

# Framing Water: Exploring Tensions between Social Norms and Environmental Sustainability through a Data Physicalization Game

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## Abstract

Mountain areas are especially vulnerable to climate change. In recent years, intermittent droughts have forced many Alpine huts to close early or rely on cable cars or helicopters to import water. To raise awareness of water scarcity among hut visitors, we developed *Framing Water*, a reflective game based on the data physicalization of each visitor's water consumption during an overnight stay. The game requires players to select their most essential water-using activities without exceeding a fixed limit. Yet it is designed not to provide a univocal answer about the right choices to make but to spark reflection and dialogue around trade-offs in daily practices. We evaluated it with 56 participants and found that water-use decisions are influenced by individual needs, values, and social norms. This work contributes to Sustainable HCI by showing how playful, data-driven artifacts can foster reflection and negotiation of resource use in response to climate challenges.

## CCS Concepts

• **Human-centered computing** → Interaction design; Human computer interaction (HCI); HCI design and evaluation methods; User studies.

## Keywords

Climate change, Data physicalization, Mountain, Responsible consumption, Reflective game design, Sustainability, Water scarcity

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## 1 Introduction

Climate change has affected mountainous areas more significantly than other regions [37, 45]. These areas rely on snow as a water reservoir; thus, they are much more sensitive to the rising temperatures, which disrupt the landscape and affect both the ecosystem and the economic sectors [4]. The Alps are particularly vulnerable to climate change, with glaciers retreating and snow cover decreasing annually [12, 15, 22, 61]. Furthermore, in the Alps, the impacts of climate change are compounded by the problem of overtourism [1, 89]. Following the COVID-19 pandemic, mountain areas were promoted as destinations with fresh air and fewer crowds. New visitors to these areas are often unaware of the frugal lifestyles practiced at high altitudes and of the problems caused by climate change, leading them to expect services that are difficult to deliver.

In the Summer of 2022, a severe drought impacted the Trentino mountains, a region in the Northeastern Italian Alps [1]. Besides problems in the agriculture and winter tourism sectors, the drought impacted the typical activities of mountain huts. Mountain huts are accommodation facilities that offer essential shelter and basic services (see Figure 1) to hikers, climbers, and other mountain tourists. Meals are often served at large communal tables that visitors share with strangers, and bedrooms are dormitories arranged with bunk beds. The level of comfort and available services depend on how remote the huts are: while those near urban areas resemble small inns, those at very high altitudes operate more like bivouacs with staff. In particular, high-altitude huts face significant logistical challenges: supplies such as food, drinking water, and cooking fuel are transported from the valleys by cableway or helicopter, electricity is usually self-produced through generators, and water for cooking, personal hygiene, and cleaning is sourced directly from nature: either from springs (when available) or by collecting rainwater or snowmelt.

Climate change exacerbates the fragility of this system. Warmer temperatures reduce snowfall and accelerate snowmelt, leaving huts dependent on their limited water reserves, which can be



Figure 1: A) A mountain hut in the Italian Alps, B) the bunk beds, C) the dining area.

quickly depleted if water-saving strategies are not implemented. This scarcity becomes particularly acute as tourism flows increase, creating tensions between sustaining visitor expectations and preserving essential resources. As a result, the problem of water scarcity in the Alps necessitates interventions that may range from optimizing water management infrastructure to rethinking tourism models, to raising visitors' awareness of the issue and encouraging them to reduce their water consumption.

We focused on high-altitude huts in Trentino and investigated how to foster visitor awareness of resource scarcity. We deem huts a compelling setting because, as temporary sites of shared living under resource constraints, they can serve as social laboratories for observing behaviors, experimenting with interventions, and exploring collective responses to sustainability challenges.

Over the past fifteen years, HCI has increasingly engaged with questions of sustainability [14, 34, 49, 74], climate change [59, 83], and eco-social justice [21, 27, 82]. Within Sustainable HCI (SHCI), a long-standing area of inquiry has been the role of technology in prompting individuals to reflect on their consumption patterns and encouraging them to adopt more responsible practices [10, 39, 79]. The domains of consumption explored in this body of work encompass mobility, energy, waste, food, and water. Practical solutions in the early 2000s often focused on fostering responsible water use by leveraging eco-feedback systems and pervasive ambient displays [30], in line with the technological trends of the period. These works aimed to motivate users to reduce their water consumption by making visible the quantities consumed [2, 47] and providing feedback when thresholds were exceeded through ambient displays. These technological interventions had the advantage of being deployed in both private and public spaces, but their effectiveness in promoting long-lasting user behavior change has been questioned [16]. More recent works have expanded to reflective approaches whose primary goal is not to prompt immediate behavioral change, but to be thought-provoking and awareness-raising. These devices aim to seed awareness and knowledge in users that they can apply later when they face related situations. Awareness and reflection are typically fostered through serious games [35, 58], speculation [9], reflection on the human-nature relationship and entanglement [86, 90], and acknowledging multiple cultural perspectives on the topic, such as those of indigenous peoples [65].

Our work builds on prior HCI research on fostering responsible water consumption by encouraging reflection rather than persuasion. We present a prototype that combines game mechanics with

data physicalization, enabling players to reflect on their needs, evaluate priorities, and make compromises. We acknowledge that the practices and rationales for water conservation in regions facing scarcity are profoundly shaped by the cultural, environmental, and social context and that these factors can lead to unexpected outcomes, such as conservation not always being desirable, environmentally responsible behavior not being recognizable, and the path to sustainability not being clear [36]. Therefore, rather than directly fostering behavioral change, our game stimulates reflection and dialogue among players about their habits and how the related water consumption might be reduced. Our research questions were:

- How can a data physicalization-based game prompt reflection on water consumption behaviors?
- What kind of reflections and trade-offs do people put into play when making decisions about when and how to reduce water consumption?

Our work contributes to Sustainable HCI by proposing a reflective game based on data physicalization that does not prescribe a single optimal solution but invites players to reflect on the trade-offs that each of them entails, including interpersonal differences, social acceptability, and the risk of problem displacement that may emerge when limited resources and close cohabitation intersect.

## 2 Related work

In the following sections, we present the HCI literature that has inspired our work and the sub-areas of Sustainable HCI to which we aim to contribute.

### 2.1 HCI for Sustainable Consumption

The sustainability of technology and the human practices that involve it emerged as a domain of interest for HCI in the late 2000s. The first works on this topic focused on applying subtle persuasive strategies, often through nudging and ambient displays, to encourage citizens to reduce their consumption [2, 11, 30]. After a decade, SHCI entered a period of reflection (still ongoing) during which scholars have made several attempts to analyze, cluster, and organize research production by approach and intervention area, and to provide a roadmap for future research. Workshops [80] as well as literature reviews [16, 19, 20, 49] have highlighted both the achievements and limitations of SHCI, emphasizing the need to move beyond technology-centric interventions aimed at changing individual behaviors and engage at a broader level with the societal,

political, and cultural dimensions of sustainability. Some of these works propose considering not only environmental needs but also social and economic ones by connecting environmental protection to the tools of sustainable development, such as the Triple Bottom Line [46, 74] and the Sustainable Development Goals [34]. Others invite HCI researchers to address the problem at different scales, ranging from small groups of activists to the regional level [20], and develop technology that supports decision-makers in designing green policies [14].

More recent contributions focused the reflection on how SHCI could be more impactful. The community has gathered in workshops to discuss the need for technological interventions that support sustainable practices, operate sustainably, and have a lasting impact [64], as well as to create synergies between different HCI approaches and other disciplines [57]. Collectively, this body of work has shifted attention from designing ‘green’ technologies in isolation to considering how digital systems shape and are shaped by complex socio-ecological contexts.

Within this constantly evolving landscape, research on sustainable consumption has remained a key strand in SHCI, focusing on how digital technologies mediate everyday practices such as food management, energy use, and resource sharing. However, this evolution in the framing of the sustainability problem has led to greater methodological diversity. For instance, studies on food practices have explored how meaningful data representations can inform sustainable choices [51] and how ICT supports sharing economies that redistribute surplus and scarcity [25]. Air quality data have been enriched with the lived experience people have of air, such as perceptions, histories, imaginations, and the socio-political context, to make them more meaningful [52]. Speculative and critical perspectives have examined the power of both positive and negative emotions to foster behavior change and how to integrate them into the design of technology [91]. Additionally, they have explored how post-growth imaginaries can challenge consumerist logics in HCI [79].

The work presented in this paper is rooted in the tradition of Sustainable HCI, as it addresses the conservation of natural resources and aims to encourage people to reduce their water consumption. However, it also advances Sustainable HCI research, facilitating the understanding of personal data consumption in relation to a collective of people (the mountain hut), not by prescribing a precise new behavior to adopt, but by fostering reflection through a game. As such, we strive to bridge everyday practice and systemic transformation, fostering reflection through a game and laying the groundwork for longer-term cultural shifts toward sustainability.

## 2.2 Reflective games for sustainability

Games have long been used to convey information, teach concepts, and raise awareness about environmental issues and sustainable behaviors. Some focused on food waste [53, 81], others on water scarcity [35], and more recently on climate change [84, 92]. A wide variety of formats have been employed for these purposes, including video games [26], board games [50], mobile apps [53], and hybrid games that combine physical and digital elements [55]. Due to their educational aims, these are commonly referred to as ‘serious games’, i.e., games that merge playful mechanisms with an

educational message and a focus on behavior change. These games allow players to explore scenarios where they can exercise their agency and visualize consequences [29, 87].

However, serious games are not free from criticism. Khaled [44] argues that they are often overly prescriptive and detached from the real world. The author highlights three problematic aspects: *safe environments*, meaning settings where players can experiment without facing real-world consequences; *clear solutions* that disempower players from tackling complex issues; and *stealth learning*, where learning occurs without explicit opportunities to connect in-game insights to real-life contexts. In response, Khaled proposed a new approach to game design based on reflection, triggering questions in players rather than offering answers.

Khaled’s proposal [44] draws on Reflective Design, an approach that gained traction in HCI after the seminal work of Sengers et al. [78]. This approach emphasizes technology’s potential to help users reflect on their own experiences, positioning reflection as a key design outcome. According to Sengers et al. [78], design should leverage exploration and surprise to trigger users’ reflexivity. In this regard, Gaver et al. highlighted the value of Ludic Design, which uses curiosity and exploration to promote engagement and meaning-making [32], as well as the productive role of ambiguity, intended as an open-ended interpretation of the technological system’s scope [31].

Although there is still no consensus on how to define or evaluate reflection, HCI researchers have continued to develop principles for designing technologies that promote it [5–7, 28]. Fleck and Fitzpatrick [28] identified five different levels of post-experience reflection, ranging from revisiting past experiences (grade zero) to critical reflection, which connects personal experiences to broader implications through analysis and explanation. Baumer et al. [5] conceptualize reflection as a three-stage process: i) *breakdowns*, i.e., moments of surprise, uncertainty, or conflict, that trigger reflection; ii) *inquiry*, which is the conscious, intentional examination of one’s previous experiences, knowledge, and assumptions; and iii) *transformations*, i.e., the changes that occur when new understanding reshapes perception or behavior. Bentvelzen et al. [7] reviewed the literature and analyzed smartphone apps to identify strategies to support reflection on personal data. These include design strategies that resonate with those identified in previous work, such as leveraging temporal perspectives (revisiting the past or projecting the future), using surprise, ambiguity, or reframing to create moments of discovery, enabling dialogue with others or with the system itself, and supporting comparison with rules or peers.

Khaled’s [44] call for more reflective game design has been taken up by part of the HCI community working with games. Mekler et al. [56] applied Fleck and Fitzpatrick’s framework to categorize types of reflection that players experience during gameplay. Miller et al. [60] synthesized prior work into a framework that leverages five strategies for prompting player reflection (Disruptions, Slowdowns, Questioning, Revisiting, and Enhancers) and connects them to the two types of transformation triggered by in-game reflection: endo-transformations, which affect in-game behaviors such as changes in play style and game conceptualization, and exo-transformations, which influence beliefs and actions beyond the game. Examples of games about sustainability that illustrate how reflective principles can be implemented in practice are Exchangeopolis [17], which

demonstrates how board games can be designed to explore scenarios and surface tensions related to tokenization in community value exchange, and Climate Club [67], which helps people make sense of collective climate actions in relation to the barriers they face.

In our work, we refer to Sengers et al.'s [78] definition of reflection as the practice of bringing "unconscious aspects of experience to conscious awareness, thereby making them available for conscious choice". Furthermore, because our game prompts reflection on personal habits, we draw on concepts from reflection on personal data [7] and reflective game design [44, 56, 60].

## 2.3 Data Physicalization

In the last 10 years, Data Physicalization has appeared as a new research subfield in HCI. It lies at the intersection of Data Visualization, Tangible User Interfaces, and Design [3, 42] and investigates the design, prototyping, and evaluation of "artifacts whose geometrical shape or material properties encode data" [42]. While screen visualizations can accommodate various datasets and support interactive exploration through tools such as dynamic filtering and search [41], physicalizations leverage active perception, multisensory engagement, and embodied interaction to enable people to think about, explore, and share data [42].

Much HCI work on data physicalization has focused on defining its design space. Some of these frameworks focus on the properties of the physicalized artefacts. Dumičić et al. [24] distinguish between the conceptual elements of physicalization, including design objectives and metaphors, and the practical elements, such as appearance and user experience. Hornecker et al. [38] propose a shared vocabulary of constituent elements of data physicalizations arranged into *explicit variables*, i.e., features that encode data; *implicit properties*, i.e., the aspects contributing to the experience of the data physicalization; and the *consequential aspects* emerging from the interaction with the artefact but not intentionally planned by the designer. Conversely, other frameworks explicitly include interaction context as a property of the data physicalizations. Sauvé et al. [68] extend the definition of physicalization to the broader concept of 'physecology', i.e., the context and the ensemble of distributed physical and digital elements that enable interaction. Similarly, Bae et al. [3] classify data physicalizations in terms of the interaction context, the physical structure of the artefact, and interactions with both the data and the artefact that embeds them. Finally, Offenhuber [62] distinguishes between epistemological and ontological perspectives that designers adopt when creating physicalizations of data. Epistemic perspectives emphasize the role of data as products of the human mind, which interprets observations captured by the senses. In contrast, ontological ones understand data as physical things, patterns in the world that exist independently of the human mind. In line with Offenhuber, van Koningsbruggen et al. [88] expanded the design space of data physicalizations to represent not only objective and mathematical data but also the soft, subjective qualities of interacting with data, which they refer to as 'tacit' data.

Data physicalization has frequently been employed to raise awareness of sustainability challenges, including water scarcity, and to encourage more sustainable behaviors. Adrien Segal has devoted much of her artistic practice to physicalizing water-related

data. In her work, Segal translates statistical data, such as the annual water consumption in the United States [75], three decades of snowfall in California [76], and the speed of Arctic ice melting [77] into data sculptures, i.e., "data-driven artifacts of various shapes and sizes (...) built by artists and designers who seek to elicit emotions and convey meaning beyond mere data" [41]. While these pieces are typically exhibited in galleries without requiring direct tactile interaction, they rely on what Hornecker et al. [38] term "imagined touch," evoking the textures of water excavation in soil [75] or the volume of accumulated snow [76]. Other examples of water-related data physicalizations include Certain Uncertainty [73], which visualizes water stress across global megacities through walkable relief maps, and The Data Soap [48], a series of soap bars patterned with colors representing water-related datasets. Closer to our domain, Mencarini et al. [58] proposed two concepts addressing water scarcity in mountain huts: (i) a participatory installation in which guests place tangible markers of their water consumption on a two-plate scale to visualize its impact on hut reserves, and (ii) a game designed to prompt reflection on personal water use during hut visits.

Building on this prior work, our study contributes to the emerging intersection of data physicalization and games. Specifically, we extend the exploration initiated by Mencarini et al. [58], which addressed the same topic by focusing on the data curation and concept ideation phases. Conversely, we designed, prototyped, and evaluated a data physicalization game that combines tangible interaction with game mechanics. To our knowledge, the only other game explicitly based on data physicalization is Co-gnito [63], a participatory game that synthesizes urban experiences from multiple players into a single collective physicalization. Our game aims to transform abstract data on water scarcity and individual consumption into concrete, manipulable forms and into a playful interaction that fosters deeper reflection on how each visitor's behavior impacts the collective life of a mountain hut.

## 3 Design and prototyping of *Framing Water*

### 3.1 Design inspiration and rationale

Mountain huts are typically not connected to aqueducts and rely on natural resources, such as springs, rainwater, or snowmelt, for their water supply. As a result, in the Summer of 2022, when an intense drought struck the Alps, many mountain huts of Trentino faced severe difficulties. Some relied on public subsidies to transport water by helicopter to remain open, while others were forced to close earlier than usual. This crisis drew considerable attention from local media and fueled public debate around the growing impacts of climate change and overtourism.

To better understand how huts cope with water scarcity, we interviewed 12 mountain hut managers. The interviews revealed that managers consider water scarcity a common condition that can sometimes become an emergency. The main strategy they put in place to adapt to the problem is limiting access to the bathrooms, as they are the largest source of water consumption. For example, in normal conditions, many hut managers proactively reduce toilet flush water discharge from 9 to 6 liters and charge extra for showers, providing them only to multi-day trekkers. In drought situations, when the hut's water reserve rapidly decreases, huts

	ARRIVAL (check-in and payment)	SETTLING IN (pick your bed, freshen up, and relax)	DINNER (food, chat, games)	GETTING READY TO SLEEP	★ NIGHT Lights off → Awakening	BREAKFAST	GETTING READY TO LEAVE	DEPARTURE
ESTIMATED TIME	16:40 – 16:50 (10 min.)	16:50 – 18:30 (1 hr 40 min.)	18:30 – 21:30 (3 hrs.)	21:30 – 22:00 (30 min.)	22:00 – 6:30 (8 hrs. 30 min.)	06:30 – 7:00 (30 min.)	07:00 – 7:30 (30 min.)	07:30
SPACE								
SOCIAL RELATIONS	The manager explains the hut rules and gives instructions	Taking turns in the bathrooms	Sitting at shared tables, often with unknown people, chatting	Toilets could be crowded, waiting for your turn	Sleeping in shared rooms with 6-10 bunk beds	Sitting at shared tables, often with unknown people	Toilets could be crowded, waiting for your turn	Coordinating with your partner
VALUES	Efficiency	Social acceptability	Socialization	Social acceptability	Social acceptability	Efficiency	Efficiency	Adventure

Figure 2: Activity model of a one-night stay at a mountain hut.

may even restrict access to toilets altogether, asking guests to relieve themselves in the surrounding nature, and suspend showering entirely. These measures frustrate guests unfamiliar with the modest, resource-conscious hospitality that mountain huts traditionally offer, which becomes even stricter during periods of drought. Nevertheless, the hut staff do not have time to explain the reasons behind water-saving restrictions to each visitor individually, especially given the increase in the volume of tourists. Often, they rely on signs posted around the hut to inform customers of restrictions and raise awareness of the situation.

Based on these premises, we decided to design and develop an artefact that could sensitize mountain hut visitors to the fact that water can be a limited resource even in the mountains and invite them to make conscious use of it. To conceive an artefact suitable for the Alpine hut context and capable of conveying this message, we drew on 3 of the 4 lessons learned by Mencarini et al. [58], namely, i) Designing for remote, off-grid contexts; ii) Facing the limit; iii) Provoking thoughts, triggering conversations. We refined them and added a new one based on the personal experiences of three of the four authors, who are long-time residents of Trentino and regular visitors to the local mountain huts. Below, we explain our design rationale.

*Merge with the hut life.* We leveraged our direct knowledge of mountain hut life to develop a model of the activity of a typical overnight stay in a mountain hut (see Figure 2). We mapped out the key activities, their duration, the spaces where they occur, the social interactions associated with them, and the values that guide them. From the activity model, we realized that the stay’s calmest and most sociable moment is after dinner, when people linger around, relax, and socialize. In fact, many huts offer books, card decks, and other board games to entertain guests. From this realization, we decided to develop a game to be played in a hut after dinner.

*Consider contextual constraints.* Since mountain huts often have infrastructural limitations - not all are reached by mobile phone signals or have Wi-Fi, charging facilities can be unavailable, and occasional energy shortages may occur - we designed our game to be low-energy-consuming and low-maintenance.

*Invite hut visitors to reflect on what they can do individually to limit their consumption.* Our goal was to convey that water is a

scarce resource and that, for everyone to benefit from it, individual consumption needs to be limited, and that limit needs to be respected. Instead of prescribing specific behaviors or presenting a single correct course of action, we designed our prototype to spark questions and conversations among hut visitors. Accordingly, we emphasized self-reflection over competitiveness as the core game dynamic.

With these constraints and opportunities in mind, we created *Framing Water*, an interactive puzzle game designed to engage visitors in reflecting on their water use while staying at a mountain hut. *Framing Water* is inspired by the Tangram, a Chinese game consisting of differently sized triangles that can be combined freely to create various shapes. Once finished playing, the pieces need to be combined into a precise order to fit into a frame, making the action of putting the game away a game itself. As in the Tangram, the *Framing Water* pieces must be arranged so they do not go beyond the edges of a hexagonal frame, and the more pieces players want to accommodate, the more challenging it is to identify the right combination to fit them, making the puzzle work as a brain teaser (for an overview of the game, see Figure 3). It is designed for single players, as the main activity consists of choosing and arranging pieces corresponding to the water consumption of one person on a board. Still, the gameplay happens in a very social context, the hut, and the decisions required by the game can be made together with other players acting as one.

### 3.2 Data Curation, Physicalization, and Materials

The puzzle pieces represent the liters of water consumed by a visitor’s different activities during a one-night stay in a mountain hut. The activities and their estimated consumption are derived from Mencarini et al. [58]. They are: toothbrushing (1 liter), eating a snack (intended as cake and tea, 2 liters), personal hygiene (intended as refreshing at sinks, 3 liters), a hot meal (including cooking and dishwashing, 3 liters), and single-use of the WC (6 liters). Each piece features an icon depicting the corresponding activity to support immediate recognition. Drinking water was excluded from these calculations, as most huts lack treatment facilities; instead,



Figure 3: The Framing Water game.

Activity	Water consumed	Puzzle pieces
Brushing teeth	1 Liter	
Eating a snack	2 Liters	
Personal hygiene (face, neck, armpits)	3 Liters	
Hot meal	3 Liters	
Single WC use	6 Liters	

Figure 4: The correspondence between activity, water consumption, and piece shape as explained in the game instructions.

potable water is supplied in bottles via cableway or helicopter and therefore does not impact the hut’s stored reserves.

Unlike Mencarini et al.’s [58] original design concept, which represented the amount of water required for each activity using square tiles linked in chains, we chose to craft the pieces in a hexagonal shape. This hexagonal shape was chosen for its modularity, as it tessellates easily and can be combined to form a larger hexagon, while also evoking the natural forms of ice crystals and snowflakes. The one-liter piece consists of one hexagon, while activities requiring more water are represented by clusters of hexagons equal to their consumption value (see Figure 4).

Adopting a hexagonal shape for the overall puzzle required us to adjust the estimations of Mencarini et al. [58]. According to them, the average consumption per overnight guest at a mountain hut is 40 liters. However, for geometrical reasons, single hexagons can be summed up into a bigger regular hexagon only in clusters of 37 or 61. Therefore, we opted for 37 liters as the maximum amount of individual water consumption, which we estimated would be used for 4 WC uses, 2 complete meals, 2 toothbrushings, 1 snack, and 1

personal hygiene item. Finally, to allow flexibility during gameplay, we added an extra piece to each activity.

### 3.3 How to Play with *Framing Water*

The game unfolds through three different phases, where its different components come into play: i) Selecting the pieces to play with, ii) Combining the pieces, and iii) Scoring. (For a detailed view of the game phases, see Figure 5).

*Phase 1: Selecting the pieces to play with.* As the first action to be completed in the game, players must select the pieces they want to play with to build the puzzle. A scenario outlined in the instructions (Figure 6) places the players in an overnight stay at a mountain hut, beginning upon arrival at 16:00 and concluding the following morning at 7:30, when the guests depart for their next adventure. Along the scenario, questions prompt players to think of what they would do regarding eating, personal hygiene, and toilet use during their stay. For each activity they foresee themselves doing, they must select the related piece. Picking the pieces to play with is a crucial phase of the game, as it is here that people start reflecting on their own habits, what is indispensable to them, and what they can consider renouncing. In this first phase, the game uses questioning [7] to maintain a slow, focused interaction [60] and encourage players to engage in *anticipatory reflection*, by which we mean projecting themselves into a future situation and considering how their everyday practices translate into water consumption quantities.

*Phase 2: Combining the pieces.* After the pieces are selected, players can access the large hexagonal board to place them. The board can accommodate 37 hexagons, corresponding to 37 liters, which is the estimated maximum amount of water each person should use during an overnight stay. A frame surrounds the big hexagon to represent the personal water consumption limit that should not be exceeded. The difficulty of combining pieces in the given frame is a metaphor of the difficulty of staying within the limits. Next to the framed board is an LED strip with 37 blue LEDs, all of which are on at the beginning of the game. As players start to place the pieces, the LEDs turn off progressively from the top, according to the piece size: if a 3-liter piece is placed on the board, it will turn off three lights. The LED strip serves as a reinforcement of the board: players are made aware of how much water they still have left to use or have saved (if they have finished playing) by counting either the number of empty spaces on the board or the number of LEDs still lit. The second phase is where the ‘Disruption’ may happen [60]. If a player has selected pieces for more than 37 liters, a dissonance will occur between their desired activities and the possibility of actually carrying them out. In such a case, the player is called upon to revise their choices and renounce some of the activities/pieces.

*Phase 3: Scoring.* Next to the LED strip, three alpine animals are represented: an ermine, an ibex, and a salamander, each accompanied by a feedback message for the players (see Figure 7):

- The ermine covers the first 22 LEDs, and its message is “Props to you for the effort, Ermine! But are you really planning to last 12 hours on less than 22 liters of water? Take a whiff - if you’re all alone, it might not be by choice!”



Figure 5: Players interacting with Framing Water during the three game phases: A) Selecting the pieces, B) Combining the pieces, and C) Scoring.

**A typical stay in a mountain hut**

**16:00 – Welcome to the Mountain Hut!**  
 You've just arrived after many hours on the trail.

- Would you like to use the toilet after your hike?
- Will you freshen up at the sink and find a way to do it with as little water as possible?
- Would you like a quick snack before dinner?

Take a piece for each activity you plan to do. Do the same for next activities too.

**19:00 – Dinner time**  
 Time to fuel up for tomorrow's adventure.  
 Will you join the hut's dinner tonight?

**21:30 – Getting ready for bed**  
 As bedtime approaches, plan your evening routine.

- Would you like to brush your teeth before bed?
- Do you need to use the toilet before settling in for the night?

**06:00 – Good morning!**  
 A new day of adventure for another adventure!

- Would you like to use the toilet before breakfast?
- Will you quickly freshen up at the sink to kickstart your day?

**06:30 – Time for breakfast**  
 Prepare to start your day.

- Will you be joining us for breakfast?
- After breakfast, would you like to brush your teeth before hitting the trail?

**07:30 – Departure**  
 Before you hit the trail

- Would you like a snack for the road or just a coffee before you go?
- Do you need one last trip to the toilet before you head out for the day?

**Ok, now you are ready to play!**

Figure 6: The scenario in the instructions aimed to help players reflect on their activities and select the corresponding pieces.

- The ibex covers LEDs 23-29, and its message is “Hey Ibex, you’re doing awesome! If you stop before 29 liters, the water you’ve saved will help reduce the stress on the mountain hut!”
- The salamander covers the last 7 LEDs (from 30 to 37), and its message is “Good job, Salamander! Thirty-seven liters is the maximum each person should consume when staying in a mountain hut. Reflecting on your actions and assembling all the pieces is a great accomplishment!”

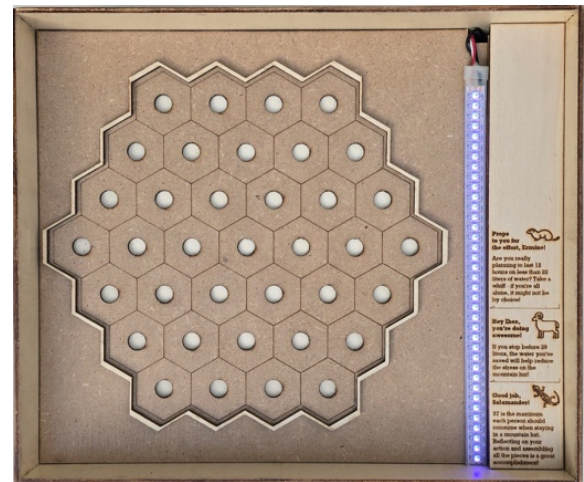


Figure 7: The LED strip with the animal description next to it.

The animals’ messages were intended to serve as *enhancers* [60], i.e., design patterns that support reflection after gameplay, provide players with hints about their results, and help them connect the game experience with real-world situations. Notably, all the messages are positive, albeit to varying degrees. The only way to lose in the game is to pick pieces for more than 37 liters and, thus, to go beyond the edges of the frame. This is because 37 liters is already a small amount of water. The game’s goal is not to push players to consume as little water as possible, but to prompt them to reflect on a realistic representation of their needs and habits. In fact, the slightly most negative feedback is that of the ermine because it is improbable for one person to consume less than 22 liters of water in 15 hours; its message aims to make players realize they might have made unrealistic choices.

These animals were chosen because they live in the mountainous area where the game was developed and have funny stories about water, hygiene practices, or bad smells. The ermine emits a foul odor as a defense mechanism, similar to a blend of rotten eggs, garlic, and burnt rubber. The ibex cleans its coat by rolling in the dust, rather than washing itself in streams. The salamander is an amphibian; it lives in humid forests but returns to the water to

reproduce. These fun facts were written on the last page of the instruction sheet to help players understand the animals' reference (for a full view of the instruction sheet, see Appendix A.1).

### 3.4 3D Printing, Laser Cutting, and Electronics

*Framing Water* is an interactive game integrating electronic, magnetic, and fabricated components. The system comprises 37 momentary switches that control a strip of LEDs, driven by an Arduino Mega 2560, and powered by four rechargeable batteries providing 6 Volts. Switches are activated by placing a puzzle piece on the board. Pieces have magnets with consistent polarity affixed to the underside of each hexagon to work as actuators. A board with 37 etched hexagonal outlines and circular holes at the center of each hexagon was laser-cut from a Medium-Density Fiber (MDF) panel to indicate where pieces could be placed and to ensure the magnets fit steadily. An additional board was added under the visible game board, where paired copper tape terminals were placed beneath 12 mm apertures at the center of each hexagon, and wiring was added. A conductive magnet in a shallow acetate retainer mounted around each switch terminal completed the circuit when attracted to a corresponding magnet embedded in a puzzle piece. A small piece of ferrous metal was attached to the exterior of each retainer to prevent the magnet from accidentally closing the switch in its rest position. This arrangement provided reliable activation while mitigating accidental circuit closure from magnetic interference. The electronics and wiring are housed in a custom plywood box, designed with a battery compartment and power switch. The game board, box, and animal description panels were laser-cut. A thin plywood frame was added to the game board to delimit the finite number of available liters. The game pieces were 3D printed in Polylactic Acid (PLA). Vinyl stickers with icons representing the corresponding activity were applied to the top surface of each piece to provide visual cues.

## 4 Evaluation

### 4.1 Goals and Methodology for Data Collection and Analysis

Through the evaluation, we aimed to assess *Framing Water*'s ability to raise players' awareness of how their oblivious behaviors can impact a mountain hut's water supply and to prompt reflection on their habits. To this end, we structured the evaluation into three parts: a pre-interaction questionnaire, observations and think-aloud during the gameplay, and a post-interaction questionnaire. Questionnaires were preferred over interviews because they allowed us to adopt a mixed-methods approach, collect both quantitative and qualitative data, and run more tests, as they could be completed autonomously while other testers were playing the game.

The pre-interaction questionnaire aimed to collect participants' basic demographic data, familiarity with mountain huts, previous experiences in such settings, and knowledge of water scarcity issues in the Alps. It included yes-or-no questions, time-range items to assess the frequency of behaviors, and short and long free-response questions to describe experiences or provide detailed opinions. During gameplay, we conducted observations and think-aloud to capture players' reflections triggered by the game. Spoken reflections, as well as the dialogues and interpersonal dynamics

of players testing the game in pairs, were noted down and then analyzed using Reflexive Thematic Analysis [13] by the first and second authors to identify the values, arguments, and trade-offs underpinning their choices. Finally, the post-interaction questionnaire was designed to evaluate: i) participants' perceived clarity and reliability of the physicalized data, using semantic differentials drawn from the *Trustworthiness of Content* module of the User Experience Questionnaire (UEQ+) [71, 72]; ii) the perceived engagement of the game, measured through 5-point Likert scales and a list of emotions inspired by Russell's Circumplex Model [66]; iii) the contribution of each game component in fostering playfulness and supporting decision-making, explored through open-ended questions; and iv) participants' understanding and awareness of how their actions affect the mountain hut's water reserve, also assessed through open-ended questions. Once collected, the quantitative data were analyzed using Descriptive Statistics [43], while qualitative data were analyzed through Content Analysis [70].

### 4.2 Procedure

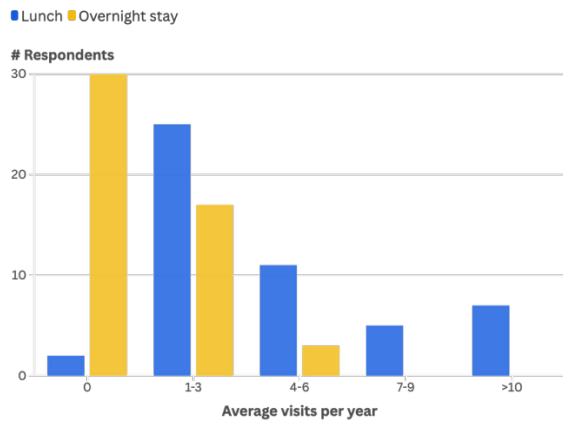
We aimed to collect feedback from both residents and tourists with varying levels of familiarity with mountain huts. To this end, we conducted testing sessions in multiple public and semi-public settings. The first evaluation was conducted with employees of our institution, which included researchers with STEM backgrounds and administrative staff. This group comprised both long-term residents of Trentino and newcomers, with different levels of experience with mountain activities and huts. The second evaluation was conducted at the city tourist office, allowing us to engage visitors unfamiliar with mountain huts. A third session was held at the headquarters of a local Alpine club section, where participants were experienced mountaineers and managers of a small hut they consider a "second home" for their association. Finally, we tested the game in a mountain hut during lunchtime on a Sunday.

We asked participants to try the game in pairs. Although the game requires thinking of the consumption of one person only, we thought that playing it in pairs would have, on the one hand, made the setting more realistic since usually people go to the mountains in groups and very rarely alone (primarily for safety reasons but also for company), and on the other hand, it would have facilitated the think-aloud method transforming it into a dialogue between two people. During the actual evaluation, we also had a few people try the game on their own, in which case we asked them to think aloud. Alternatively, a small audience formed around the playing pairs and commented to varying extents. In all cases, all players filled out the questionnaires. We welcomed both Italian and international players: the game instructions and questionnaires were prepared in both Italian and English.

Before conducting the actual evaluation, we ran a pilot evaluation with two pairs of participants to refine the questionnaires and instructions based on the feedback received.

### 4.3 Results

We had 56 participants (30 males, 25 females, and 1 participant who preferred not to disclose their gender). Their average age was 35 years, with a standard deviation of 10 years (see Appendix A.2 for demographic details and participant anonymization). Almost all

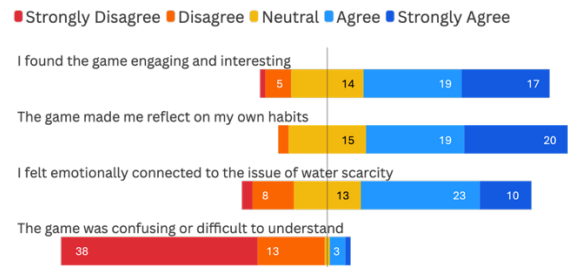


**Figure 8: Visits to a mountain hut on average per year, either for lunch or for staying overnight.**

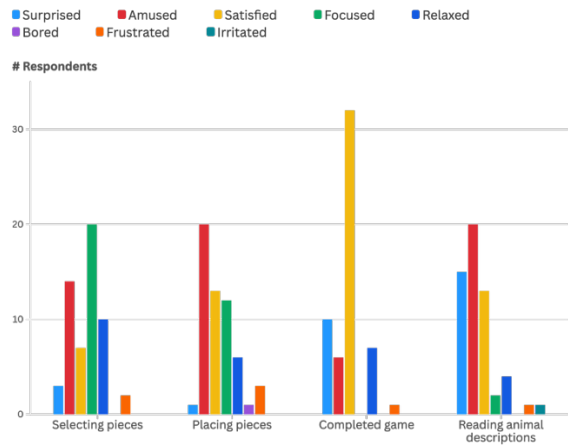
participants (50, i.e., 89%) had been in a mountain hut. Of these, 48 visited mountain huts in Northern Italy, while the remaining 2 visited in France and Turkey. Participants with hut experience have been going there for an average of 17 years. The long time is not surprising, given that we conducted our study in a mountainous area. Of the fifty people who have been in a hut, two have never stopped there for lunch, twenty-five usually visit a hut for lunch 1-3 times a year, eleven people 4-6 times, five people 7-9 times, and seven more than 10 times a year. Regarding overnight stays, 30 respondents reported never spending the night in a mountain hut. Of the 20 who have experience sleeping in a hut, seventeen usually spend a night there 1-3 times per year, and three people 4-6 times (for a visual report of the average visits to a mountain hut per year, see Figure 8).

Thirty respondents (60%) have experienced water problems while being in a hut. They mentioned that either it was not possible to take a shower (even if willing to pay extra for it) or it was allowed for a very short time (6 mentions), water use was limited (5 mentions), there were signs in the bathrooms inviting to use as little water as possible and only if really necessary (5 mentions), tap water was not drinkable (3 mentions), water supply was interrupted due to a power failure and the guests had to use bottled water (1 mention), and a hut having chemical toilets (1 mention). The types of problems reported indicate that some of our respondents are not fully aware of how mountain huts operate: showers are rarely available, mainly for people undertaking multiple-day treks, and huts seldom have water treatment plants that produce drinking water. Similarly, among all respondents, a low level of knowledge was observed regarding the water provisioning systems mountain huts rely on: 29 respondents did not know, 10 expressed true but only partial knowledge, 7 provided incorrect or too vague answers, and 5 attempted to guess. Finally, 5 gave correct answers.

**4.3.1 Engagement.** Thirty-six respondents (64%) agreed that the game was engaging and interesting, thirty-nine (70%) that it prompted them to reflect on their own habits, and thirty-three (59%) that it made them feel emotionally connected to the issue of water scarcity. More than 90% of participants disagreed that the



**Figure 9: Distribution of answers on the Likert scale items measuring engagement with the game.**

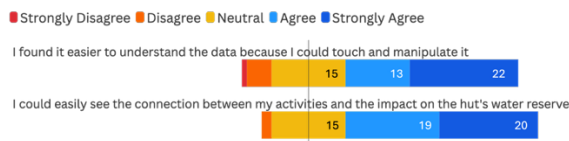


**Figure 10: Graph of players' emotions during the different gameplay phases.**

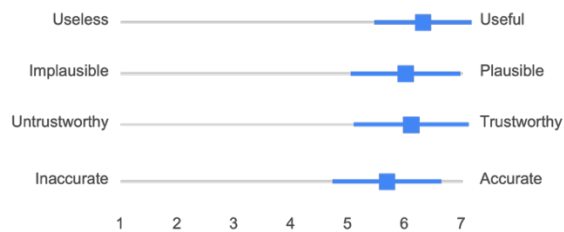
game or any of its parts were difficult to understand. For a visual representation of the level of engagement expressed by players, see Figure 9.

Then, when asked to associate an emotion with each of the game phases, it emerged that during the selection of the pieces, they mainly felt focused (20 respondents, i.e., 36%), amused (14, i.e., 25%), and relaxed (10, i.e., 18%); placing pieces on the board made twenty of them feel amused (36%), thirteen satisfied (23%), and twelve focused (21%); when the game was completed they felt mostly satisfied (32 respondents, i.e., 57%) and surprised (10, i.e., 18%); and finally when reading the animal descriptions twenty respondents felt amused (36%), fifteen surprised (27%), and thirteen satisfied (23%). For a visual representation of the emotions felt by players in each phase of the game, see Figure 10.

**4.3.2 The User Experience of Data Physicalization.** The tangible interaction with the physicalized data facilitated the understanding of the water scarcity issue. Thirty-five participants (62%) agreed that it was easier to understand the data because they could touch and manipulate it, and thirty-nine (70%) agreed that they could easily see the link between their consumption and the impact on the hut's water reserve (Figure 11). As P07 wrote in an open question, "The physical tiles convey information more easily: different shapes



**Figure 11: Distribution of answers to Likert-scale items measuring the understandability of data physicalization.**



**Figure 12: Level of trustworthiness of the data presented in Framing Water, as perceived by players.**

and sizes, with each hexagon corresponding to one liter consumed, make it easier to understand the 'weight' of actions regarding water consumption. The greater difficulty in fitting the larger pieces together suggests that actions associated with those have a greater impact".

When we asked to compare the tangible experience of Framing Water with a purely visual one, they described it as more immersive and engaging: "Holding the data in your hands helps you get more involved by performing the physical gesture" (P02), "Certainly clearer and more stimulating" (P52). Some respondents distinguished between a static visualization, experienced passively, and an interactive digital visualization, such as a touchscreen interface or a digital version of the game. They acknowledged that digital interaction could be compelling too and has the advantage of reaching a larger audience and enabling multiple players to participate simultaneously. Still, they pictured it as less impactful than the physical game. Three participants also mentioned that manipulating the data was perceived as aiding memorability, thus echoing findings from the literature, which often suggest that physicalization outperforms visualizations in terms of clarity, engagement, and memorability [23, 85].

Regarding how solid and reliable participants perceived the data embedded in the game, we asked participants to answer the 'Trustworthiness of Content' module of the User Experience Questionnaire (UEQ+) [71, 72]. On average, respondents judged the data represented in the game, i.e., the liters of water associated with each activity, as highly reliable overall. They rated it useful (Utility = 6.32 on average on a semantic differential scale that was going from 1 to 7), plausible (Plausibility = 6.01 out of 7 on average), trustworthy (Trustworthiness = 6.03 out of 7 on average), and accurate (Accuracy = 5.75 out of 7 on average) (Figure 12). The slightly lower accuracy score can be attributed to a few complaints about the estimate of brushing teeth at 1 liter, which some respondents found excessive.

**4.3.3 Role of Each Game Component.** The game parts were not found to be challenging to understand, with an average rating of 1.4 on a 5-point Likert scale (1 = Strongly disagree, 5 = Strongly agree). In the open questions, participants reported that all parts of the game contributed to raising awareness of water consumption and helped them make informed decisions. Both the informative elements, such as the instructions, and the physical ones were acknowledged as influential in decision-making during gameplay. The timeline of an overnight stay in the instructions (Figure 6) was the one mentioned more often (17 times) as support for the players to reflect on their habits: "The daily routine example highlighted possible choices I had not immediately thought of" (P29), followed by the images of the pieces with liters (Figure 4), which was mentioned 9 times. The limited space on the board and the pieces' size helped them realize the impact of their actions and sacrifice some of their preferences accordingly: "How big the shapes are, and how small the frame looks" (P39) and "The available space is diminishing. I'm starting to feel anxious. Maybe I will renounce brushing my teeth or breakfast" (P08), and the activity itself: "The puzzling of the pieces helped me to reflect more on my choices" (P24), "Why are these [WC] pieces so inconvenient to place?" (P41).

The LED strip and the corresponding animals' descriptions served as an assessment at the end of the gameplay, "[I think the message is] Try not to smell like an ermine but don't be an amphibian too" (P49). The LED strip had been referred to as the 'saving meter' or 'mountain horoscope' ("Ah, this is a mountain horoscope, you need to understand what animal you are" (P04)). Interestingly, two people noticed that the game can work without the LED strip. This aspect was known to the game designers, who inserted the LED strip as a reinforcement but also designed the game to work without any technology, given the arduous mountain context. The animals were generally well received; only 4 people out of 56 found their descriptions unclear or unhelpful. Positive feedback highlighted that they were fun, engaging, and educational since they allowed players to learn new, fun facts about the animals: "The description of the ibex's habits -which I wasn't familiar with- perfectly represents water conservation" (P50). Some participants interpreted them as an invitation to accept different lifestyles: "More than helping to understand consumer choices, animals add a friendly and empathetic element and, in some ways, represent different lifestyles" (P07). One participant strongly identified with the animals and saw a holistic environmental message in them: "Funnily, we understand that we are animals too, and we have to save water to live in harmony with nature" (P12).

**4.3.4 Effectiveness of the game in raising awareness.** We qualitatively assessed the game's ability to convey information about water consumption in daily activities, raise awareness about water scarcity in mountain huts, and encourage limiting consumption by asking participants what they had learned from playing the game. Below, we report occurrences of the themes and quotations from the answers. Please note that the total number of occurrences exceeds the number of participants, as some participants reported gaining more than one insight.

Playing with *Framing Water* was mentioned six times as an opportunity to learn about the problem of water scarcity in mountain huts for the first time: "I never really thought about this topic

before, so it forced me to think about that” (P28), “The fact that mountain huts are not connected to the centralized water system” (P12). reported that the game helped broaden their perspective on water consumption, which occurs not only in the bathroom but also through cooking and cleaning: “It’s helpful to think about how different water consumptions add up. This way, by looking at the whole picture, it’s easier to figure out what can be avoided and helps prioritize” (P06). The majority of participants said they had learned about the actual water use of specific activities (23 mentions), especially flushing toilets, which many found surprising: “I hadn’t noticed that using the bathroom uses so much water. I knew the toilet tank was large, but I hadn’t made the connection with consumption [and impact] in isolated places” (P38), “I did not know that flushing the toilet consumes 6 liters of water!” (P10), “To flush the WC is like two meals” (P16). Seven people affirmed that the game helped them understand that there should be a limit to personal consumption and to quantify it: “How much one should use to preserve the water resource for others in such a case” (P41). The game also sent back an image of players’ own behavior, e.g., “[I have learnt] that I make moderate use of water” (P20) vs. “How much water I waste” (P09). Finally, four people highlighted that they understood that changing habits is possible.

**4.3.5 Pair dynamics and reflections triggered by the game.** The majority of our participants (68%) played in pairs. We had only one group of four people, one group of 3, and 11 participants who played individually. Playing in pairs while reflecting on a single person’s consumption often led players to make decisions together by negotiating habits or by taking on complementary roles, i.e., a leading player making choices on their own behalf, and a co-player helping to reflect on them. Here, we report extracts from the dialogues we deemed particularly meaningful for representing participants’ reasoning and the underlying needs, values, and compromises they were willing to make.

**Strategies to conserve water while meeting essential needs.** Pairs discussed original solutions to use less water. Most efforts were aimed at finding alternatives to using running water to wash themselves: “Maybe if we bring some wet napkins, we can avoid using some water for personal hygiene” (P31) or reducing the number of WC flushes: “Maybe if you are in a group, you can flush just once? It is the toilet that uses too much water” (P16). Soon, limitations to their efforts and non-negotiable needs emerged as well. For example, a pair was willing to renounce a hot breakfast in favor of caffeine pills, unless they had to spend many days in the mountains:

P28: “I could do without a hot meal, but I will need something [to eat] in the morning and coffee.”

P29: “Yeah, sure.”

P28: “I could bring caffeine pills to avoid water usage.”

P29: “If there were more days, I would want a more balanced diet and a hot meal.”

Doubts about what they could afford respecting their usual lifestyle arose quite soon: “I don’t know if we shall brush our teeth once or twice. I always bring wipes for hygiene when I arrive, but I would wash my face with water in the morning” (P23). Personal hygiene was the most challenging activity to compromise on,

either for personal values (as exemplified by the dialogue below) or for willingness to be socially acceptable:

P44: “I want a shower.”

P45 - “You can’t have a shower though.”

P44 - “Fine, I will take two quick wash pieces.”

Many players mentioned that they could relieve themselves in the woods outside the hut, rather than waste water by flushing toilets. However, this option must be carefully considered as not all huts are surrounded by woods; those above the timberline are situated in a rocky landscape. Moreover, the area cannot become contaminated with human excrement and paper, as this could attract wild animals, and some areas are UNESCO World Heritage sites. These trade-offs further complicate the decision-making process, as some behaviors aimed at reducing water consumption may inadvertently create other sustainability issues. However, this awareness was shown just by a few players who affirmed: “I would use the WC because it is better not to leave paper outside the hut” (P42) and “I don’t know how to go without the WC at least once, maybe twice. Maybe I can go outside, but is it hygienic to go out in front of the hut? Maybe using water for this purpose is an investment they [the hut staff] are happy to make” (P29).

**Negotiating different values.** The pairs of players discussed habits, priorities, and possible waivers. Sometimes their views aligned, while at other times they diverged significantly, showing how subjective perceptions of fundamental needs can be:

P34: “I would wash my face in the morning, but I probably wouldn’t use 3 liters.”

P32: “[Then] Breakfast and teeth again.”

P34: “And I would go to the toilet again.”

P32: “I would not [need the toilet again], and you don’t need to wash your face.”

P34: “You don’t wash your face in the morning?!”

When disagreements arose, participants sought compromises that balanced their preferences with what they felt was best for the hut. Later, in the questionnaire, 13 respondents mentioned that the game helped them realize personal differences in what is considered essential and what can be renounced. They stated that they had learned “that each person has a different concept of minimum water use” (P48), “Different people have different needs” (P49), and “It’s the total that makes the difference, not the individual choices” (P31).

**Willingness to comply with social norms.** Negotiations around social hygiene norms in a shared space, such as the hut, where the tension between personal comfort, social expectations, and water conservation is evident, sought a reference point in social norms or shared practices. What would be more appropriate to do about personal hygiene and flushing the toilet emerged as the most controversial. Some players considering being clean a form of respect toward other visitors (“I will never renounce personal hygiene when I reach the hut [as respect] for the other guests” (P08)), while others expected a general situation of people gathering after a day-long hike and giving in to urban norms of cleanliness: “It’s a hut, not a spa, so it is fine to be a bit smelly” (P42). The question of

whether to flush the toilet after peeing came up again, in light of what others would do. For example:

P34: “Definitely, the first thing I have to do is go to the toilet. Could I not flush?”

P32: “It’s okay for me if it is okay for the hut.”

Or “Do you wait to flush or not, especially overnight? I don’t remember the rules at other huts that I have stopped at” (P28). Apparently, if it is a common practice agreed upon by the staff and shared by other guests, such as P32, P34, and other players who raised the same issue, they would be okay with not flushing the toilet.

In the following section, we will discuss the results in relation to previous works that informed the design of Framing Water and this study. By doing so, we aim to clarify our contribution to the HCI community.

## 5 Discussion

Our work aimed to inform tourists visiting mountain huts about the problem of water scarcity, help them understand the impact of their actions, and encourage more conscious water consumption. To this end, we designed, prototyped, and evaluated a data physicalization game that offers a reflective and playful experience. Our work was guided by two research questions: (1) How can a data-physicalization-based game prompt reflection on water-consumption behaviors? and (2) What kinds of reflections and trade-offs do people put into play when making decisions about when and how to reduce water consumption? The game is designed to foster reflection by engaging its players in open-ended decision-making. Players can make their choices following their preferences while staying within the recommended water consumption limit to ensure that all hut visitors have access to water. Our evaluation showed that the game can effectively raise awareness of water scarcity in mountain huts and highlight the impact of individual actions. Each phase of the game prompted different types of reflections. From players’ think-aloud reasoning or conversations with co-players, we were able to identify the content of their reflections, which spanned from non-negotiable needs to possible compromises between individual values, social norms, and the willingness to contribute to water preservation.

In the following subsections, we discuss the findings of the evaluation in relation to previous literature on Sustainable HCI, Reflective Game Design, and Data Physicalization, and outline our contribution to the HCI research community.

### 5.1 Reflecting while playing with data

From the evaluation, it emerged that Framing Water effectively raises players’ awareness of water scarcity, a problem that has intermittently affected the Northeastern Italian Alps in recent years, and of the impact that individual water consumption behaviors can have on it.

As intended by the design, each game phase prompted reflection in the players, thanks to game elements that worked in specific ways across the three phases. In the initial phase, the selection of pieces to play with was intended to provide a slow start to the activity, allowing players to reflect and think critically about the

information presented. Here, three factors supported the reflection: i) the timeline of a typical overnight stay at the hut, with questions about water-consuming activities they would undertake, which initiated a sort of *anticipatory reflection* that merges revisiting habits (a typical phase of initial reflection [7, 28]) with projecting future behavior; ii) the table connecting daily activities, liters of water used, and images of the puzzle pieces designed to facilitate the understanding of the impact of each activity and pave the way for informed in-game decision-making about what is essential and what is not; iii) the conversation with the co-players, which added to the reflection through comparison with peers, enabling one to see things from a different perspective [7, 28].

The second phase, when players build the puzzle by combining the pieces, is when a ‘disruption’, intended as a moment of cognitive friction or conflict that arises in reflective games [60], may occur. The size of the pieces, linked to the quantity of water they represent by a mathematical formula [42], and the large hexagonal frame surrounding the board, a tangible metaphor for the water consumption limit, clearly conveyed the impact of choices through the tangibility of a physical constraint [23, 42]. When the selected pieces exceed the space allowed by the frame, players must return to the previous phase, reconsider their choices, and choose new, smaller pieces. Still, the game does not envisage a clear, unique solution. It does not provide a precise path to follow or suggest specific solutions to reduce water consumption. Its open-ended nature encourages players to think of what the best solution is for them [60]. The ambiguity that characterizes the gameplay is critical to the awareness it aims to raise [31].

Finally, during the third and final phase, the LED strip and the animals’ descriptions serve to assess the players’ performance and connect it with consequences outside of the game. They prompted players to change their ‘posture’ [40] towards the use of water in high mountains, that is, the ensemble of knowledge, beliefs, cultural norms, and economic paradigms at the basis of our worldview and our position within it. If, until now, the reflection prompted has been in-action [69] and the change provoked has been at the game strategy level (endo-transformation [60]), the animals’ description offers the players the possibility to reflect on-action [69] and act as a bridge between the game experience and the real life, paving the way for exo-transformation [60].

The value of Ludic Design [32], ambiguity [31], open-ended games [60] in interactive systems aimed to make their users reflect has been clearly explained by Gaver et al. [31], who state, “By impelling people to interpret situations for themselves, it encourages them to start grappling conceptually with systems and their contexts, and thus to establish deeper and more personal relations with the meanings offered by those systems”. By leaving several different paths open for staying within the limits, our game stimulated speculative thinking, encouraging participants to explore new possibilities of conduct and question their limits (e.g., by wondering how long they could stay without a hot meal). This underscores the value of technological systems that support climate action without prescribing rigid behaviors or assuming an authoritarian approach to users’ lives [16], but by creating space for agency, allowing people to make decisions and adjust their actions once they understand the broader collective goal. Establishing a shared objective thus

provides a framework within which individuals can exercise flexibility in aligning personal practices with collective sustainability. For HCI, this translates into an invitation to be less prescriptive when it comes to personal choices, as a way to encourage people to reflect on and take responsibility for their actions. As Giaccardi et al. affirm [33], “prototyping has become a relational practice. The prototype is no longer a stable step toward a finished product but a way to explore relations, navigate uncertainty, and cultivate shared reflexivity and creativity across human and nonhuman agencies”.

## 5.2 Tensions between Individual Needs, Social Norms, and Environmental Sustainability

The game stimulated discussions among co-players around values and social norms, prompting participants to reflect on trade-offs across multiple dimensions: individual (e.g., hygiene, safety), social (e.g., respect for others), and environmental (e.g., conserving water while avoiding littering in the forest).

At the personal level, the evaluation revealed that participants had different needs and values, which influenced what daily activities they considered essential or optional. Interacting with the game, they recognized that respecting limits ensures fair access to water for all hut guests and helps maintain ecological balance. At the same time, they realized that individual needs vary, and how one lives within such limits is ultimately a personal decision.

Nevertheless, choices regarding personal hygiene proved to be the most controversial from a social perspective. Some participants adopted solutions that aligned with the social norms they presumed were in place at the hut, seeking to balance environmental sustainability with social acceptability. For instance, they would flush the toilet every time or prioritize hygiene over snacks as a sign of respect for fellow hut guests. Others were more willing to compromise on their hygiene and flush toilets less often, drawing on the different customs they associated with mountain hut life. In both cases, participants’ choices were underpinned by the belief that some social norms were in place at the hut (although which remained unclear) and the expectation of reciprocity among hut visitors. Social norms are “the predominant behaviors, attitudes, beliefs, and codes of conduct of a group. As perceived, they influence the expectations, opinions, and actions of group members and facilitate social coordination and solidarity within the group” [18]. In practice, they prescribe certain behaviors and proscribe others. Our participants’ reasoning echoed a well-established social psychology notion: while social norms hold considerable potential for encouraging sustainable practices, they must be clearly communicated and collectively endorsed to be effective [8].

From an environmental perspective, the search for a solution proved to require systemic thinking. Players motivated to save water at all costs sometimes did not fully consider the unintended consequences of their proposed solutions. For instance, some proposed relieving themselves in the surrounding woods to address the large volume of water used in toilet flushing. While this was a widely accepted alternative, it disregards important contextual factors: not all huts are located near woods (many are situated at higher altitudes), and such practices can create new problems, including the spread of litter (e.g., tissues), environmental pollution, aesthetic degradation, and attraction of wildlife. If adopted at scale,

seemingly “easy” solutions, such as relieving oneself in the woods, could lead to problem displacement: from water consumption to environmental degradation.

The reflections expressed by the players suggest that, although having freedom of choice within a given limit enhances the acceptance of the limit itself and provides reflection and agency on how to act sustainably, consumption is not an individual decision-making problem, but rather a set of socially and culturally embedded practices. Besides the environmental limit, another limit is given by the social aspects of life and the rules that govern it. Furthermore, it is very challenging to have a complete understanding of all the consequences actions might entail. This becomes particularly challenging when the problem is complex and pertains to social and environmental contexts that can be progressively broader in scope, ranging from the hut to the region, to the geographic area, and so on. In line with Hirsch and Anderson [36], these findings suggest that HCI must carefully consider the contexts in which water conservation is promoted, recognizing the tensions between individual needs, social expectations, and environmental impacts to design suitable solutions.

## 5.3 A Wicked Problem to be Addressed at Different Scales

In addition to the differences in needs and values, people also differ in the influence and power they hold. As mentioned in the Introduction, the problems of water scarcity and overtourism cannot be solved solely by promoting responsible water use among tourists. Addressing these challenges also necessitates interventions at a higher level, such as optimizing water management infrastructure, relocating mountain huts, or rethinking tourism models, which require political decision-making. For example, considering that mountain huts in Trentino were built in the 19th and 20th centuries, when the Alpine climate was cooler and more stable, and tourism has increased in the last 5-10 years, the decision the local government took in summer 2023 to supply water through helicopter and cable car is one viable option. Another could have been to cancel tourists’ bookings and use the money allocated for the helicopter to compensate the hut managers for their income loss. This way, tourists would be made aware of the problem, while the hut managers would be economically safeguarded. In the long term, other options could include capping tourist numbers (with the risk of making the Alps an exclusive destination) or relocating the huts. Still, all these options need careful consideration of their consequences and trade-offs.

The trade-offs created by the area’s economic dependency on tourism and the depletion of natural resources reflect the nature of the wicked problem of climate change. Wicked problems are interconnected and interdependent, global in scope but manifesting in place- and culture-specific ways [40]. Typically, they comprise multiple stakeholders with conflicting agendas and concerns who lack a shared understanding of the problem and require ecologies of interventions implemented across multiple scales and time horizons [40]. Although addressing the issues related to the clash between water scarcity and overtourism in the Alps requires an ‘ecology

of interventions' that promotes individual behavioral change, collective action, and effective policies, dealing with resource management gives us a handle on a challenging and complex problem, and tourists' awareness is pivotal in avoiding irresponsible behaviors in a delicate environment. To tackle wicked problems, HCI should continue its work at various scales [20], in conjunction with policymaking [14] and public awareness-raising [59], ultimately orchestrating joint action across multiple levels.

Our work builds on prior HCI research on fostering responsible water consumption through a data physicalization-based game that encourages reflection on personal habits and their consequences. Our contribution to the HCI community, focusing on Sustainability, Data Physicalization, and Reflective Game Design, is threefold. It consists of i) a game that balances certainty and uncertainty, that is, clear goals (i.e., staying within the 37-liter limit) and openness of solutions. This approach to game design for sustainability ensures that players reflect on, explore, and take agency and responsibility for their choices, while providing a clear message; ii) a new approach to reflection that connects revisitation of past experiences for anticipatory purposes, that is, the anticipation of future behaviors; iii) the elicitation of a series of tensions that emerged when deciding what activities to make. These tensions arise between individual needs, social expectations, and environmental sustainability and call for trade-offs that are not easy to identify, underscoring the wicked nature of the problem. We invite the HCI community to incorporate these three lessons learned into their future work on sustainability.

## 6 Limitations and future work

This work presents a few limitations. First, although *Framing Water* is designed to be played in mountain huts, we primarily tested it in various locations throughout the valley, with a single day of testing at lunchtime in a hut. Furthermore, at the time of testing the game (Summer 2025), water scarcity was not as evident in the region. Both factors may have influenced the evaluation's outcome. Secondly, another limitation is that, although it raises discussion among players, the content and game dynamics have been set by us, the researchers who designed it; thus, we have somewhat influenced the topics players could discuss, and their role is confined to acting on their choices and behaviors. These limitations are typical of serious games about climate issues, as noted by Loroño-Leturiondo et al. [54].

Given the interest and willingness to learn more about the water scarcity issue and the huts' infrastructure that the game has sparked among many participants, future work could involve adding a trans-media information system that allows players who want to know more to delve deeper into the details. This could be achieved by adding a QR code on the box pointing to a website explaining the water scarcity problem in the Alps, or, since there is not always a phone signal in the mountains, an explanatory poster in the hut. Then, to tackle the problem at its root, we suggest that hut managers add a section to their websites that explains the problem and the good-behavior norms, so visitors are informed before they reach them.

## 7 Conclusion

Mountainous areas are particularly vulnerable to the effects of climate change and may face increased water scarcity. The growing phenomenon of overtourism exacerbates this issue, as an increasing number of visitors travel to the Alps in both summer and winter, concentrating in the few areas where snow and pleasant temperatures persist. The work presented in this paper aimed to inform tourists visiting mountain huts about water scarcity, help them understand the impact of their actions, and encourage more conscious water consumption. To this end, we designed, prototyped, and evaluated a reflective game based on data physicalization that prompts players to reflect on the water consumption associated with their daily activities, including eating, personal hygiene, and toilet flushing. The game consists of pieces that represent the water consumed by each activity and must be arranged into a frame representing the individual water consumption limit, making it halfway between a puzzle and a brainteaser. Still, the game does not offer a clear, univocal answer to this problem or to how tourists should behave. Instead, it serves as a thought-provoking experience, encouraging players to reflect on what is essential to them and what they can relinquish. The evaluation revealed that the game's ability to prompt players to ask themselves questions and find answers (or not) lies in its ambiguity about the best choices for respecting the environment and other hut visitors, determining essential water consumption, and identifying socially acceptable behaviors. Although water conservation in the context of climate change cannot be solved solely by raising people's awareness of the impact of their choices, as it requires multiple interventions at different scales, *Framing Water* offers practical and theoretical insights for one possible action: raising awareness among mountain hut tourists.

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
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## A APPENDICES


### A.1 Framing Water instructions

The instructions were printed on an A4 sheet, front and back, in a landscape orientation. The sheet was then folded in half to reveal its layout, which spanned four A5 pages.


#### Fun facts!



For defense, the ermine emits a foul odor, similar to a mixture of rotten eggs, garlic and burnt rubber.



The ibex is a great water saver! Instead of washing itself in streams, it cleans its coat by rolling in the dust.



The salamander is an amphibian closely related to water. It lives in humid forests, but returns to the water to reproduce.

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#### Water scarcity is a global issue

"Roughly half of the world's population currently experiences severe water scarcity for at least part of the year" (*The United Nations World Water Development Report 2024*), and mountains experiencing the effects of the water crisis act as a crucial early warning system for global issues related to climate change (IPCC).

Mountain huts are not connected to centralized water systems, but depend on local water sources, such as snow, rain, and springs, for their water provisioning. However, as glaciers and snowfields shrink and precipitation becomes less forecastable and constant due to global warming, huts face severe challenges securing water through traditional methods like snowfield piping or rainwater storage. Therefore, their survival depends on efficiently managing limited water resources.

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#### What can you do to help?

1

Limit water use to primary needs (avoid wasting it on washing clothes, boots, etc.)

2

Consider the impossibility of washing yourself as if you were at home.

3

Accept the limited variety of the menu, with dishes proposed by the manager also based on the available water.

4

Limit the use of plates and dishes (drink the second beer in the glass of the first!).

Source: Gocce di Montagna by AKU e le guide Alpi di San Martino di Castrozza

# FRAMING WATER


An interactive game that encourages reflection on water consumption in the mountains


*Imagine: you've just arrived at the mountain hut for an overnight stay after a long hike. You're tired and can't wait to take off your backpack, freshen up, and enjoy a nice slice of cake. But at check-in, the hut manager tells you that they have limited water reserves and asks you to be careful and use as little water as possible. How much water will you be able to save during your night at the hut? Will you be able to stay within the limit of 37 liters of water per person?*


Every activity that you participate in, from eating to brushing your teeth, consumes water. Your goal is to conclude your stay utilizing as little water as possible without sacrificing activities essential to you in order to ensure that there will be enough water for the mountain hut to stay open for future guests to enjoy the beauty of this place.


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#### How to play

 **Select Your Pieces**  
Follow the steps of a typical mountain hut stay in the next page, reflect on your needs and pick the corresponding pieces.

 **Highlight Your Choices**  
Take the wooden layer out to reveal the game board and turn on the LED strip with the switch on the side of the box. The Ermine, Ibex, or Salamander will help you assess how you are doing.

 **Place Your Pieces**  
You have access to 37 liters of water during your overnight visit. Place your pieces within the frame and exchange them if your choices change.

 **Evaluate Your Challenge Level**  
You will have achieved a good balance between meeting your needs and saving some water if you managed to find the right combination of pieces without exceeding the big hexagon. Are you an Ermine, an Ibex, or a Salamander?

 **Challenge Other Guests of the Mountain Hut**  
Write your name, date, and result in the notebook. You can leave comments as well!






#### Pick the pieces you will play with

Follow the steps of a typical overnight stay at a mountain hut listed in the next page, think about your needs and choose the pieces to use during the game.


At key times during your stay, you will be asked to make water-use choices. For each activity you plan to do during your overnight stay, pick a piece that matches the liters of water that the activity consumes. Once you have chosen your pieces you can start to play!

Remember:

- In mountain hut, showers are rarely allowed.
- Drinking water is often delivered through helicopter. So, it does not affect the hut's water reserves.


Activity	Water consumed	Puzzle pieces
Brushing teeth	1 Liter	
Eating a snack	2 Liters	
Personal hygiene (face, neck, armpits)	3 Liters	
Hot meal	3 Liters	
Single WC use	6 Liters	


#### A typical stay in a mountain hut

 **16:00 – Welcome to the Mountain Hut!**  
You've just arrived after many hours on the trail.


- Would you like to use the toilet after your hike?
- Will you freshen up at the sink and find a way to do it with as little water as possible?
- Would you like a quick snack before dinner?

Take a piece for each activity you plan to do. Do the same for next activities too.


 **19:00 – Dinner time**  
Time to fuel up for tomorrow's adventure.  
Will you join the hut's dinner tonight?

 **21:30 – Getting ready for bed**  
As bedtime approaches, plan your evening routine.


- Would you like to brush your teeth before bed?
- Do you need to use the toilet before setting in for the night?

 **06:00 – Good morning!**  
A new day of adventure for another adventure!

- Would you like to use the toilet before breakfast?
- Will you quickly freshen up at the sink to kickstart your day?

 **06:30 – Time for breakfast**  
Prepare to start your day.

- Will you be joining us for breakfast?
- After breakfast, would you like to brush your teeth before hitting the trail?

 **07:30 – Departure**  
Before you hit the trail

- Would you like a snack for the road or just a coffee before you go?
- Do you need one last trip to the toilet before you head out for the day?

Ok, now you are ready to play!

## A.2 Table 1 with participants' demographics anonymized.

Table 1: Participants anonymization.

Anonymization code	Gender	Age	Role	Years visiting mountain huts
P01	F	29	Resident	25
P02	F	26	Resident	20
P03	F	34	Resident	7
P04	F	37	Resident	5
P05	F	43	Resident	20
P06	F	57	Resident	30
P07	F	56	Resident	35
P08	F	24	Resident	2
P09	F	31	Resident	10
P10	F	48	Resident	0
P11	M	31	Resident	30
P12	F	33	Resident	0
P13	F	25	Resident	10
P14	M	25	Resident	0
P15	M	29	Resident	2
P16	M	36	Resident	8
P17	M	36	Resident	0
P18	F	29	Resident	25
P19	M	35	Resident	30
P20	M	40	Resident	35
P21	M	30	Resident	6
P22	M	22	Resident	5
P23	F	31	Resident	3
P24	M	28	Resident	25
P25	M	28	Resident	0
P26	M	44	Resident	39
P27	M	40	Resident	20
P28	M	27	Resident	15
P29	M	46	Resident	40
P30	M	27	Resident	10
P31	F	27	Resident	4
P32	M	30	Resident	15
P33	M	23	Resident	15
P34	F	44	Researcher / Alpine Club member	20
P35	M	41	Resident	20
P36	M	27	Resident	20
P37	F	28	Resident	28
P38	M	30	Resident	0
P39	F	32	Resident	0
P40	M	32	Resident	1
P41	F	42	Resident	0
P42	Prefer not to answer	28	Resident	28
P43	M	25	Resident	3
P44	F	41	Alpine Club member	11
P45	M	48	Alpine Club member	3
P46	M	55	Alpine Club member	30
P47	M	45	Alpine Club member	5
P48	F	41	Alpine Club member	35
P49	M	44	Alpine Club member	30
P50	M	43	Alpine Club member	5
P51	F	19	Hut visitor	15
P52	F	19	Hut visitor	15
P53	F	27	Hut visitor	23
P54	M	63	Hut visitor	30
P55	F	50	Hut visitor	45
P56	M	28	Hut visitor	15