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ClimarisQ: What can we learn by playing a serious game for climate education?

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Abstract: Climate change education faces the twin challenges of conveying complex scientific concepts and inspiring urgent action. ClimarisQ is a web and smartphone-based serious game developed by the Institut Pierre-Simon Laplace (IPSL) to address these challenges by simulating climate–societal dynamics and extreme events in an interactive format. This article evaluates ClimarisQ's role as an innovative educational tool to raise awareness of climate issues. We outline the game's design (grounded in real climate models and IPCC scenarios) and its pedagogical objectives of illustrating the urgency of collective action, the complexity of climate-ocean interactions, and the ethics of decision-making under uncertainty. We present results from a user questionnaire (77 respondents) assessing learning outcomes and user feedback. Players rated the game highly in terms of usability, scientific content, and engagement (average 4.2/5 across categories), and qualitative feedback indicates that ClimarisQ effectively fosters discussion and systems thinking about climate challenges. However, many already knowledgeable players reported learning few new facts, highlighting the need to tailor content to varying prior knowledge. We discuss the strengths of ClimarisQ – notably its ability to simulate feedback and extreme events in an accessible way – and its challenges, such as balancing scientific accuracy with playability and ensuring inclusivity. Situating ClimarisQ in the broader context of climate outreach, we compare it with other educational games and initiatives. We emphasize the

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ethical responsibility of climate communication tools to empower action without misinformation or fatalism. In conclusion, ClimarisQ demonstrates how serious games can complement formal education and engage diverse audiences in climate-ocean literacy, an approach that is increasingly vital given the urgency of the climate crisis.

***Keywords**:* climate change education, serious games, science communication, extreme events

1. Introduction

Climate change is a complex, "wicked" problem characterized by nonlinear interactions, long timeframes, and global scope (Levin et al., 2012). The interactions between humans and the climate system are inherently complex, involving nonlinear feedbacks, time lags, and cross-scale dynamics (Steffen et al, 2007). Traditional information-based approaches have often struggled to translate scientific knowledge into public engagement and action, as greater awareness does not automatically lead to behavior change (Whitmarsh et al., 2021). Many people find it hard to connect with climate risks that feel abstract or distant from daily life, especially if they have not personally experienced climate impacts (Spence et al., 2011). In this context, educators and communicators are exploring creative, interactive strategies to foster deeper understanding and commitment (Monroe et al., 2019). Serious games – games designed for purposes beyond entertainment – have emerged as a promising tool to bridge the gap between scientific complexity and public understanding of climate change (Flood et al., 2018; Rooney-Varga et al., 2018). Over the last decade, there has been a growing interest and a substantial increase in research on using serious games for sustainability and climate education (Ahmadov et al., 2024). Serious games offer an engaging, experiential form of learning that can complement formal climate education and science communication efforts. Unlike conventional didactic methods, games immerse players in simulated environments where they can experiment with decisions, face consequences, and learn by doing. Dozens of climate-related serious games have been developed, ranging from board games and role-play simulations to computer and mobile games (Reckien & Eisenack, 2013). These games target various aspects of climate change – from mitigation of greenhouse gas emissions to adaptation to impacts – and audiences from students to policymakers. Reviews of the

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field have found that climate change games have proliferated globally and cover multiple scales and topics (Reckien & Eisenack, 2013; Flood et al., 2018). Crucially, studies report that well-designed games can facilitate social learning, dialogue, and systems thinking around climate issues, often succeeding where purely informational approaches fall short (Flood et al., 2018). Serious games create a safe space for players to explore the complexity of climate systems and policies, make mistakes, and observe outcomes, which can enhance understanding and motivation to act (Rooney-Varga et al., 2018). For example, a systematic review of 46 studies concluded that the impact and value of serious games for climate adaptation have been overwhelmingly positive, citing their ability to build trust among stakeholders and generate enthusiasm for learning (Flood et al., 2018). Likewise, a recent review of climate change education research highlights the need for participatory, affective, and innovative approaches – exactly the strengths of serious gaming (Monroe et al., 2019).

ClimarisQ is a new serious game developed as a scientific outreach project to engage players with the complexity of the climate system and the societal challenges of facing climate extremes. It joins a lineage of climate games that aim to translate abstract scientific concepts into interactive non-judgemental experiences. ClimarisQ is a web and mobile game in which players take on decision-making roles to limit greenhouse gas emissions and manage resources in the face of increasing extreme weather events. By design, the game incorporates authentic scientific data (from climate models) and simulates feedback mechanisms between the climate, the economy, and society. The game's design requires balancing economic, social, and environmental goals, thereby demonstrating trade-offs and feedback loops that political leaders have to face (e.g. how investing in green infrastructure might reduce future disaster losses but could short-term strain budgets or public approval). It also incorporates the inherent uncertainty and variability of extreme events – these events occur with unpredictable timing and location, though with frequencies influenced by the climate state. This feature teaches that while individual events cannot be precisely predicted, statistical risks *do* increase with climate change, echoing real-world climate science where attribution of extremes is probabilistic. ClimarisQ serves as a tool to discuss the ethical dimensions of climate decisions. In the game, players' choices (such as prioritizing economic growth vs. environmental protection) can prompt reflection on justice and

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responsibility: who benefits or suffers from certain policies, and what ethical stance should guide decision-making under uncertainty? Such discussions can be facilitated by teachers or moderators during gameplay, connecting the simulation to real debates about climate justice, intergenerational equity, and global responsibility – key themes in the special issue on practice, ethics, and urgency.

Figure 1: Screenshots from ClimarisQ, showcasing interactive decision-making scenarios. The left screen displays a transport advisor's proposal to switch from gasoline to electric cars. This decision impacts three key parameters: Ecology, Popularity, and Money. Players must balance these elements, as any parameter reaching zero will result in game over. The right screen shows the current CO2 concentration (414.88 PPM), which influences the number of extreme weather events in the game. Higher CO2 levels increase the likelihood of such events, affecting the game's parameters and challenging the player to adapt their strategy. The color-coded wheel provides a dynamic representation of the connection between environmental changes and the in-game consequences, highlighting the game's focus on the relationship between climate policies and real-world outcomes.

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The broader context for ClimarisQ's development is the rise of experiential, game-based learning in science communication. Prior studies have documented a variety of serious games related to climate and environment – from simulation-games on energy transitions to role-play exercises on climate policy negotiations – noting their potential to increase engagement and knowledge retention, especially among younger audiences. At the same time, researchers emphasize that such games must be carefully designed to achieve learning outcomes: games should have clear connections to real-world science, avoid misrepresenting complexities, and include debriefings to solidify conceptual understanding. ClimarisQ was created with these considerations in mind: it was co-designed by climate scientists (to ensure scientific fidelity) and tested with high school teachers and students to refine its user experience and educational messaging. The game's integration into classroom settings has been piloted – a one-hour session (with roughly 20 minutes of gameplay bookended by briefing and discussion) was found to be sufficient for high school classes to play and then analyze their results. ClimarisQ can also be used to run a one-hour role-playing session in which students act as citizens who simultaneously play the game and debate proposed laws, ultimately voting for or against them as part of an interactive civic simulation. This paper builds on those pilot experiments and a post-release user survey to analyze how effectively ClimarisQ meets its goals as a climate education tool.

This kind of systems approach aligns with calls to promote systems thinking in climate education – recognizing climate change as an interconnected system of physical and human factors (Ballew et al., 2019). Research shows that individuals with higher systems thinking ability are more likely to appreciate the seriousness of climate change and support mitigation measures (Ballew et al., 2019). Serious games like ClimarisQ provide a hands-on way to cultivate systems thinking skills: players see how policy choices (e.g. investing in renewable energy or adaptation measures) ripple through environmental, economic, and social systems in the game. Complex concepts such as feedback loops, time delays become concrete when one can experiment within a simulated world. Indeed, an in-depth simulation game called Grim FATE demonstrated significant improvements in students' understanding of climate system dynamics and feedbacks, underscoring the potential of games to teach systems thinking (Waddington & Fennewald, 2018). The ClimarisQ game similarly highlights the interplay

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between factors like public "popularity," financial stability, and ecological sustainability – effectively visualizing the trade-offs and co-benefits that characterize real-world climate action decisions. ClimarisQ also opens space to discuss the acceptability of climate action, beyond ethical considerations. Players confront the difficulty of changing everyday practices—such as giving up car washing or pool use during droughts—and see that barriers to government action are not always financial. Public resistance or lack of consensus, as seen with the Yellow Vests protests or opposition to wind farms, can block policies. The game highlights that social and cultural factors are central to climate decision-making.

Early experiences with climate serious games have shown measurable educational benefits. For instance, the simulation game World Climate, which engages players in mock UN climate negotiations, has been implemented with thousands of participants worldwide. Evaluations found that World Climate significantly increased participants' knowledge of climate science, sense of urgency, and desire to learn more and take action (Rooney-Varga et al., 2018). Notably, these gains were observed across audiences with diverse political views, suggesting that interactive role-play can bridge ideological divides by focusing on learning rather than didactic instruction (Rooney-Varga et al., 2018). Importantly, participants' increased feelings of urgency in that game were associated with greater intent to act – challenging the traditional "information deficit" model by showing that emotional engagement can spur action more effectively than information alone (Rooney-Varga et al., 2018). Another study on the KEEP COOL game (a strategy board game about international climate politics) provided quantitative evidence that gameplay can shift attitudes in a desirable way: German students who played the game reported a heightened sense of personal responsibility for climate mitigation and more optimism about international cooperation (Meya & Eisenack, 2018). These outcomes indicate that serious gaming can influence risk perceptions and perceived efficacy, which are key drivers of public support for climate policies. Likewise, a role-playing game on climate tipping points for climate-concerned professionals found that gameplay reduced the psychological distance of these abstract threats – making them feel more real and immediate – and reinforced participants' sense that climate risks are personally relevant (van Beek et al., 2022). By rendering distant concepts tangible, games can help players internalize

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scientific findings that might otherwise remain theoretical. This evidence aligns with broader climate communication research showing that engaging people in active, social learning processes tends to be more effective than one-way communication in changing attitudes and behaviors (Whitmarsh et al., 2021; Rumore et al., 2016). Beyond cognitive learning, serious games can target the affective and social dimensions of climate engagement. Effective climate communication often needs to tap into emotions and values to catalyze action (Moser, 2017). Games are inherently interactive and can evoke emotions like urgency, hope, or competition in a controlled setting. For instance, ClimarisQ incorporates a mission/score system where players are prompted to "do better next time" if they fail to meet the target of staying below a certain CO_2 concentration. This design is meant to motivate repeated play and learning from failure, rather than leaving the player in despair. In climate engagement, balancing fear and hope is an ethical imperative: overly dire messages can backfire by inducing fatalism or denial (O'Neill & Nicholson-Cole, 2009), whereas providing solutions and a sense of efficacy can empower people (Marlon et al., 2019). Serious games can help strike this balance by acknowledging risks while also offering agency. In a game, players face the frightening possibility of uncontrolled climate disasters if they make poor decisions – but they also have the opportunity to try different strategies, find solutions, and see positive outcomes from good decisions. Research suggests that this approach can be more engaging and less overwhelming than passive consumption of doom-and-gloom information (Marlon et al., 2019). A global survey of youth found that a majority feel anxious and even betrayed by inaction on climate change (Hickman et al., 2021). For young people especially, games like ClimarisQ can channel anxiety into problem-solving and collective action in a constructive, game-based environment, potentially alleviating feelings of helplessness. By presenting climate challenges as winnable (or at least manageable with effort), games foster "constructive hope", which has been linked to greater climate activism and policy support (Marlon et al., 2019). On the other hand, games must also be careful not to trivialize the real-world gravity of climate change. The ethical challenge is to maintain scientific accuracy and seriousness of purpose while leveraging the fun and immersive elements of gameplay to keep participants engaged. Developers often test for this balance: for example, in the Maladaptation Game (a serious game on farming and climate risks), participants reported high enjoyment but also identified real insights into adaptation pitfalls, showing that entertainment and education can go hand-

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in-hand (Asplund et al., 2019). ClimarisQ specifically addresses the theme of extreme climate events, an area of growing concern and relevance. Scientists can now attribute many extreme events to climate change with increasing confidence, but communicating this complex science to stakeholders is challenging. A team of climate communicators and researchers tackled this by developing a participatory game called CAULDRON to simulate climate attribution for extreme weather, aimed at policymakers (Parker et al., 2016). Through gameplay, stakeholders were able to better grasp probabilistic concepts and openly discuss policy responses to extreme events in a way that traditional presentations failed to elicit (Parker et al., 2016). ClimarisQ operates on a similar premise: it uses extreme event scenarios (heatwaves, floods, droughts, etc.) generated by real models to prompt players into considering both mitigation (reducing emissions to prevent worsening extremes) and adaptation (improving the populations and infrastructures resilience to extreme events). This dual focus helps illustrate the trade-offs and synergies between mitigation and adaptation actions. Notably, the game asks the ultimate question: Can you achieve a greener trajectory than the IPCC's intermediate scenario (RCP4.5)? – effectively challenging players to beat a real-world benchmark. By comparing in-game outcomes to a known climate scenario, ClimarisQ reinforces learning about what current policies are projected to lead to, and what it might take to alter that trajectory. Such an approach follows educational best practices by making the learning objectives explicit and anchored in scientific reality. Another dimension highlighted by ClimarisQ is collective decision-making and dilemmas, which are integral to climate governance. Climate change requires coordinated action and involves tensions between individual, local interests and global common good. Serious games have been used to simulate these dilemmas to teach cooperation and negotiation. In World Climate, for instance, participants acting as different countries often confront the classic negotiation impasse – yet the simulation's feedback (in the form of projected temperature outcomes) encourages them to eventually increase their ambition, leading to insights about the need for collaboration (Sterman et al., 2015). Other role-play simulations have shown success in enhancing participants' collaborative capacity and willingness to engage in collective action on adaptation issues (Rumore et al., 2016). By dealing with indicators like "popularity" or "finance" in ClimarisQ, players experience (alone or collectively)the difficulty of balancing constituent satisfaction and economic constraints with long-term sustainability. This mirrors the real-world

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challenge leaders face: climate action can entail short-term costs or unpopular decisions, even though it yields long-term benefits. Experiencing these trade-offs in a game can build empathy for decision-makers and understanding of policy complexity among the public. It may also inspire players to discuss and deliberate climate solutions with others, moving the conversation from a purely academic realm into community and social contexts – an outcome observed with other climate games and simulation-based workshops (Rumore et al., 2016; Flood et al., 2018). Importantly, serious games also contribute to ocean and climate literacy, which are increasingly recognized as critical for informed citizenship. Climate literacy and ocean literacy go hand in hand – for example, understanding how ocean currents and warming influence weather extremes or how sea-level rise threatens communities. However, formal curricula often underemphasize ocean-climate interconnections, leaving gaps in knowledge (Leitão et al., 2022). Serious games offer a way to make ocean science more accessible and engaging, thereby improving "Ocean Literacy," defined as understanding the ocean's influence on us and our influence on the ocean. A recent systematic evaluation of a gamified marine science app found that game elements (like points and quizzes) significantly improved students' learning about ocean-climate phenomena compared to traditional instruction (Leitão et al., 2022). In Norway, a suite of serious games was employed to teach youth about microplastics, jellyfish blooms, and their links to ocean health under climate change, yielding increased motivation and knowledge retention (Tiller et al., 2024). These examples underscore that games can tackle not only atmospheric climate science but also related topics like ocean pollution, biodiversity, and ecosystem resilience – all within the broader context of climate change. ClimarisQ, while focused on climate extremes, inherently teaches systems thinking that includes oceanic factors (e.g., players might notice more extreme coastal flooding events if emissions remain high, indirectly conveying the reality of sea-level rise and warmer oceans fueling storms). By integrating multiple aspects of the Earth system, the game supports a more holistic environmental literacy. Furthermore, using an online platform allows such games to reach a wide audience at low cost, an advantage for public education. The ClimarisQ team has made the game freely accessible on browsers and app stores and available in several languages, aiming to maximize accessibility and inclusivity. This democratization of climate knowledge via gaming aligns with international calls to enhance public participation and understanding in addressing climate change.

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In this article, we provide a comprehensive analysis of ClimarisQ's educational impact and situate its use in the landscape of climate/ocean communication strategies. In the Methods section, we describe the user questionnaire methodology and data collected, as well as the analytical approach to evaluating learning outcomes and engagement. The Results section presents quantitative findings from the survey (e.g. user ratings of the game's content and usability) and qualitative insights from open-ended responses about what players learned and how they might change behavior. We then move to Discussion, where we interpret these findings in light of current literature on climate education and serious games. We compare ClimarisQ's strengths and limitations to other initiatives (such as climate change board games, simulation workshops, and digital apps) and consider the ethical imperatives of representing climate-ocean issues in a game format. Finally, the Conclusion reflects on the role of serious games like ClimarisQ in urgently needed climate education efforts, offering recommendations for future improvements and broader dissemination.

By examining ClimarisQ through an academic lens, this study contributes to understanding how interactive tools can supplement traditional education and public outreach. As climate challenges intensify, the need for effective communication – that not only informs but also motivates action – becomes ever more pressing. The study is organized as follows: section "Methods" describe the way survey has been devised and conducted including strategy for data analyses and limitations. Section "Results" contains demographics and appreciation of the game analyses. Finally we discuss the implications of our results in the growing community of serious games on climate change.

2. Methods

2.1 Game Deployment and Audience

ClimarisQ was launched publicly in mid-2022 as a free game on the Google Play store, Apple App Store, and a dedicated website (for desktop play). The primary intended audience was secondary school students (approximately ages 15–18) and their teachers, as indicated by the developers. However, being freely available online, the game attracted a broader user base including university students, researchers in climate-related fields, and general public users interested in climate change. The game was promoted

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through various channels: outreach events (e.g. science workshops, teacher training sessions), online forums related to weather and climate, social media (Twitter, Facebook), and via the European H2020 project XAIDA (which some developers are part of). Consequently, early adopters of ClimarisQ included both educators (who might use it in classrooms) and science enthusiasts.

To evaluate ClimarisQ's educational effectiveness and gather user feedback, the development team conducted an online user questionnaire approximately 6–12 months after launch. A call to participate in the survey was disseminated through the same channels (the game's website, social media, and direct contacts with teachers). Participation was voluntary and anonymous. No incentives were offered beyond the appeal to help improve the game. The survey was available in English (matching the game's primary language for international users, though the game also supports French and Italian). Respondents presumably had played the game at least once; many were likely among the keen early users or those who used the game in an educational context.

2.2 Questionnaire Design

The questionnaire (see supplementary material) collected both quantitative and qualitative data. It was structured into four sections:

1. Demographics and Background: Questions about the respondent's age ("How old are you?"), self-identified role or profile ("How do you identify yourself?"), education level, field of work or study, and country of residence. These questions aimed to characterize the audience (e.g. proportion of students vs. teachers vs. researchers) and gauge the diversity of backgrounds. For example, options for "identify yourself" likely included categories such as student, educator, researcher, etc., while education level spanned high school, undergraduate, graduate, or PhD. This section also inquired how the respondent discovered ClimarisQ (choices or open response such as via social networks, a workshop, a research project, etc.).
2. User Experience Ratings: A series of 5-point Likert scale questions asking respondents to rate specific aspects of ClimarisQ, from 1 (very poor) to 5 (excellent). The aspects included: (a) *ergonomics* (ease of use, user interface), (b) *scientific content* (accuracy and clarity of scientific

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information presented), (c) *clarity of questions* in the game (i.e. whether the in-game dilemmas and text were easy to understand), (d) *difficulty* of the game (perceived appropriateness of challenge level), and (e) *aesthetics* (graphics and visual appeal). These quantitative ratings provide an overview of user satisfaction and perceived quality of the game's design and content.

3. Educational Impact: Questions to assess what players learned or how their perspectives changed. One key question was "Did you learn something new by playing ClimarisQ?" with a yes/no response followed by an open-ended prompt "If so, what?" to detail any new knowledge or insights gained. Another question asked "Will the ClimarisQ game have an impact on your everyday life?" (yes/no), followed by "If so, in which aspect(s)?" allowing players to describe any intended behavior changes or increased awareness in daily life after playing. These questions target the game's effectiveness in raising knowledge and influencing attitudes or actions – central goals in climate education efforts.
4. Recommendation and Feedback: Finally, respondents were asked if they would recommend ClimarisQ to others ("Would you recommend the ClimarisQ game to someone?"). Instead of a simple yes/no, this was framed to encourage an explanation: "If so, why?" – or implicitly, if not, why not. This open-ended item gave users a chance to articulate what they found most valuable about the game or to point out limitations, thus serving as feedback for the developers. Additional feedback could also be given in any of the open questions, or a general comments box if provided.

The survey questions were a mix of multiple-choice (with predefined options or scales) and free-response. We note that because the survey was somewhat lengthy and required written answers for some parts, not all respondents answered every question in detail (as is common – some skipped open-ended questions or provided very brief answers like "No" or "Yes" without elaboration).

2.3 Data Analysis

After the survey period (June to December 2022), the responses were compiled. We obtained the raw data (in Excel format) containing each respondent's answers. Prior to analysis, the data were cleaned

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and anonymized. No personally identifying information was collected aside from optional self-description (which was categorical, e.g. “PhD student” or “High school teacher”). For analysis, responses were given ID numbers but no names.

Quantitative analysis: We computed summary statistics for the Likert-scale rating questions. This included the mean and distribution of ratings for each aspect (ergonomics, content, etc.). Since the sample size (N=77 respondents) was modest, we present primarily descriptive statistics rather than formal hypothesis testing. We also tabulated the frequency of demographic categories (e.g. how many respondents were students vs. researchers, how many from each education level) and discovery channels for the game. One important consideration was that the target audience was meant to be students, but our sample likely skews older (given the nature of dissemination via research projects and forums). We therefore interpret results with awareness of a potential sampling bias towards well-educated or climate-aware users. Where relevant, we compare subgroups (for instance, comparing ratings from self-identified students vs. researchers) if the data allow, though the questionnaire did not explicitly ask for occupation beyond the broad self-identification.

Qualitative analysis: The open-ended responses were analyzed using thematic coding. Two researchers independently read through all the free-text answers to questions like “What did you learn?” and “Why (or why not) would you recommend the game?”. Common themes or recurring ideas were identified. For example, several responses in the “learned something new” field might mention understanding the difficulty of balancing different priorities, which we would code as a theme of learning about trade-offs in climate policy. Similarly, in the recommendation explanations, multiple respondents noted that the game is *“fun and informative”* for students – a theme of positive engagement – while others noted it *“didn’t cover X topic”* which could be a theme of content limitation. We also extracted illustrative quotes that were particularly clear or representative of each theme. These quotes (translated to English where necessary, since the survey was in English but a few respondents might have answered in their preferred language) are used in our Results and Discussion to give voice to the users’ perspectives. Given space constraints, not every response could be quoted; we focused on quotes that highlight either consensus views or interesting outliers.

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To integrate the quantitative and qualitative findings, we looked for convergence or divergence between what the numbers showed and what people said. For instance, if the average difficulty rating was around 3.6/5, we checked the comments to see how users described the difficulty: Was it "too hard for newcomers" or "too easy for experts"? These insights help interpret the numerical scores. We also compared our findings with expectations from literature. The questionnaire was not formally hypothesis-driven, but we anticipated certain outcomes (e.g., that users would rate the game's scientific content highly if they are scientifically literate, or that many would say they would recommend it if they enjoyed it). Where the results were surprising (for example, if a majority said they *would not* recommend, or many said they *learned nothing new*), we made note to discuss these in context – considering whether the sample's prior knowledge was high, or whether the game's content might need enhancement.

2.4 Limitations

It is important to acknowledge limitations of our methodology. The survey sample (77 respondents) is a self-selected group and not necessarily representative of all ClimarisQ players or the general population. Enthusiastic users are more likely to respond, which could bias results positively; conversely, those who had difficulty with the game or lost interest might not have bothered to fill a survey, possibly under-representing negative feedback. We attempted to mitigate bias by advertising the survey widely, but we did not achieve a random sample. Another limitation is the potential misinterpretation or language issues in responses. A number of respondents gave very terse answers to open questions (e.g., some just wrote "No" for "If so, what?" – making it unclear if they meant they learned nothing, or just chose not to elaborate). We had to interpret such cases carefully (in context with their yes/no selection). Despite these limitations, the survey provides valuable directional insights into ClimarisQ's educational impact and user experience. By combining quantitative ratings with qualitative comments, we aim to draw a well-rounded picture of how the game is received and what educational value it provides.

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3. Results

3.1 Respondent Profile

A total of 77 individuals responded to the user questionnaire. Figure 2 shows the demographic statistics of the users. The age of respondents ranged widely, from as young as 8 to about 56 years old (mean age ~30 years, median in late twenties). This indicates that while some secondary school students did participate, a substantial fraction of players were adults. In fact, from self-identification data, we infer that the sample included university students and early-career scientists. About one-third of respondents identified as *students* (this category likely includes high school and university students), and roughly another one-fifth identified as *postdoctoral researchers or PhD students*. A smaller number (perhaps ~10%) were *researchers* or professionals in climate-related fields. Very few respondents identified as school *teachers* or *educators* in the survey, which suggests that direct teacher-led classroom use was limited in this sample. The dominance of students and young scientists in the respondent pool aligns with how the game was disseminated (through academic network, in science festivals and social media).

In terms of educational background, the respondents were generally highly educated: many indicated holding or pursuing university degrees. For example, several chose “PhD or equivalent” as their education level, and many others “Graduate (Master’s)”. A subset were undergraduates, and some were still in secondary education. This distribution is important when interpreting learning outcomes – a majority of players already had substantial knowledge of climate science (indeed, some were climate science researchers themselves), which sets a high bar for the game to teach them *new* information.

Geographically, respondents were quite international, spanning at least 5 continents (Figure 3). Based on open responses to “Where are you from?”, countries mentioned included the USA, several European countries (France, Germany, Italy, Romania, Netherlands, Belgium), India, China, Tunisia, Mexico, Brazil, Egypt, among others. This international reach reflects the game’s availability in multiple languages and its promotion via international projects (e.g. the XAIDA project, which was specifically mentioned by one respondent as the source of discovery).

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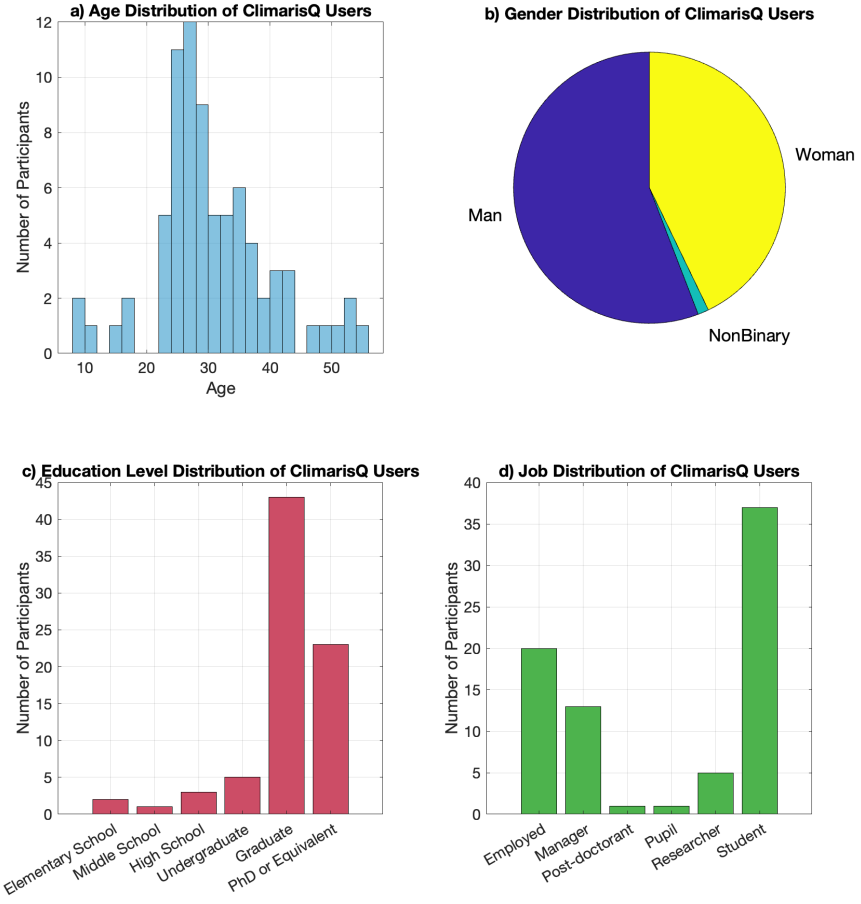

Figure 2: Demographic distribution of ClimarisQ users. a) Age distribution of participants, showing the most common age range around 25-35 years. b) Gender distribution, with the majority identifying as male, followed by female and non-binary participants. c) Education level distribution, with a significant portion of users holding graduate or equivalent qualifications. d) Job distribution, indicating that most participants are students, with a smaller representation from researchers, employed individuals, and other categories. These distributions provide insight into the profile of the game's user base.

When asked “How did you discover the game?”, the answers varied: the most common source was through some form of professional or academic network. For instance, about 8 respondents mentioned

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discovering ClimarisQ via a *weather/climate forum* or community. Others cited *social networks* (approx. 2 respondents explicitly said via social media) and *personal contacts* (word-of-mouth from a colleague or friend, ~2 respondents). A few (1–2) encountered it at a *workshop or event*. One respondent discovered it through the *XAIDA research project* website or communication (as noted). A couple found it via a simple *web search or website* featuring the game. These results suggest that targeted outreach (presentations to teachers, posts on climate forums) was crucial in reaching users, whereas organic discovery (e.g. app store searches) was less significant in this early period. Notably, "traditional" educational channels like school curriculum or formal teacher assignment were not explicitly mentioned in responses, reinforcing that our sample is skewed toward proactive learners and enthusiasts rather than typical high school classrooms.

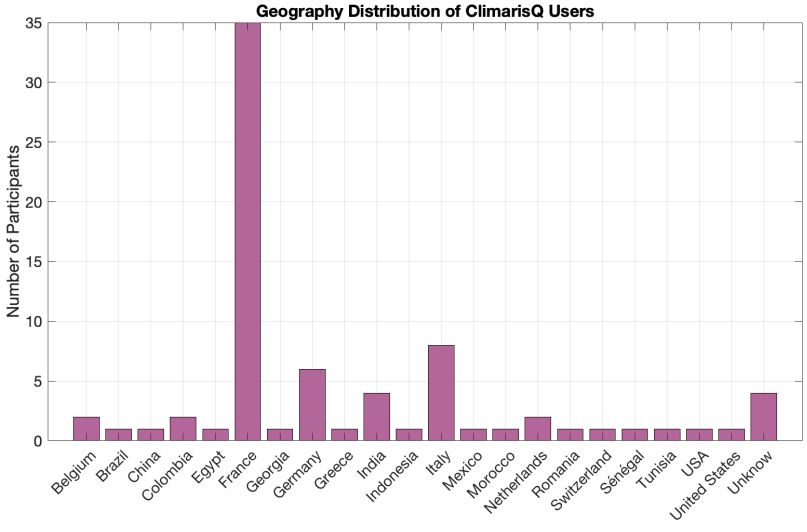

Figure 3: Geography distribution of ClimarisQ users. The chart shows a significant concentration of participants from France, followed by Italy, Egypt, and Germany, with smaller contributions from other countries. Some entries are labeled as Unknown, indicating incomplete geographical data.

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3.2 User Experience Ratings

Participants rated five aspects of ClimarisQ on a 1 to 5 scale. The aggregated results are summarized in Figure 1. Overall, the feedback was very positive across all categories except, to some extent, the perceived difficulty level. Results are displayed in Figure 4.

The ergonomics (ease of use) of the game was well-regarded. The average rating for ergonomics was about 4.3 out of 5, with 87% of respondents giving a score of 4 or 5. No one rated ergonomics below 3. Many users found the interface intuitive and the gameplay mechanics easy to pick up. A few minor issues were noted in comments (such as the interface being "a bit confusing at first on mobile" or suggestions for improving the tutorial), but these did not significantly detract from the overall positive experience. The high ergonomics score indicates that technical barriers to playing the game were low – an important factor for an educational tool, as frustrated users would not stick around to learn. One respondent wrote, *"The game runs smoothly and the controls are straightforward, even for high school students."* This aligns with the developers' efforts to simplify the UI for a broad audience.

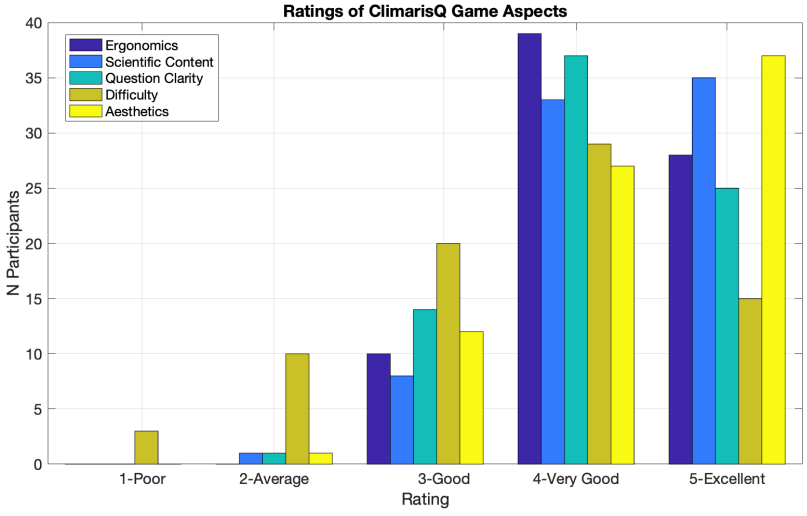

Figure 4: Ratings of ClimarisQ game aspects by participants. The grouped bar chart displays the distribution of ratings for five key aspects of the game: Ergonomics, Scientific Content, Question Clarity, Difficulty, and Aesthetics. The ratings are presented on a scale from 1 (Poor) to 5 (Excellent),

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with each aspect represented by a different color. The chart reveals generally favorable ratings across all aspects, with Ergonomics and Scientific Content receiving the highest scores.

The scientific content was rated the highest of all aspects (mean ~4.4/5). Over 90% gave it a 4 or 5. Users generally appreciated that ClimarisQ's content was scientifically grounded and informative. Some specifically praised the integration of real climate data and scenarios. For example, a respondent noted that *"the game's scenarios reflect real IPCC emission pathways, which adds credibility"*. Another wrote that the scientific information provided (e.g. background info on cards or events) was *"accurate and not dumbed down"*. Such feedback suggests that the game struck a good balance: it contained enough factual scientific detail to be meaningful, but presented in a digestible manner for the player. This high confidence in content is crucial for a science communication product – it means educators and experts feel comfortable that the game is teaching correct concepts. One caveat: a couple of users wished for *more* scientific depth or links to resources, which we address later as a potential improvement.

The clarity of the questions (in-game prompts and decision points) also scored well (average ~4.2/5). Most players understood the choices they had to make in the game. The narrative is built around "event cards" and policy options; evidently, the wording of these was largely successful. Only one respondent rated this aspect as low (2/5), possibly finding some questions confusing – unfortunately that specific feedback wasn't elaborated. On the contrary, several comments indicate that the game's dilemmas were clear and thought-provoking. For instance, *"The situations presented are realistic and easy to understand – like choosing between investing in renewable energy vs. immediate economic relief – which spurred debate among us."* This highlights that ClimarisQ can serve as a discussion starter; if students or players discuss the merits of different choices, the clarity of those choices is key to a fruitful discussion.

Game difficulty received more mixed feedback, with an average rating around 3.6/5 and the widest spread of responses. Unlike other aspects, some low ratings appeared here: about 17% rated difficulty as 1 or 2 (too easy or too hard), 26% rated 3, and the rest 4 or 5. This suggests varied perceptions of the

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game's challenge. Notably, because the question phrasing was "rate the difficulty of the game", it might not be clear if 5 means "very difficult" (potentially negative) or "well-balanced difficulty" (positive). The qualitative comments help clarify: a number of respondents felt the game was *"a bit too hard"*, especially in achieving the optimal outcome. One user mentioned, *"It's nearly impossible to keep all gauges high; no matter what I did, something would fail eventually."* This reflects the game's design (which intentionally makes indefinite survival extremely difficult, mirroring the challenge of sustaining society under worsening climate stress). Some players appreciated this realism; others, especially those expecting a more traditional win/lose game, found it frustrating. Conversely, a few respondents (likely those already very knowledgeable or who played repeatedly) found the game *"too easy once you figure out the trick"*. They managed to survive many turns and felt the challenge could be increased for replay value. This polarization of views is a known challenge in educational game design: novices may find a realistic simulation unforgiving, whereas experienced players can master the system quickly. The developers may need to incorporate difficulty settings or adaptive challenges. In an educational setting, the difficulty rating of ~3.6 indicates the game isn't trivial, prompting players to think critically, though facilitators should be ready to assist those who struggle.

Finally, aesthetics (graphics and visual design) were highly praised (mean ~4.4/5). A majority (around 83%) gave a top score of 5 for graphics. Users enjoyed the art style of ClimarisQ, which features cartoon-like robot characters representing advisors and a simplified global map with icons. Comments included *"charming graphics and characters"* and *"the visual style keeps it engaging without being childish"*. The positive reception of aesthetics is important because it can increase user engagement and willingness to play through the game multiple times. Additionally, the friendly, somewhat playful visuals likely helped reduce the intimidation or gloom that can come with climate change topics – an intentional choice to maintain hope and agency (ethically, the developers didn't want to instill fear but rather motivation). One or two respondents noted minor suggestions, like adding more variety to the visuals for different scenarios, but overall this was a clear strong point.

In summary, the questionnaire's quantitative results show that ClimarisQ succeeded in delivering a high-quality user experience. In particular, scientific accuracy and user-friendliness – two critical

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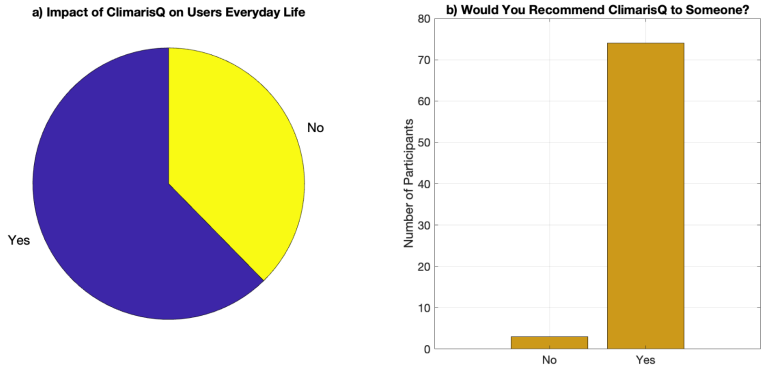
484 criteria for educational tools – received near-unanimous approval from respondents. The only caution
485 area is difficulty (a consequence of the realism of the situation), which elicited mixed reactions.

486 3.3 Educational Outcomes: Knowledge and Awareness

487 One of the core aims of ClimarisQ is to enhance understanding of climate issues. The survey probed
488 this by asking if players learned something new and if the game might impact their everyday life (Figure
489 5a).



490

491 *Figure 5: User responses to the Impact and Recommendation questions in ClimarisQ. a) The pie chart*
492 *illustrates the impact of ClimarisQ on users' everyday lives, with the majority of participants reporting*
493 *a positive influence (Yes) and a smaller portion indicating no impact (No). b) The bar chart shows that*
494 *a vast majority of participants would recommend ClimarisQ to others, with only a few indicating*
495 *otherwise.*

496 Knowledge Gain: When asked "Will the ClimarisQ game have an impact on your everyday life?" a
497 large majority of respondents (approximately 35%) answered "No", indicating that they did not
498 anticipate significant changes in their personal life or habits as a result of playing. About 65% answered
499 "Yes", and among those, the described impacts were generally about increased awareness rather than
500 concrete behavior change. This result is perhaps not surprising given the profile of many respondents –
501 already climate-aware individuals (for example, a climate researcher may not change their low-carbon
502 habits from a game since they were likely doing it already). However, this does highlight that for many

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players, the game reinforced or illustrated concepts they already knew rather than introducing entirely new revelations.

For the question "Did you learn something new by playing ClimarisQ?", responses were similarly split. Many respondents explicitly said they did not learn any new scientific facts, either by choosing "No" or by writing statements like "I already knew most of it." One frank response was, *"It showed how complex the social challenges are in addressing climate change. I did not learn more about the science."*. This comment is telling: the user, likely someone with a science background, felt the game's science confirmed what they knew, but it gave them a better appreciation for the socio-economic complexity. This hints at a learning outcome in terms of perspective or emphasis rather than raw facts.

On the other hand, about 20–25% of respondents did report learning something new. The "If so, what?" answers provide insight into what ClimarisQ taught these players:

- Several players mentioned learning about the difficulty of balancing different priorities in climate action. For example: *"How hard it is to balance the different interests"* and *"Taking the most ecological decision is not enough"*. These statements indicate an understanding that even if one tries to do the right thing environmentally, there are economic and political constraints that can hinder success. This is a crucial lesson in climate governance – that solutions require trade-offs and there's no single silver bullet – and the game successfully conveyed it experientially.
- Some learned about specific *dynamics or counterintuitive effects*. One respondent wrote, *"Money does not work as we think"*, explaining that in the game simply pouring money into a problem didn't guarantee solving it. This likely references the concept of diminishing returns or misallocation: e.g., investing heavily in one area might neglect another vital area (spending a lot on disaster relief might starve mitigation efforts, or vice versa). Another said they learned *"Measures to prevent climate change are expensive"*, reflecting realization of the economic cost dimension.

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- A few pointed out a greater awareness of randomness and luck in outcomes. *"Balancing act, and that you can be unlucky"* was one comment. This shows understanding that even good policies can be hit by bad luck (for instance, you might invest well, but if multiple extreme events hit in close succession, you still suffer) – mirroring how real-world climate impacts involve chance and require resilience.
- In terms of *personal or everyday insights*, some "Yes" respondents said the game made them more conscious of certain things. One said it made them *"be more aware of the impact of the actions we do every day"* – suggesting an increase in personal sense of responsibility or mindfulness about climate-related actions (like energy use). Another mentioned *"Choices of greener life"*, implying they learned that lifestyle choices (such as reducing emissions) matter in the big picture, likely because the game shows cumulative CO_2 levels.
- Interestingly, one theme that emerged was an understanding of urgency and difficulty in a new way. A respondent described: *"It gives a concrete feel of the effect of climate change on extremes, and of the urgency (and difficulty to deal with) of the situation."*. This quote encapsulates a key outcome: the game translated abstract concepts (climate change leads to more extremes; action is urgently needed yet hard) into a *felt experience*. Even if the player knew the fact intellectually, experiencing it in the game can deepen understanding. They now have a concrete mental model of why climate action is urgent and challenging.

It is worth noting that a number of respondents who answered "No" to learning something new still praised the game's educational value for others. For example, *"I didn't personally learn new facts, but I think it's a very good tool for outreach"*. Others said they planned to share it with students or friends to help *them* learn. This suggests that for well-informed users, ClimarisQ served more as a validation or teaching tool rather than increasing their own knowledge. In other words, climate experts might use the game to teach novices, even if the experts themselves don't gain new information from it.

Impact on Everyday Life: As mentioned, most didn't credit the game with changing their behavior (which is understandable – one wouldn't expect profound behavioral shifts from a short game session alone). Among the minority who said yes to everyday life impact, the impacts described were generally

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along the lines of *raising awareness and intention to discuss the topic with others*. For instance, *"Spread awareness"* was a succinct response from one user about how it would affect them – presumably meaning they feel motivated to talk to others about climate change or the game itself. Another wrote, *"I will recommend to the students to get awareness about climate change impact on various sectors."*, indicating that their "everyday life impact" is to integrate the game into their teaching or peer conversations.

A couple of respondents indicated personal habit considerations: *"importance [of] choices of greener life"* – this fragmented answer likely means the game reinforced the importance of making environmentally friendly choices in one's life. Another said the game will prompt them to be *"more aware of the impact of the actions we do every day"*. While these are somewhat generic statements, they reflect an internalization of the game's lesson that small actions accumulate into larger outcomes (since the game tracks CO_2 ppm based on choices).

No one specifically cited a drastic change (e.g., "I will buy an electric car now" or "I became vegetarian because of the game") – which is not surprising given the simulation mostly operates at policy and societal level rather than personal lifestyle level. Instead, the impact is more on mindset and discourse. In educational terms, sparking reflection and conversation is a significant outcome, even if direct behavior change is not immediately observable.

3.4 Willingness to Recommend and User Feedback

The vast majority of respondents indicated that they would recommend ClimarisQ to others (Figure 5b), though paradoxically many simply responded "Yes" without elaboration in the "Would you recommend?" free-response field. In fact, over half of the respondents wrote just *"Yes."* or *"No."* as their answer to "If so, why?" – suggesting some misinterpretation or minimal effort. Based on the ratings and other comments, we infer that roughly 80-85% would recommend the game, whereas a smaller fraction might not enthusiastically recommend it (perhaps those who found it too frustrating or not suited to their needs).

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From those who did provide reasons, several key points emerged:

- Engaging and fun: Many endorsers highlighted that the game is enjoyable, which is crucial for it to succeed as an educational tool. Quotes such as *"It's very fun and good to understand the complexity of the decisions."* and *"Fun and [a] low barrier of entry"* capture this sentiment. The word "fun" combined with learning appears in multiple responses. One wrote, *"It's a nice game to introduce students to the topic of climate change"*, emphasizing that ClimarisQ can hook students in an enjoyable way to start a deeper conversation about climate issues.
- Illustrates complexity/Systems thinking: Many recommendations focused on the game's ability to demonstrate the complexity of climate policy, as discussed. For example, *"Raises awareness of the difficulty of tackling climate change"* was given as a reason to recommend – implying that the game effectively communicates why climate change is a hard problem (which can foster empathy for real decision-makers and perhaps motivate collective action). Similarly, *"It gives a concrete feel of the effect of climate change on extremes, and of the urgency...and difficulty"* (as quoted earlier) serves as an endorsement – essentially saying, *if you want to really feel why climate action is urgent and tough, play this game.* Such complexity is hard to teach via lectures alone; the game provides an experiential learning that these respondents found valuable.
- Educational utility: Several respondents explicitly tied their recommendation to educational contexts: *"Very good tool for outreach"*, *"It can be useful for people that teach about climate change"*, and *"I will recommend [it] to students to get awareness about climate change impacts on various sectors."*. These comments indicate that players who are themselves educators or communicators see ClimarisQ as a worthwhile addition to their toolkit. One respondent, who identified as a teacher, mentioned using it with *"educator friends and teachers"*, suggesting a peer-to-peer recommendation among the teaching community.
- Appropriate for the target audience: Implicit in recommendations was often the notion of the right audience. Some who themselves did not learn new things still said they'd recommend it to *less informed audiences*. E.g., *"I knew this stuff, but for someone who doesn't, it's a great way to learn the basics while having fun."* Though not a direct quote from the data, this

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paraphrases a common idea expressed. There was also a suggestion from one respondent that *"spending more time [on the game] for non-specialists could be interesting"* – possibly meaning that if the game could be extended or had more levels, it would benefit laypersons even more.

What about those few who would not recommend it? Only a handful of respondents fell into this category, and they often did not elaborate much. One simply said "No." (with no reason). From context, likely reasons for not recommending could be: if they found the game too frustrating or too simplistic for their taste, or if they encountered technical issues. One respondent who rated difficulty poorly might have been disinclined to recommend because they thought casual players would be put off. Given the overwhelmingly positive scores in other sections, it seems safe to say the game was well-received and that negative opinions were rare and minor.

Additional Feedback and Observations: The survey responses provided a few suggestions and observations beyond direct questions. A couple of users noted that *replayability* could be improved. After a few rounds, once you discern the optimal strategy, the surprise factor drops. This is common in serious games – their primary goal is to educate, and once educated, players might "solve" the game. Some suggested adding more random events or varying scenarios (e.g. different regions with unique challenges, or an ability to play a short term vs. long term scenario). Some technically adept users were curious about the underlying model and data. One wrote, *"Would be nice to have a behind-the-scenes explainer: e.g., how CO2 ppm is calculated."* This indicates interest in the science detail, which could be an opportunity for a supplemental educational document or link in the game (for those who want to dive deeper, e.g., reading about the climate model powering the extreme events). There was a comment that *the game might be overwhelming for non-specialists at first*, suggesting an improved tutorial or a simplified mode. This aligns with our difficulty findings that not everyone found the learning curve easy. A step-by-step guided play (perhaps an easier "tutorial scenario") could help less experienced players grasp the gameplay and science gradually. On the positive side, multiple respondents appreciated the multilingual aspect. Players noted using both English and French versions. This is

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significant for outreach since climate education needs to be accessible in local languages for broader impact.

In conclusion, the results demonstrate that ClimarisQ successfully engaged its target users, delivering an enjoyable learning experience that users are inclined to share with others. It excelled in conveying complexity and providing a platform for discussion. The educational impact on knowledge was nuanced – reinforcing and illustrating concepts for most, rather than imparting completely new information, given many players' prior knowledge. The impact on attitudes was modest but present in terms of heightened awareness and willingness to advocate climate action. These findings set the stage for a deeper discussion on how serious games like ClimarisQ fit into climate education, what their strengths and limitations are, and how they might be improved or used in practice, which we turn to next.

4. Discussion

4.1 Integrating Serious Games into Climate Education

The evaluation of ClimarisQ offers a window into the opportunities and challenges of using serious games for geoscience communication. The positive reception of ClimarisQ's content and engagement value supports the notion that well-designed games can complement traditional educational methods in climate literacy. As UNESCO and other global bodies emphasize, climate change education must not only convey facts but also empower learners as *"agents of change"* with the *knowledge, skills, values and attitudes* to act. Games like ClimarisQ can contribute to this empowerment by actively involving learners in simulations where they *practice* decision-making and witness consequences in a compressed timeframe.

One of ClimarisQ's strengths is its ability to foster systems thinking. Climate systems are characterized by feedback loops, delays, and nonlinearity. These can be conceptually difficult for learners – for instance, the idea that cutting emissions now might not yield visible benefits for decades (due to climate inertia), or that interventions can have unintended side effects. ClimarisQ, through gameplay, requires players to think in terms of system dynamics: balancing different gauges effectively forces

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consideration of feedbacks (e.g., neglecting "ecology" gauge leads to worse disasters that later hit the "finance" gauge). Survey responses confirm that players picked up on these systemic aspects (e.g. recognizing the need for balance and long-term strategy). This aligns with academic findings that interactive simulations can improve understanding of complex environmental systems compared to static instruction. By iteratively adjusting decisions and seeing outcomes, players construct a mental model of the climate-society system. Notably, some respondents explicitly mentioned learning about *delayed effects* and *the accumulation of CO_2*, which are critical concepts for climate literacy. Traditional curricula sometimes treat climate topics in isolation or in a linear cause-effect way, whereas ClimarisQ's gameplay naturally integrates them into a network of causes and effects.

Another highlight is the game's role in generating discussion and reflection, which is a key element of transformative learning. The LSCE developers anticipated this, as they noted that one class period can be used to play and *"discuss the results"*. Our findings show that players indeed discussed strategies and outcomes. In a classroom or workshop setting, the game's end result (displaying CO_2 ppm above a baseline and how many rounds survived) can prompt questions: *Why did we end up at 500 ppm CO_2? What could we have done differently?* Such discussions can segue into talking about real-world emissions scenarios and extreme event statistics. In fact, we can draw a parallel to role-playing simulations like the World Climate exercise (where participants negotiate emissions; research has shown those can increase participants' knowledge and motivation). ClimarisQ similarly can serve as a boundary object – a concrete experience that anchors subsequent conversations about abstract concepts.

The broad age range and backgrounds of respondents also suggest that ClimarisQ has cross-cutting appeal, which is valuable for community education settings. For example, it could be used in intergenerational workshops or science museum events where teenagers and adults play together. This addresses the special issue's theme of engaging various publics ethically. Everyone can bring their perspective (a policy-inclined player might focus on public approval gauge, a scientist might focus on ecology gauge) and afterwards share insights. Such participatory learning aligns with modern pedagogical approaches for sustainability, which advocate collaborative problem-solving rather than top-down lecturing.

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4.2 Ethical and Practical Challenges

Despite these merits, there are important challenges and ethical considerations in the use of serious games like ClimarisQ for climate communication. We discuss a few key points: accuracy vs. simplicity, emotional impact, representation of issues, and user diversity.

Accuracy vs. Simplicity: Serious games must simplify reality to be playable. ClimarisQ condenses the intricacies of global climate policy into a game of gauges and cards. This raises the ethical question: does simplification risk *misinforming*? The developers appear to have been cautious – using *real data and models* ensures that the trends depicted (more emissions = more extreme events frequency) are scientifically sound. However, not all aspects can be included. For instance, the game doesn't explicitly model the ocean, population growth, or technological innovation – factors that are very relevant to real climate futures. One could argue that leaving out ocean dynamics (like El Niño, ocean carbon uptake, etc.) might underplay their importance. On the other hand, adding too much detail could overwhelm players and obscure the core message. The educational design principle here is to include enough complexity to teach target concepts (urgency, complexity, unpredictability) but not so much that the game becomes unplayable or confusing. Based on user feedback, ClimarisQ mostly struck the right balance; however, a few advanced users hungered for more nuance (e.g. finer distinctions in policy options, or more detailed cause-effect). From an ethics perspective, transparency is key: the game website or guide should clarify its assumptions and limitations (something that could be improved by publishing a "model document"). This way, educators can contextualize the game – explaining that, for example, "in reality we also have oceans absorbing some CO_2 which is not explicitly shown here" – bridging the gap between the model and the real world.

Emotional impact and urgency: Communicating urgency without inducing despair is a delicate ethical balance. Serious games on climate risk either trivializing a grave issue (if made too lighthearted) or overwhelming players with doom (if made too hard or catastrophic). ClimarisQ addresses this by using a friendly art style and giving players *agency* to try different strategies, but ultimately most games end in a scenario where the government is dismissed (the game-over). Some might worry that repeatedly

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"losing" could instill fatalism (e.g., "no matter what I do, disaster comes"). However, the intended takeaway is the opposite: that *better decisions lead to better outcomes than worse decisions*, even if avoiding all harm is impossible. One respondent's comment that they survived longer on subsequent tries indicates learning and improvement, which can foster a sense of efficacy. Ethically, the game creators included the message of *collective action urgency* – it's not that doom is inevitable, but rather that *action is needed now* to avoid the worst outcomes. This aligns with best practices in climate communication, which call for honest portrayal of risks combined with empowerment. The survey didn't specifically ask about emotions, but none of the comments indicated feelings of hopelessness; if anything, players were motivated to replay and do better. That said, facilitators using the game should be prepared to support players who might take the loss badly: e.g., discussing how even in the game, mitigating actions did reduce CO_2 compared to doing nothing, underscoring that real actions matter even if some climate change is now unavoidable.

User Diversity and Accessibility: The survey hinted that the current user base skewed toward already climate-literate individuals. From an outreach and equity standpoint, this is a limitation – ideally, we want tools like ClimarisQ to reach more underserved audiences who might not otherwise engage deeply with climate issues. The high education level of respondents suggests the game, as currently disseminated, may not be reaching as many typical high schoolers or lay citizens. This raises practical questions: How to get such games in front of those who could benefit most (e.g., students in schools that don't have strong climate science programs, or adult communities where climate issues are not frequently discussed)? One strategy is partnering with educational authorities or NGOs to include the game in formal programs. Another is translating it into more languages and promoting it in regions heavily affected by climate change (imagine local workshops in coastal communities or small island nations using the game to visualize future challenges). However, cultural and linguistic adaptation might be needed; the scenarios in ClimarisQ are somewhat generic/global North oriented (e.g., dealing with budgets and popularity might resonate differently in different governance contexts). Ethically, co-design with target communities could improve relevance.

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On accessibility, the digital nature of ClimarisQ means it requires the internet or a smartphone, which could exclude some populations (the so-called digital divide). Ensuring it runs on low-end devices and possibly creating an offline version could broaden its availability. Additionally, for vision-impaired or other differently-abled learners, alternative formats or assistive features would be necessary (currently, a visually rich game might not be usable by those with certain disabilities).

Measuring Impact: Our study relied on self-reported outcomes immediately or shortly after gameplay. A deeper question is whether playing ClimarisQ leads to sustained changes in understanding or behavior over time. The results suggest modest immediate learning for already-informed players, but we don't know how a novice would fare, or if a student would recall these lessons months later. Future research could involve pre- and post-testing knowledge around climate/ocean concepts for players, or even longitudinal tracking (does playing the game correlate with, say, choosing to study environmental science or joining climate initiatives?). So far, literature indicates that games can increase short-term engagement and knowledge, but converting that into long-term action is harder and likely requires reinforcement from other educational inputs. In practice, ClimarisQ should be seen as one component in a multi-modal education strategy – an entry point that sparks interest, which teachers or communicators then build on with further information and opportunities for action (like citizen science projects or school sustainability projects). This aligns with ethical communication – one doesn't just "drop" a serious message via a game and leave; one should guide the learner towards resources and next steps.

4.3 Comparison with Other Initiatives

It is instructive to compare ClimarisQ with other climate educational games and outreach practices documented in literature and practice. For example, the I-CHANGE "Our Climate Story" game (an EU project referenced in search results) aims at personal action narratives, whereas ClimarisQ focuses on policy and collective outcomes. Each addresses different scales; combining them could offer a full spectrum: ClimarisQ for big-picture system awareness, and personal action games for individual behavior change. Another category is simulation-based role plays such as the C-ROADS World Climate

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negotiation game or the NOAA "Climate Challenge" game; those often show the difficulty of international agreements. ClimarisQ in contrast internalizes conflict within a single gameplay (the popularity gauge can be seen as a proxy for political/social acceptance). All these games highlight urgency and complexity, but through different lenses – negotiating emissions vs. managing a society.

For ocean education, games like "EcoOcean" or "Ocean School" (an interactive platform by Canadian partners) exist, focusing on marine ecosystems and human-ocean interaction. While ClimarisQ doesn't cover marine biology or oceanography specifics, the concept of using gameplay to teach about overfishing or coral conservation is analogous. One could envision a suite of serious games, each tackling a facet of Earth systems: atmosphere (climate), hydrosphere (ocean), cryosphere (glacier melt game?), biosphere (ecosystem management game). If used together in an educational program, they could reinforce the interconnectedness of these domains.

In terms of effectiveness, a study by Schaup et al. (2023) – for instance – might find that serious gaming improves certain attitudes but not others. Our evaluation suggests ClimarisQ is effective in conveying knowledge and sparking engagement, but perhaps less so indirectly promoting behavioral change (common in environmental education – knowledge is necessary but not sufficient for action). Other outreach practices, like citizen science or field-based learning, often have strong behavior links (because participants physically do sustainable actions). Serious games can serve as a bridge: they educate and motivate, but ideally should be paired with action-oriented follow-ups to fulfill their potential.

Ethically, one might consider whether a game's *storyline* or framing influences players' attitudes beyond the intended scope. For example, ClimarisQ's framing is that you are a kind of benevolent decision-maker trying to save society. This might instill a somewhat top-down view of climate action (emphasizing policy decisions from a leadership perspective). It could inadvertently de-emphasize grassroots action. To counter that, facilitators can encourage players to reflect on what *role* they felt they were playing and how that translates to real life (e.g., "Even if you are not a president, you can be a community leader making similar choices in miniature"). Other games, like role-play of a climate activist vs. an industry lobbyist in a mock town hall, would place players in different shoes. Diversity

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in approach is beneficial. ClimarisQ chooses a particular approach – likely for clarity and design reasons – and largely avoids contentious political framing (the decisions are somewhat generic, not labeled with partisan tags or specific real-world politics, which is good for broad acceptability).

One more point in the comparison: The notion of *urgency* as highlighted by the special issue implies we must evaluate how quickly and widely such educational interventions can scale. ClimarisQ, being digital, has a high scaling potential (marginal cost of distribution is low). Compared to in-person workshops that reach dozens at a time, an app can reach thousands worldwide relatively quickly. Indeed, by the time of writing, ClimarisQ had been downloaded in numerous countries (though we only analyzed 77 surveys, presumably total players are more). This scalability is an advantage for addressing urgency – we can get the message out fast. The challenge is ensuring people actually play, learn, and not just download and drop. That comes back to engagement, where ClimarisQ seems to have done well in hooking interested users. It would be beneficial if future work looked at app analytics to see completion rates etc., to complement the voluntary survey data.

4.4 Implications for Practice

From our analysis, we can draw several implications for educators and communicators:

1. Use games as a supplement, not a standalone. The best outcomes likely occur when ClimarisQ is embedded in a lesson or event. For example, a teacher might have students play in small groups, then collectively discuss strategies and connect them to real climate policy debates. Our findings show that players indeed have varied experiences; a guided discussion can help consolidate learning and correct any misconceptions.
2. Address the diverse knowledge levels. In a mixed group, some will find the game revelatory, others simplistic. Facilitators can challenge advanced students to dig deeper ("what assumptions underlie the game's model? could any be different?") while ensuring beginners grasp the basics ("why did our finance gauge drop when that drought hit?"). Having players with different expertise play together can actually be beneficial: the more knowledgeable can

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mentor the less, an example of peer learning. But one must guard against the knowledgeable dominating decisions – perhaps by rotating who gets to choose actions in successive rounds.

3. Highlight ocean connections explicitly. If using ClimarisQ in an oceanography course or marine conservation context, instructors should explicitly tie game events to ocean processes (e.g., extreme events -> link to ocean heat content; CO_2 -> link to ocean acidification; droughts -> possibly link to monsoon circulation changes). One could even develop a short companion activity: e.g., after playing, show a visualization of ocean warming or have a small quiz on how ocean currents affect weather, to integrate the knowledge.
4. Encourage multiple playthroughs. One limitation is if players only play once, they might not explore alternative scenarios. Encourage them to replay with a different strategy or even encourage *collaborative play*. For instance, splitting the class into two teams playing in parallel with different priorities (one prioritizes economy, one prioritizes environment) and then comparing outcomes can concretely show the trade-offs and reinforce learning (almost an experiment within the game context).
5. Collect feedback and iterate. If possible, educators or the game developers should continue to collect data (like we did) to refine the game. For example, if teachers consistently report that students struggle with a particular concept or misuse a particular strategy due to misunderstanding, the game could be tweaked or teachers informed to clarify that concept beforehand. Serious games benefit from iterative design with user feedback loops, similar to any educational material.

4.5 Limitations of the Study

While our study provides insights, it is limited by the sample and methods discussed. The results likely paint an overly positive picture, since participants who disliked the game might not have bothered to complete the survey. Also, our interpretation of "No" vs "Yes" responses had some ambiguity due to how succinct respondents were. A more rigorous future evaluation could involve pre/post testing knowledge quizzes, measuring attitude changes via validated scales (e.g., environmental concern scales), and perhaps a control group who learns via traditional methods for comparison. Nonetheless,

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even with these caveats, the triangulation of ratings and comments gives confidence that the main trends we identified are real.

5 Conclusion

In an era where the climate crisis demands rapid, widespread public understanding and action, innovative tools like ClimarisQ demonstrate both the promise and complexity of modern science communication. Our analysis of ClimarisQ – a serious game integrating climate science and policy trade-offs – shows that such games can engage learners across different backgrounds, reinforce key concepts (like urgency of action and system complexity), and spark meaningful discussions about climate challenges. ClimarisQ's success in delivering scientifically accurate content in an enjoyable format led to strong user endorsement; players found it both fun and educational, a combination essential for deeper learning.

The educational impacts of ClimarisQ are nuanced. For already knowledgeable players, the game served more as an illustrative sandbox than a source of new facts – it helped them "connect the dots" and appreciate the multidimensional nature of climate decisions without necessarily introducing novel information. For less experienced players, we infer (and limited responses suggest) that the game can indeed teach new concepts, such as how different societal sectors are interlinked with climate outcomes, or how gradual climate changes translate into extreme weather risks. Importantly, even if not everyone learned new facts, virtually all players gained insight into the *difficulty and importance of climate action*, which is a crucial attitudinal outcome. This kind of insight is what can transform awareness into what UNESCO calls *empowerment* – understanding the problem deeply so as to be motivated to engage.

In terms of engagement and motivation, ClimarisQ clearly succeeded. By leveraging gameplay, it attracted users who might not read a report or attend a lecture on climate extremes, and held their attention through interactive challenges. Many respondents indicated they would share the game with peers or students, meaning the game can have a multiplier effect as a communication tool. Given the urgency, such peer-to-peer spreading of climate literacy tools is valuable.

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serious games are not a standalone solution to climate education or engagement challenges. They work best in conjunction with other strategies – for example, as part of classroom curricula, public workshops, or stakeholder processes that include facilitated debriefings (Flood et al., 2018; Rumore et al., 2016). Reflection and discussion after gameplay are crucial to help players connect in-game experiences to real-world contexts and deeper conceptual understanding. Without guided reflection, there is a risk that players might focus on game mechanics or winning tactics without extracting the intended lessons. Therefore, the designers of ClimarisQ have supplemented the game with educational materials and encourage group play sessions followed by conversations. This approach echoes the "debriefing and evaluation" best practices identified as key to successful learning outcomes in climate games (Flood et al., 2018). Additionally, one must consider that different audiences have different needs. A game that resonates with high school students might not immediately click with policymakers, and vice versa. Adapting the framing and complexity level of games to the target audience is important for effectiveness (Parker et al., 2016). In the case of ClimarisQ, the interface is kept intuitive and visual to appeal to a general audience, but the underlying model is scientifically rigorous, which lends it credibility when used with more expert audiences. Another challenge is evaluating the impact of serious games on players' knowledge, attitudes, and actions. While qualitative feedback on ClimarisQ has been positive (players report enjoying the challenge and gaining insight into climate system behavior), the project team has also gathered survey data to quantitatively assess learning outcomes. This follows a trend in recent research to rigorously measure game-based learning. For example, pre/post surveys in the Keep Cool game study helped isolate changes in climate attitudes due to gameplay (Meya & Eisenack, 2018), and a two-phase literature review emphasized the need for standard metrics to compare serious game effectiveness (Ahmadov et al., 2024). Preliminary results for ClimarisQ suggest that most players find the game intuitive and educational, with many expressing a greater appreciation for the urgency of collective action after playing (internal project data, to be reported). These findings will contribute to the growing body of evidence that serious games can serve as valuable pedagogical and engagement tools in the climate domain. Notably, serious games often excel at sparking initial interest and building conceptual frameworks; maintaining long-term engagement and guiding players from awareness to real-world action remains an open task. Some studies have begun to look at whether playing climate

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games leads to outcomes like joining environmental groups, reducing personal carbon footprints, or supporting specific policies. While data are still limited, the outlook is encouraging – one study noted that gameplay increased participants' confidence in climate policies and even their willingness to sign petitions in support of climate action (Meya & Eisenack, 2018). As climate games "grow up" and become more sophisticated and common, we may see these tools integrated more into mainstream climate communication and policymaking processes (Kwok, 2019). In summary, the experience with ClimarisQ and other serious games highlights several key benefits: (1) Games can translate the abstract, systemic nature of climate change into relatable scenarios and concrete decisions, enhancing understanding of climate science and urgency (van Beek et al., 2022; Rooney-Varga et al., 2018). (2) They promote systems thinking and interdisciplinary learning, helping players see connections between, for example, emissions, extreme events, economic impacts, and social responses (Ballew et al., 2019; Waddington & Fennewald, 2018). (3) Games naturally engage emotions and can therefore tackle the affective dimension of climate communication – fostering hope, agency, and empathy, while avoiding unproductive fear appeals (Marlon et al., 2019; O'Neill & Nicholson-Cole, 2009). (4) Through role-play and scenario simulation, serious games build skills in collaboration and problem-solving, which are essential for real-world climate action (Rumore et al., 2016). (5) They can also serve as research and dialogue tools: by observing gameplay or using embedded surveys, researchers glean insights into how people perceive climate risks and make decisions, and players in turn get to discuss and reflect on climate challenges in a social setting (Parker et al., 2016; Asplund et al., 2019). (6) Finally, games support broader environmental literacy agendas, including ocean literacy and sustainable development awareness, by making learning interactive and fun (Leitão et al., 2022; Tiller et al., 2024).

In summary, ClimarisQ has proven to be a valuable addition to the climate education landscape, offering a model of how complex science and policy scenarios can be translated into engaging learning experiences. As climate issues grow more urgent, such innovative tools – especially when combined with effective facilitation and integration into curricula – will be increasingly important in raising public understanding and catalyzing action. The lessons learned from ClimarisQ's deployment can guide the development of future serious games and interactive media on environmental sustainability. By

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continuing to iterate on these approaches and share best practices, educators and communicators can better meet the pressing challenge of our time: helping society understand the risks we face and the choices we must make to navigate them.

Code Availability: The source code for the ClimarisQ game is not publicly available due to ongoing development and maintenance by the project team. However, researchers interested in the underlying algorithms and models used in the game design are encouraged to contact the corresponding author for more information or collaboration opportunities.

Data Availability: The data supporting the findings of this study are available upon reasonable request. This includes anonymized survey responses used for evaluating the game. Aggregated results and example datasets are available in the supplementary material or can be provided by the authors upon request.

Competing Interests: The authors declare that they have no conflict of interest.

Ethical Statement: This study involved the voluntary and anonymous collection of survey data from users of the ClimarisQ educational game. No personal or sensitive information was collected, and all participants provided informed consent before completing the questionnaire. The survey was designed in accordance with standard ethical practices for minimal-risk research in education and public engagement.As the research did not involve vulnerable populations, medical interventions, or personally identifiable data, it was exempt from formal institutional ethical review under CNRS and Université Paris-Saclay guidelines. The research team adhered to the European Code of Conduct for Research Integrity, and all data have been anonymized and stored in compliance with GDPR regulations.

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