A major threat to the validity of this classic approach is the choice of task: if the task is not a justifiable abstraction of a common way in which people can be expected to use the design, then the experiment cannot provide insights into which design "is better". Experimental design basically aims to operationalize "better" into something measurable, like time taken or errors made. One could argue that in the area of SHCI, time taken is most likely not an informative measure. One could even imagine that if people engage longer with a design, then they might take away more from that interaction. Errors might be more relevant, as one could argue that a "good" design enables people to understand something better and make less erroneous decisions.

However, in climate mitigation scenarios there are no obvious "right" and "wrong" decisions. Instead different kinds of benefits and costs are attached to different kinds of decisions and one has to weigh these benefits and costs to make an informed decision. To take individual decisions as an example, costs are often monetary, but they can also come in terms of increased time spent (such as taking the train instead of flying), or in terms of reduced comfort (such as

lowering the thermostat or getting up earlier to use public transportation instead of a personal car), and they can even be more abstract, such as increased risk of unemployment. Benefits are often rather intangible and far away in time and space, such as limiting global temperature increases to a certain level, overall well-being of the population or reduction in inequality between or within countries.

Combining the toolboxes of HCI and behavioral economics enables researchers to study determinants of behavior and selecting among design options before committing to designs with which it is worth running long-term field studies.

5 EXAMPLE

A first research project coming out of this collaboration centers around what we call augmented-reality waste accumulation visualizations or *ARwavs* [3]. ARwavs are virtual representations of waste accumulation embedded in people's immediate physical surroundings. Figure 1 shows four examples for different types of waste produced over the course of a day: food waste, waste water, resources for electronic devices, and plastic cups from a coffee machine. ARwavs are a type of eco-feedback information display [10]: they make typically hidden or invisible consequences of human actions visible, but they do not necessarily show the outcome of actual behavior, like a meter would. Instead, they enable people to extrapolate and (virtually) accumulate *potential* individual or group actions over time to get a sense of the outcome.

On the HCI side, such displays can be evaluated in many ways. For instance, by questioning to what extent these representations give a visceral sense of quantities (e.g., whether people get a better sense of the quantities compared to alternative representations) or are engaging on affective aspects (e.g., whether people feel more emotions or feel more engaged). A first study [3] with 20 participants focused on the latter, comparing the emotion intensities felt by employees when seeing their company's building waste visualized in different ways. Participants overall reported

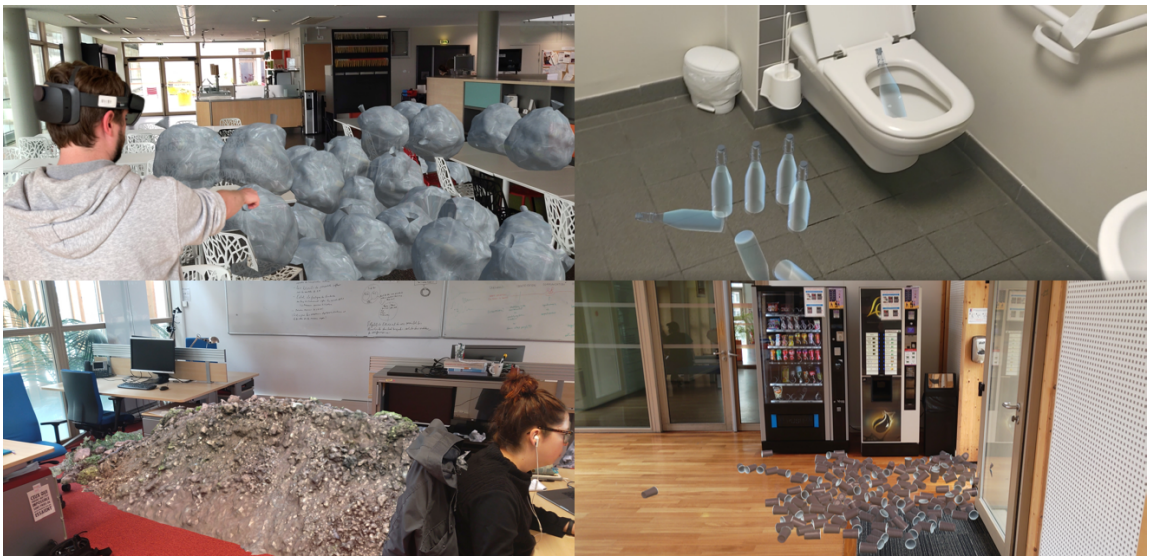

Fig. 1. Illustrative examples of prototyped ARwavs. (a) On the top left hand corner, a user looks at the amount of waste produced by his corporate restaurant in a week. The waste is represented by virtual trash bags which are displayed directly in the restaurant using augmented reality. (b) On the top right hand corner, 9 Litres of water represented using water bottle next to the toilets (average flush amount of water).(c) On the bottom left, the approximate amount of material displaced and emitted to manufacture 8 smartphones . (d) Bottom right, the quantity of single-use plastic cups accumulated for a given period of time. Captured with Hololens 2.

higher emotion intensities after having seen the amount of waste shown using an ARwav (see Figure 1 (a)), than a similar visualization displayed on a screen, or a simple numerical statement of the amount of trash bags.

We conducted an experiment [1] based on a variation of a public bad game in which groups of five participants were facing an usual recycling/incineration dilemma with an "end-of the-world" termination possibility related to non-responsible behaviors. 277 participants were involved in this experiment. The experiment was incentivized as participants disposed of an endowment they had to decide whether to keep or use to recycle their waste. Recycling was costly, but the free incinerator option had a limited capacity. The selfish strategy was to incinerate as much as possible, while hoping that others would not do the same, as an overfilled incinerator would "explode", and this would lead to zero profits for all. Participants had the possibility to make provisional choices and they could receive feedback from controllers in charge of the incinerator to gauge the likelihood of it "exploding". Those controllers had access to the state of the incinerator through headsets in which the corresponding visualizations from[3] were implemented. Feedback was harsher at the extreme values (low and high provisional incineration quantity) and adjustments in the final incinerated quantity were faster when using the visualizations.

6 CONCLUSION

The mitigation of climate change is a vast problem that no single discipline can solve on its own, and researchers from different domains work towards the same goal, moving towards a more sustainable lifestyle. Energy-economy modelers work to identify which kinds of lifestyles are compatible with the goal, behavioral economists study which factors are predictors of pro- or anti-social behaviors, and HCI and visualization researchers explore the vast space of sustainability *in* design [5] (that is, how to consider sustainability in the material design of products), and sustainability *through* design [19] (that is, how to design technology to facilitate sustainable decision-making). Each domain has accumulated rich knowledge, which may also be of use in other domains to select among the many different options a researcher is often confronted with when trying to decide which factors to include in a study design or which dimensions to explore in a rich design space. Interdisciplinary approaches can be a promising way to navigate these gardens of forking paths.

ACKNOWLEDGMENTS

This research is funded by ANR, the French National Agency for Research (Agence Nationale de la Recherche, grant ANR-22-CE33-0003 Be·Aware).

REFERENCES

[1] Ivan Ajdukovic, Ambre Assor, Aymeric Ferron, Eleonora Montagner, Eli Spiegelman, and Angela Sutan. 2023. The man who saw the (end of) the world: is AR a credible tool to enhance pro-environmental behavior? Behavioural Science and Policy Events, UCD.

[2] Ivan Ajdukovic, Eli Spiegelman, and Angela Sutan. 2019. Égoïste maintenant, ou altruiste (pour) demain? Stratégies inter vs intragénérationnelles pour la conservation d'une ressource commune. *Revue économique* 70, 6 (2019), 1153–1170. https://doi.org/10.3917/reco.706.1153 Publisher: Cairn/Softwin.

[3] Ambre Assor, Arnaud Prouzeau, Pierre Dragicevic, and Martin Hachet. 2022. Augmented Reality Waste Accumulation Visualizations. (Dec. 2022). https://hal.science/hal-03907474 preprint.

[4] Rachel Bick, Erika Halsey, and Christine C Ekenga. 2018. The global environmental injustice of fast fashion. *Environmental Health* 17 (2018), 1–4. https://doi.org/10.1186/s12940-018-0433-7

[5] Eli Blevis. 2007. Sustainable interaction design: invention & disposal, renewal & reuse. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. 503–512. https://doi.org/10.1145/1240624.1240705

[6] Felix Creutzig, Leila Niamir, Xuemei Bai, Max Callaghan, Jonathan Cullen, Julio Díaz-José, Maria Figueroa, Arnulf Grubler, William F. Lamb, and Adrian Leip. 2022. Demand-side solutions to climate change mitigation consistent with high levels of well-being. *Nature Climate Change* 12, 1 (2022), 36–46. https://doi.org/10.1038/s41558-021-01219-y Publisher: Nature Publishing Group UK London.

[7] Angela Druckman and Tim Jackson. 2009. The carbon footprint of UK households 1990–2004: a socio-economically disaggregated, quasi-multi-regional input–output model. *Ecological economics* 68, 7 (2009), 2066–2077. https://doi.org/10.1016/j.ecolecon.2009.01.013 Publisher: Elsevier.

[8] Marie Ekström, Michael R. Grose, and Penny H. Whetton. 2015. An appraisal of downscaling methods used in climate change research. *Wiley Interdisciplinary Reviews: Climate Change* 6, 3 (2015), 301–319. https://doi.org/10.1002/wcc.339 Publisher: Wiley Online Library.

[9] Valeria Faralla, Alessandro Innocenti, Stefano Baraldi, Luca Lusuardi, Maurizio Masini, Vincenzo Santalucia, Diletta Scaruffi, and Matteo Sirizzotti. 2021. The effect of future self-continuity on delaying immediate gratification. A virtual reality experiment. In *Proceedings of the 32nd European Conference on Cognitive Ergonomics*. 1–8.

[10] Jon Froehlich, Leah Findlater, and James Landay. 2010. The design of eco-feedback technology. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. Association for Computing Machinery, New York, NY, USA, 1999–2008. https://doi.org/10.1145/1753326.1753629

[11] Toshio Fujimi and Kodai Fujimura. 2020. Testing public interventions for flash flood evacuation through environmental and social cues: The merit of virtual reality experiments. *International Journal of Disaster Risk Reduction* 50 (2020), 101690. https://doi.org/10.1016/j.ijdrr.2020.101690 Publisher: Elsevier.

[12] Nobuyuki Hanaki, Yukio Koriyama, Angela Sutan, and Marc Willinger. 2019. The strategic environment effect in beauty contest games. *Games and Economic Behavior* 113 (2019), 587–610. https://doi.org/10.1016/j.geb.2018.11.006 Publisher: Elsevier.

[13] Ernan Haruvy, Sherry Xin Li, Kevin McCabe, and Peter Twieg. 2017. Communication and visibility in public goods provision. *Games and Economic Behavior* 105 (2017), 276–296. https://doi.org/10.1016/j.geb.2017.08.002 Publisher: Elsevier.

[14] Alessandro Innocenti. 2017. Virtual reality experiments in economics. *Journal of behavioral and experimental economics* 69 (2017), 71–77. https://doi.org/10.1016/j.socec.2017.06.001 Publisher: Elsevier.

[15] IPCC. 2018. Summary for policymakers. In *Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3–24. https://doi.org/10.1017/9781009157940.001.

[16] IPCC. 2022. Summary for policymakers. In *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. https://doi.org/10.1017/9781009157926.001

[17] John H. Kagel and Alvin E. Roth. 2020. *The handbook of experimental economics, volume 2*. Princeton university press.

[18] Michael Lettenmeier, Tuuli Hirvilammi, Senja Laakso, Satu Lähteenoja, and Kristiina Aalto. 2012. Material footprint of low-income households in Finland—Consequences for the sustainability debate. *Sustainability* 4, 7 (2012), 1426–1447. https://doi.org/10.3390/su4071426 Publisher: MDPI.

[19] Jennifer C. Mankoff, Eli Blevis, Alan Borning, Batya Friedman, Susan R. Fussell, Jay Hasbrouck, Allison Woodruff, and Phoebe Sengers. 2007. Environmental sustainability and interaction. In *CHI'07 extended abstracts on Human factors in computing systems*. 2121–2124. https://doi.org/10.1145/1240866.1240963

[20] Ariane Millot, Rémy Doudard, Thomas Le Gallic, François Briens, Edi Assoumou, and Nadia Maïzi. 2018. France 2072 : Lifestyles at the core of carbon neutrality challenges. In *Limiting Global Warming to Well Below 2 °C: Energy System Modelling and Policy Development*, G. Giannakidis, K. Karlsson, M. Labriet, and B Ó Gallachóir (Eds.). Lecture Notes in Energy, Vol. 64. Springer. https://hal-mines-paristech.archives-ouvertes.fr/hal-01896027

[21] Jantsje M. Mol, WJ Wouter Botzen, and Julia E. Blasch. 2022. After the virtual flood: Risk perceptions and flood preparedness after virtual reality risk communication. *Judgment and Decision Making* 17, 1 (2022), 189–214. https://doi.org/10.1017/S1930297500009074 Publisher: Cambridge University Press.

[22] Christian Remy, Oliver Bates, Alan Dix, Vanessa Thomas, Mike Hazas, Adrian Friday, and Elaine M. Huang. 2018. Evaluation Beyond Usability: Validating Sustainable HCI Research. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, Montreal QC Canada, 1–14. https://doi.org/10.1145/3173574.3173790

[23] Christian Remy, Oliver Bates, Vanessa Thomas, and Elaine M. Huang. 2017. The limits of evaluating sustainability. In *Proceedings of the 2017 Workshop on Computing Within Limits*. 103–110. https://doi.org/10.1145/3080556.3080567

[24] Johan Rockström, Will Steffen, Kevin Noone, Åsa Persson, F. Stuart Chapin, Eric Lambin, Timothy M. Lenton, Marten Scheffer, Carl Folke, Hans Joachim Schellnhuber, Björn Nykvist, Cynthia A. de Wit, Terry Hughes, Sander van der Leeuw, Henning Rodhe, Sverker Sörlin, Peter K. Snyder, Robert Costanza, Uno Svedin, Malin Falkenmark, Louise Karlberg, Robert W. Corell, Victoria J. Fabry, James Hansen, Brian Walker, Diana Liverman, Katherine Richardson, Paul Crutzen, and Jonathan Foley. 2009. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society* 14, 2 (2009). https://doi.org/10.5751/ES-03180-140232 Publisher: Resilience Alliance Inc..

[25] The French Agency for Ecological Transition (ADEME). 2022 [Online]. *Assessment of the Environmental Impact of a Set of Refurbished Products*. Technical Report. https://librairie.ademe.fr/cadic/7385/ademe_impact_environnemental_reconditionnement_rapport_en.pdf

AUTHORS

Yvonne Jansen is a researcher in human-computer interaction and data visualization at the French Center for Scientific Research (CNRS). Her research interests include data physicalization, situated and embedded visualization and more generally how to help people make sense of complex data and phenomena, especially in the context of climate change.
Ambre Assor is a PhD student in human-computer interaction, mixed-reality and data visualization at Inria, Bordeaux. She studies new ways of embedding data visualizations referring to unseen physical objects of interest (e.g., distant, out-of-view objects) in the physical space, using AR.
Pierre Dragicevic is a researcher in human-computer interaction and data visualization at Inria, Bordeaux. He studies how data visualizations affect reasoning and decision-making, with a focus on visualizations beyond desktop settings, and on humanitarian applications.
Aymeric Ferron is a PhD student in human-computer interaction, mixed-reality and data visualization at Inria, Bordeaux. He studies innovative and immersive ways of presenting complex ecological data in order to make their understanding easier to non-expert.
Arnaud Prouzeau is a researcher in human-computer interaction and mixed-reality at Inria, Bordeaux. He studies the use of immersive technology to visualise and analyse data and assess their impact on users' understanding and decision-making.
Martin Hachet is a researcher in human-computer interaction and mixed-reality at Inria, Bordeaux, where he leads the Potioc project-team. His current interest is on hybrid systems (physical/digital) for engaging people in educative experiences.
Thomas Le Gallic (CIRED) is an energy-economy modeler whose research focuses on lifestyle change within the climate change mitigation challenge. His research interests include how to extract information from climate change scenarios ensembles and how to make their results interpretable for potential users (from individuals to policymakers).
Ivan Ajdukovic is a researcher in social psychology at BSB. His research topics are mainly related to pro-environmental attitudes and behaviors, how people share a common resource and quality of like at work.
Eleonora Montagner is an associate professor of philosophy of management at BSB and a member of the French School of Daseinanalyse (Husserl Archive - ENS Paris). In her research Eleonora focuses on phenomenology and aesthetics, exploring issues related to otherness and embodiment.
Eli Spiegelman is a behavioral economist. He does experimental research on strategic and individual choice, investigating the effect of attention, group identity and temporal spillovers on cooperation and decision under uncertainty.
Angela Sutan is a behavioral economist and head of the LESSAC lab at BSB. She studies eductive reasoning, social and anti-social behavior with a focus on effective incentives to enhance behavioral change.