Game-based Climate Change Engagement: Analyzing the Potential of Entertainment and Serious Games

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Video games have risen as a popular medium with the potential to become a powerful tool for public climate change engagement. However, little is known about how existing digital games can fulfill this role. This study systematically compiles 150 video games that represent climate change, including serious ($n = 109$) and for entertainment ($n = 41$). The games are analyzed by adapting an existing framework (15 dimensions: achievable, challenging, concrete, credible, efficacy-enhancing, experiential learning, feedback-oriented, fun, identity-driven, levelling-up, meaningful, narrative-driven, reward-driven, simulating, social) and statistically compared. The analysis reveals that most games comply with most recommended attributes, but credibility, achievability, meaningfulness, and social features are uncommon or rare. Statistical results comparing serious games and games for entertainment associate six attributes with serious games (achievable, challenging, credible, efficacy-enhancing, experiential learning, feedback-oriented), and one (narrative-driven) with games for entertainment. The findings suggest that researchers would benefit from widening their lens to detect previously overlooked opportunities for game-based climate change engagement, communication, and education. The study also provides a systematic mapping of extant games depicting climate change for interested developers, designers and educators.

CCS Concepts: • **Applied computing** → **Computer games**; *Environmental sciences*; • **Social and professional topics** → **Informal education**.

Additional Key Words and Phrases: games; gamification; game-based learning; serious games; video games; digital games; education; climate change engagement; global warming; sustainability

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1 INTRODUCTION

Climate change has already impacted ecosystems and human societies, and further global warming is expected to increase risks related to health, food and water access, security, and economic growth [85]. This issue is perceived internationally as the top global threat, a concern that has grown since at least 2013 [112]. As social unease increases, diverse parliaments and governments have declared “climate emergency” to signal extraordinary resource mobilization [22]. Meanwhile, influential politicians still deny climate change [121] and often support disinformation campaigns to create public controversy.

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The rising climate concern and the evidence of uncertainty and misinformation call for scientifically accurate and engaging messages to help citizens become petitioners and agents of climate action. However, communicating climate change involves challenges at the interplay between its complexity and our psychological and environmental limitations [59, 95]. To create a state of engagement with climate change, three domains have been signaled as important: cognitive, affective, and behavioral [80]; that is, understanding climate change, responding emotionally to it, and acting accordingly [96]. While engagement as a broad concept has been interpreted as pertaining to either or all of these three dimensions by various scholars, including in the field of HCI [26], here we focus exclusively on engagement with climate change.

Given the urgency required and the difficulty of achieving widespread and active climate change engagement, new methods are being used to convey climate messages in a way that promotes public understanding, interest, and action. Gamification, or the use of games across society, culture and technology for purposes other than entertainment [60], is one of such methods. Multiple game-based interventions have been found to engage players with climate change [41]. At the same time, some of the most influential game companies have begun exploring how to bring more environmentally conscious messages and designs to their games [108]. Video games' popularity as culturally influential artifacts, reaching 2.5 billion players worldwide [143], is well known.

However, most of the games for climate change that can be found in the academic literature are not readily accessible to the public [41], have disappeared since they were reviewed [69, 79, 115], or have not been systematically examined in terms of potential for climate change engagement. In addition, specific types of games, such as those not intended for education and those created for mobile platforms, tend to escape the researchers' gaze.

For these reasons, the literature would benefit from a current, broad and systematic analysis and discussion on video games' potential to promote climate change engagement and education. This study aims to address this gap by answering the question, "What attributes supporting climate change engagement do existing video games possess, according to the 15 attributes in the framework for climate change engagement through video games by Ouariachi et al. [107]?" After a systematic online search, we selected 150 publicly accessible computer, browser, and mobile games representing climate change (see auxiliary file 1 for a complete list) and analyzed them using the cited analysis framework.

Our second research question is, "What differences are there between serious games and games for entertainment in terms of climate change engagement?" In this study, we classify games according to purpose, either entertainment ($n = 41$) or serious ($n = 109$). Serious games are those with additional goals such as education, persuasion and/or raising awareness. We statistically analyze and discuss the differences between serious and entertainment games in relation to their climate change engagement potential, an unexplored issue in current literature as will be discussed next.

This article is part of the multidisciplinary efforts to engage humans with climate change, and specifically of research exploring the role that games may have in promoting said engagement [41]. In this regard, the article adds to recent HCI games scholarship (e.g., [13, 66, 98, 100, 132]). By answering the first question, we seek to provide a deeper understanding of the current landscape of games and climate change, including the most common engagement features and gaps. In practice, this should aid (a) scholars interested in focusing future empirical interventions on particular games or engagement strategies, for example investigating how effective the least common attributes are in bringing engagement to better decide if a conscious effort should be made to use them more; (b) game developers and designers, including researcher-developers, interested in knowing the state of the art of games representing climate change before starting a new project; and (c) educators seeking to use games in the classroom. By comparing serious and entertainment games, we hope

to bring a more nuanced understanding of their similarities and differences at present, which may spark more interest in the use of entertainment games for research and education, and encourage developers of both serious and entertainment games to examine the other side more closely as a source of inspiration.

2 BACKGROUND

Video games are often viewed as artifacts that intend to provide entertainment [129]. Meanwhile, Djaouti, Alvarez and Jessel [25] define serious games as software that combines a purpose different from entertainment (i.e., a “serious” purpose) with the structure of a video game. Although entertainment games can simulate aspects of reality, chiefly those pertaining to the simulation game genre, they are not considered serious games if they were not designed with a serious purpose in mind [99]. Entertainment games can be, and they often are, used for a serious intention, but this entails a shift in their purpose or a modification of their content [25]. Therefore, the difference remains in the purpose when designing the game, which will be our basis for classifying games as serious or for entertainment.

However, intention is not the only variable that defines whether a game will successfully engage players with a topic such as climate change. First, entertainment media can contribute to informal science engagement through, for example, the portrayal of scientific phenomena [30]. Digital games and mobile platforms provide novel avenues for public engagement with science, including environmental science communication [144]. Second, as mentioned above, commercial video games for entertainment are used in formal education regularly [138], expanding their presence beyond developers’ intended contexts. Third, games can be theorized as communicative and persuasive artifacts regardless of purpose. Scholar Ian Bogost identifies video games as pieces of procedural rhetoric, defined as “persuasion through rule-based representations and interactions . . . tied to the core affordances of the computer” [11, p. ix]. Thus, all games can potentially influence players’ awareness, attitudes, and behaviors.

Beyond the rhetoric framework, games can also provide climate learning opportunities, since interactive and engaging methods have been hailed as one of the most effective strategies in teaching about the topic [93]. Extensive engagement with games provides opportunities for deep, actively acquired and critically examined learning [56]. Knowledge can be enhanced, and new skills acquired, when players are involved in a medium perceived as engaging and motivating. Since good game design is associated with good learning [57], understanding how existing climate change-related games engage and motivate players helps to identify potentially impactful examples to be used in science communication and education. Although impact depends on the context and audience, the existing literature provides a design roadmap to increase the chances of game-based climate change engagement. Some of those recommendations form the basis for the analysis framework used here [107], such as the importance of providing achievable goals [140], simple messages connected to players’ identity [62] and a sense of agency [136].

Climate change games are serious games that focus on climate change processes, impacts, and responses [149], from global climate policy [137] to declining insect populations [100]. These games have been used and promoted in multiple contexts, sparking collaborations between HCI and game practitioners and non-profit organizations [98] as well as companies. Students have also been encouraged to design their own climate science games, reaching in some cases good levels of quality [132]. Several empirical studies have found games and gamification effective in cognitively, affectively, and behaviorally engaging with climate change in educational, professional and other life contexts [41]. For example, digital games have been shown to improve students’ climate literacy [61, 101] and raise their awareness of energy-related behaviors [71]. A serious game that presented a story in a virtual location based on a real city increased players’ concern [8], and the use of

playful technology raised discussion and encouraged pro-environmental behavior among university students [66]. In daily life, games and gamification have been found to foster energy efficiency [67, 94] and other pro-environmental behaviors [77]. Nevertheless, digital games have also failed to produce significant attitudinal effects, which has been attributed to specific perceived faults such as insufficient graphic quality and lack of challenges and interactive affordances [104]. In another case, players of the serious game *Fate of the World* [117] found that its excessive difficulty led to feelings of fatalism, which could have hindered behavior change [137]. More recent games aim to address climate grief through gameplay meant to be empowering and motivating, but no empirical results exist yet [13].

Existing content reviews have analyzed climate change games, but they present issues. A review of digital and analog games from 2013 [115] noted that most had been published between 2008 and 2010 and focused either on the local or global scale, but the sample is outdated and the analysis did not focus on engagement potential. A more recent review of browser games [106] noted a tendency to incorporate positive elements such as a focus on the local scale, visualization of climate change, and depictions of future consequences, but focused only on Spanish games. Finally, other game reviews focused on sustainability as a whole [69, 79, 125], and thus their findings are difficult to contextualize regarding climate change engagement. In most cases, the games reviewed [71, 79, 115] seem to have disappeared from the internet.

Furthermore, representations of climate change in entertainment games have been less explored when approaching the topic. As a result, the ways in which games for entertainment may engage players are largely unknown except for a few specific examples. Abraham and Jayemanne [3] found different types of relationships between humans and environments in video games, including the environment as mere backdrop, resource, antagonist, and text, but these did only implicitly (albeit importantly) relate to climate change. Abraham [2] focused on the aesthetics of a single game, *Arma 3* [65], as potentially engaging with low-carbon technologies, while Chang [14] critically engaged with several aspects of video games that relate to the non-human world, including issues of content and representation, but did not seek to provide an exhaustive review. Thus, no systematic analysis of climate change affordances in video games for entertainment exists, let alone a comparison with those of serious games. Finally, mobile games, suitable for realizing the potential of pervasive gaming [149], also lack attention, as do recent developments in the area of immersive virtual reality (VR). Immersive virtual environments (IVEs) have been shown to promote climate change learning [83], pro-environmental behaviors [7], and a sense of connection to nature [6].

This brief overview provides the supporting argument for this work: that a current, broad and systematic examination is needed in the area of video games and climate change. Furthermore, the analysis of games for entertainment is already a novel inclusion, as is the comparison with serious games. As stated in the introduction, this analysis could benefit at least three audiences: scholars, developers, and educators. Next, we describe the search and selection procedures and detail the engagement criteria used for analysis.

3 METHODS

This study reviews video games representing climate change that can be accessed online and played in computers (Windows, macOS, Linux), browsers (e.g., using Flash, Unity Web Player or HTML5), and mobile devices (Android and iOS). The process followed two phases: search and selection, and content analysis.

3.1 Search and selection

A search was performed between February and August of 2019 in Google Search and the game and app distribution platforms Steam, itch.io, Google Play, and App Store (through the AppApp.io and

find.io search engines, given that a PC was used for the initial search and therefore the App Store was not directly accessible). These distribution platforms were chosen due to their popularity and extensive catalog regarding games for, respectively, computers, computers and browsers, Android devices, and iOS devices, all including VR and augmented reality (AR) games. The initial Google search uncovered relevant websites (such as NASA Climate Kids) and databases (e.g., Games for Change and Games4Sustainability) where further games were found. In Google Search, we used the string ("*video game*" OR "*online game*" OR "*educational game*") AND ("*climate change*" OR "*global warming*" OR "*sustainability*" OR "*environment*"). Searches on game platforms and databases used only the keywords in the second parenthesis. In Google, the search was concluded when a page did not provide any new relevant results, while in the rest of the platforms, websites and databases all search results were considered.

The initial results were screened for inclusion by a single researcher who read official descriptions or reviews, watched trailers and gameplay videos, or played for up to 10 minutes. Four criteria were required:

- (1) The game complies with the definition of video game presented above. This excludes climate models and simulations that do not feature video game design elements, applications that provide information, and simple quizzes.
- (2) The game is available for download (regardless of price or revenue model) on a computer or mobile, or directly playable on the web. Prototypes and games in development were included if published and functional.
- (3) The game includes English or knowledge of the language is not necessary during gameplay.
- (4) Climate change or related aspects, such as disaster risks or sustainable behaviors, are present, including representations through interaction, storytelling or aesthetics.

A total of 150 video games were found to comply with all criteria. Next, they were classified according to purpose, either entertainment or serious (see auxiliary file 1). Two sources have been used to ascertain purpose: explicit statements of intention beyond entertainment in the games themselves or in paratexts surrounding them (e.g., marketing materials, developer messages, interviews); and the organizations involved in their creation (the participation of activist, educational and scientific organizations or networks is considered conducive to a game with a secondary purpose). Absence of a clear secondary purpose makes the game for entertainment only.

3.2 Content analysis

This study examines game content through the 15-attribute climate change engagement framework developed by Ouariachi et al. [107]. To build it, its authors interviewed 12 designers and scholars involved in the creation of climate change and sustainability games and used grounded theory to identify relevant engagement affordances. Next, the resulting 15 attributes were classified according to the three dimensions of climate change engagement. Finally, the framework was validated through a discussion with adolescent students, a frequent target group of climate change serious games [106], and complemented with relevant literature in the fields of social psychology, communication, and education.

A systematic search process was performed in Scopus in September 2020 to make sure that no other suitable tool had been overlooked. The string *TITLE-ABS-KEY ((game* OR gamif*) AND ("climate change") AND (model OR framework OR recommendations OR guidelines))* returned 606 documents, none of which described other methods for content analysis of climate change engagement through games. The most similar is an analytical framework for climate change visualization [142]. Other existing game design and analysis frameworks that we were previously aware of (e.g., [27, 40, 42]) have a broader focus, such as sustainability.

The framework is used here as a checklist, as has been done in at least another study [105]. A binary value (yes/no) has been assigned to each one of the 15 attributes for each game (see auxiliary file 1) by the main author, an individual with professional experience in game design and research as well as over two decades of frequent video game play. Therefore, the analyst's perspective amalgamates three distinct relationships to games: as user, scholar, and maker. The descriptions for the 15 attributes are listed next. Positive and negative examples of each attribute can be found in auxiliary file 2.

- (1) **Achievable.** The players can take or discover positive actions related to climate change that are within laypersons' reach in the real world.
- (2) **Challenging.** The game's climate-related tasks require effort to perform.
- (3) **Concrete.** The game avoids long texts and statistics about climate change in favor of simple and direct messages, preferably integrated into the game mechanics.
- (4) **Credible.** The game incorporates trustworthy information sources for climate change or related topics, such as journalists, well-known organizations, and scientists. Sources can be fictional or represent real-world organizations and agents.
- (5) **Efficacy-enhancing.** The game promotes a sense of agency and control, allowing players to make their own decisions and see the consequences, showing that climate change issues such as its impact on our well-being can be addressed.
- (6) **Experiential learning.** The game focuses on doing rather than thinking, favoring experience over rational analysis and intertwining climate change concepts with the narrative.
- (7) **Feedback-oriented.** The game provides clear, immediate, positive, and encouraging feedback, giving information to achieve goals related to climate change.
- (8) **Fun.** The game is fun, amusing in a way that hooks, especially thinking of its intended audience. The concept of "fun" will be further discussed.
- (9) **Identity-driven.** The game features characters the player cares about and can help, possibly leading to an emotional connection.
- (10) **Levelling-up.** There are different levels or missions related to climate change in the game, creating a clear progression through milestones that get more challenging or complex to manage every time. In this study, this can also mean that players level up themselves, getting access to more skills.
- (11) **Meaningful.** The game evokes intense feelings. Climate change is perceived as a serious matter to tackle, but also one that can be addressed.
- (12) **Narrative-driven.** The game makes a meaningful use of fantasy, i.e., significant narrative events related to climate change. Stories can be linear or arise through interaction with systems with multiple outcomes.
- (13) **Reward-driven.** The game rewards the player for passing levels or meeting targets related to climate change, for example with stars, badges, awards, achievements, points, currency, or new items.
- (14) **Simulating.** The game simulates systems with multiple variables, choices and specific outcomes related in some way to climate change (e.g., the carbon cycle).
- (15) **Social.** The game features a social component (e.g., multiplayer modes, leaderboards, or simple social media sharing features).

To support the validity and reliability of the work, we have employed diverse verification strategies [20] adapted to the analysis of games [75]. These consist of providing unique examples and detailed descriptions of the concepts presented, describing the analyst's background (see above), playing games extensively to reach a high level of familiarity, complementing the first person experience of the games with other sources (such as manuals and gameplay videos), and iterating

through the results during the analysis and writing process to ensure cohesiveness of interpretation in the assigned values. After completing the analysis and assigning one value to each attribute for every game, the data were analyzed using the IBM SPSS Statistics (version 25) software.

4 RESULTS

This chapter presents the content analysis and the statistical tests performed to explore differences in engagement between serious and entertainment games.

4.1 Content analysis of climate change engagement

The content analysis reveals differences between specific attributes and among games. Attributes have been classified into four groups. Very common attributes (feedback-oriented, concrete, experiential learning, fun, and challenging) are found in 77.33% to 88% of the games in the sample. Common attributes (reward-driven, efficacy-enhancing, identity-driven, levelling-up, narrative-driven, simulating), in 51.33% to 68.67%. Uncommon attributes (credible, achievable, meaningful), in 30.67% to 33.33%, and the only rare attribute (social), in 18.66%. Table 1 shows the purpose with the highest percentage for each attribute in bold.

Table 1. Percentage of games by presence of individual engagement attributes

	Serious (n = 109)	Entertainment (n = 41)	Overall (N = 150)
Achievable	42.20	4.88	32
Challenging	81.65	65.85	77.33
Concrete	88.07	82.93	86.67
Credible	38.53	19.51	33.33
Efficacy-enhancing	74.31	29.27	62
Experiential learning	74.31	53.66	68.67
Feedback-oriented	93.58	73.17	88
Fun	76.15	82.93	78
Identity-driven	55.96	63.42	58
Levelling-up	52.30	56.10	53.33
Meaningful	33.03	24.39	30.67
Narrative-driven	44.04	70.73	51.33
Reward-driven	66.06	63.42	65.33
Simulating	52.29	48.78	51.33
Social	16.51	24.39	18.67

Although the relative weight or impact of different attributes in terms of engagement potential has not been measured, overall differences in number of attributes can be observed between the two purposes (see Figure 1). Table 2 displays additional descriptive statistics (mean, standard deviation, median, and minimum and maximum values).

4.2 Statistical analysis of climate change engagement by purpose

The correlations between purpose and individual engagement attributes were evaluated through chi-square test of independence (χ^2) using exact significance values. A Fisher's exact test (FET) was used in one case where the expected value of a cell in the chi-square was below five. The relation between the games' purpose and the 15 climate change engagement attributes is shown in Table 3. "Yes" counts indicate how many games presented each attribute. The expected "Yes"

Fig. 1. Number of games by number of engagement attributes present.

Table 2. Descriptive statistics for all games, serious games, and entertainment games

	M	SD	Md	Min	Max
All games (N = 150)	8.55	2.77	9	1	14
Serious (n = 109)	8.89	2.62	9	2	14
Entertainment (n = 41)	7.63	2.97	8	1	12

count reflects the value that would be expected assuming no difference between the two purposes. Significant correlations (i.e., with a p-value less than alpha, .05) have been marked with asterisks and bolding the corresponding subgroup. The phi coefficient has also been included as a measure of the effect size. The closer the value is to 1, the stronger the association between the variables. Three thresholds are used in this study: weak (≤ 0.2), moderate (> 0.2 and ≤ 0.6) and strong (> 0.6). This follows a guideline for Cramér's V (IBM, n.d.), which is equivalent to the absolute phi value in 2x2 tables.

Following the classification by Ouariachi et al. [107], six significant correlations affect the cognitive dimension, five the emotional and four the behavioral (Table 4), thus covering the engagement spectrum.

5 DISCUSSION

By analyzing both serious and entertainment games' engagement potential regarding climate issues, our study is placed at the intersection of environmental social science and games and gamification research. It is concerned with game artifacts, their messages, and their effects on players. While extant literature has mostly focused on reviewing serious games (e.g., [115, 149]), specific geographical areas [106], and neighboring or broader issues such as sustainability (e.g., [27, 39, 79], our study provides new knowledge by collecting and closely analyzing the most extensive corpus of video games in the field, irrespective of purpose. These studies have categorized

Table 3. Relation between purpose and individual engagement attributes

Attribute	Purpose	“Yes” count	Expected “yes” count	Chi-square result	Association (Phi)
Achievable	Serious	46/109	34.88	$\chi^2(1)=19.074$, p=.000***	Moderate (.357)
	Entertainment	2/41	13.12		
Challenging	Serious	89/109	84.29	$\chi^2(1)=4.249$, p=.0496*	Weak (.168)
	Entertainment	27/41	31.71		
Concrete	Serious	96/109	94.47	$\chi^2(1)=.683$, p=.426	
	Entertainment	34/41	35.53		
Credible	Serious	42/109	36.33	$\chi^2(1)=4.850$, p=.033*	Weak (.180)
	Entertainment	8/41	13.67		
Efficacy-enhancing	Serious	81/109	67.58	$\chi^2(1)=25.657$, p=.000***	Moderate (.414)
	Entertainment	12/41	25.42		
Experiential-learning	Serious	81/109	74.85	$\chi^2(1)=5.907$, p=.019*	Weak (.198)
	Entertainment	22/41	28.15		
Feedback - oriented	Serious	102/109	95.92	FET, p=.001**	Moderate (.280)
	Entertainment	30/41	36.08		
Fun	Serious	83/109	85.02	$\chi^2(1)=.798$, p=.391	Moderate (.280)
	Entertainment	34/41	31.98		
Identity-driven	Serious	61/109	63.22	$\chi^2(1)=.679$, p=.461	
	Entertainment	26/41	23.78		
Levelling-up	Serious	57/109	58.13	$\chi^2(1)=.173$, p=.716	
	Entertainment	23/41	21.87		
Meaningful	Serious	36/109	33.43	$\chi^2(1)=1.045$, p=.329	
	Entertainment	10/41	12.57		
Narrative-driven	Serious	48/109	55.95	$\chi^2(1)=8.499$, p=.006**	Moderate (-.238)
	Entertainment	29/41	21.05		
Reward-driven	Serious	72/109	71.21	$\chi^2(1)=.092$, p=.848	
	Entertainment	26/41	26.79		
Simulating	Serious	57/109	55.95	$\chi^2(1)=.147$, p=.718	
	Entertainment	20/41	21.05		
Social	Serious	18/109	20.35	$\chi^2(1)=1.217$, p=.347	
	Entertainment	10/41	7.65		

Note. * p < .05, ** p < .01, *** p < .001.

existing games in the past and described affordances for engagement based primarily on theoretical frameworks, while we use a content analysis framework that is both topic-specific and empirically constructed. Our results suggest that most games, especially serious, feature most engagement attributes, but some are uncommon or rare. In the following paragraphs, we delve deeper into

Table 4. Attributes significantly associated to serious games and to entertainment games positioned according to Ouariachi et al.'s [107] framework.

	Significant association	Cognitive	Emotional	Behavioral
Achievable	Serious	X	X	X
Challenging	Serious	X	X	
Credible	Serious	X		
Efficacy-enhancing	Serious		X	X
Experiential learning	Serious	X		
Feedback-oriented	Serious	X	X	X
Narrative-driven	Entertainment	X	X	X

discussing how each attribute relates to the corpus of games we collected as well as to neighboring literature.

5.1 Findings on climate change engagement attributes

Very common, common, uncommon, and rare attributes are commented next, accompanied by their number in the list presented in the Methods to facilitate consultation.

5.1.1 Very common attributes. **Feedback-orientation (7)** is almost ubiquitous (88%) in the games analyzed. Feedback has been associated with deep learning when it assesses performance [38], and presents educational benefits especially when guiding players towards a goal [67]. Although it could be argued that being the villain can be a learning experience, we follow the framework in considering only feedback connected to environmentally desirable real-life outcomes [107]. In some games, feedback is not verbal but a positive consequence. For example, in *Eco* [53] nature will thrive if players respect the environment, which is often positive for their interests. This is also communicated through data visualizations. In contrast, other games do not reinforce actions (e.g., *Memory Reloaded* [92]), or encourage damaging the environment (e.g., *Carbon Warfare* [126]) or humanity (*Climate Change Simulator 2018 Chinese Hoax Edition* [87]). Finally, some games do not promote action related to climate change issues (e.g., *Arma 3* [65]).

Concreteness (3) was also present in most games (86.67%), which generally avoid long explanations (e.g., *A Caribou's Tale* [33]); relying on scientific data alone to foster climate change engagement is ineffective [96]. Considering that climate change involves complexity and uncertainty, and humans present cognitive barriers to action [59], complicated systems (e.g., *Balance of the Planet* [19]) could be too demanding, even when they are part of the core gameplay. In other cases, games present information as decontextualized lessons and quizzes (e.g., *Copenhagen Challenge* [23]), thus focusing too on pure information as a form of communication. In other cases, such as *2020 Energy* [135], explanations were kept shorter and served the purpose of contextualizing and aiding specific player actions.

While most games have been considered **“fun” (8)** in this study (78%), what constitutes a fun activity varies from person to person. Fun in video games is often associated with the thrill of challenge, but playful experiences' diversity includes e.g. fantasy, discovery, self-expression [63], captivation, or sympathy [81]. For example, games can be fun due to aesthetic value (e.g., *Koral* [17]). Given this conceptual openness, only games that are remarkably simple, short, or unresponsive, and those that are purely technical (e.g., *2050 Calculator* [134]), purposely difficult (e.g., *3rd World Farmer* [47]), or complex (e.g., *Balance of the Planet* [19]) have not been labeled as fun. Creators themselves are sometimes aware of this. Chris Crawford, creator of *Balance of the Planet* [19],

notably declared how his game, while being “very educational, won’t necessarily be a lot of fun” [12].

Challenges (2) related to climate change (77.33%) include resource management in a multi-choice system (e.g., *Sustainable Shaun* [76]), on occasion with multiplayer features (e.g., *New Shores* [46]); choosing from diverse options (*2020 Energy* [135]), often in combination with linear stories (e.g., *Where Rivers Meet the Sea* [102]); dexterity tests (e.g., *CleanPower* [73]); question-based problems (e.g., *The Wheel of Climate Change* [86]), or tasks to help fictional characters (e.g., *Future Delta 2.0* [44]). Some games combined these challenge types.

The balance between challenge and skill is key for an optimal game experience [21]. Due to skill being entirely player specific, we have chosen not to judge games as “too hard to be challenging”. On the other hand, some games were extremely simple and would present only testimonial obstacles to almost anyone, thus “too easy” was a criterion we used. Other games only touched upon climate change through visual aesthetics (*Arma 3* [65]) or the background story and setting (*Redout: Enhanced Edition* [1]), so neither did they present a suitable challenge. It is worth noting that despite a lack of relevant mechanics, aesthetics could bypass potential cognitive resistance to procedural rhetoric [2].

5.1.2 Common attributes. Experiential learning (6) (68.67% of the games) evaluates if players are pushed to experimenting and trying without concern for punishment, especially in concrete environments. Broadly, cognitive psychology findings suggest the preponderance of experience and intuition over analysis [68]. Environmental education has successfully applied “experiential, inquiry-based, or constructivist” approaches [93]. These games encourage exploration (e.g., *The Sandbox EDU* [110]), favor dexterity over reasoning (e.g., *Life of Pika* [35]), propose simple puzzles that cannot be failed (e.g., *Where Rivers Meet the Sea* [102]), have short gameplay cycles or segments (e.g., *1000 days to escape* [124]), feature long-term scenarios where the player cannot lose (e.g., *Habitat the Game* [37]), or connect them with climate change through visuals (e.g., *Arma 3* [65]). These contrast with most strategy games (e.g., *Anno 2070* [119]), where options need to be carefully gauged and consequences anticipated.

Games were considered **reward-driven (13)** (65.33%) if they rewarded positive environmental actions explicitly with, for example, new in-game resources (e.g., new skills), points or achievements (e.g., *A New Beginning - Final Cut* [36]). For example, *Bioharmonious* [45] encourages striving for a more sustainable solution by rating players’ efforts. In many other games most actions are not positively acknowledged (e.g., *Interactive Energy & Climate Simulation* [74]), or not related to climate change (e.g., *Redout: Enhanced Edition* [1]). Since rewards honor players for their actions, many can validate their performance and often accompany other forms of positive feedback (e.g., verbal).

It is also worth noting that some of the games analyzed provide rewards that can lead to unsustainable practices, although we have not observed a direct connection to pro-environmental behaviors. For example, *Anno 2070* [119] players can obtain achievements for keeping a healthy ecosystem, but also unlock buildings that impact the environment negatively even when they are leading the eco-friendly faction (although the industrialist faction’s buildings are worse in this sense). However, those buildings do not unlock due to positive climate actions, but city development. Conversely, games that do reward sustainable actions explicitly with new in-game goods tend to provide mechanisms that reinforce those actions, as pro-environmental behavior is often the players’ only choice in these games. In *Trash Time* [10], one of such games, money can only be obtained by recycling and is only spent in upgrades that increase the efficiency of the recycling process.

Engaging people in practical decisions improves understanding [139]. **Efficacy-enhancing (5)** games (62%) put players in control and encourage them to decide for themselves within their fictional role. Some games teach action about energy and other climate change-related issues (e.g., *Interactive Energy & Climate Simulation* [74]), inspire real behaviors (e.g., *Rising* [9]) or encourage support to pro-environmental causes (*Battling Extinction* [114]). Some games have a real setting (*Future Delta 2.0* [44]), but others use metaphors (e.g., *Solar Energy Defenders* [147], where a vampire attack should be repelled through the effective use of solar panels, tested personally). Efficacy can be enhanced by providing facts (e.g., *EcoTrivia: Save the Animals!* [32]). Others do so by showing opposition to the villain-player (e.g., *Oiligarchy* [91]). Games that do not enhance efficacy are often fast-paced, have animals in the leading roles, put the player as an uncontested villain, or take place in settings such as post-apocalyptic worlds beyond repair (e.g., *The Descendant* [18]).

Identity-driven (9) games (58%) can appeal to social support and trust, a strategy recommended by experts [16, 96], through fictional characters. Identification with fictional characters can also support emotions, an important engagement dimension [15]. Games present characters as protagonists, but also friends, advisors, family or anthropomorphized entities (animals, robots) that act and even communicate like humans (e.g., *Life of Pika* [35]). However, few games allow players to adopt multiple roles or viewpoints, which may have a large learning effect on the social dynamics of climate change [5].

Over half of the games (53.33%) are divided in sections or levels (**levelling-up, 10**), which can compartmentalize complexity and assist in balancing flow. Divisions can manifest as missions, tasks, objectives, days, years, historical eras, spaces... In some cases, players themselves level up and unlock new possibilities. For example, upgrades in *Climate Pursuit* [84] provide a tangible representation of progress and at the same time expand the menu of available options, scaling up adaptation capacities to face the rising challenge. A few games offer different difficulty levels for similar tasks (e.g., *Infrared Escape* [34]).

The **narrative (12)** attribute (i.e., a meaningful event sequence, either scripted or emergent, related to climate change) appears in 51.33% of the games and manifests in various forms. Some include different protagonists and storylines (e.g., *World Rescue* [24]), or the same protagonist facing different situations (e.g., *Climate Quest* [31]). In others, a single premise justifies the action (e.g., *Energy Hog* [131]). Narratives can involve animals (e.g., *A Caribou's Tale* [33]) or other beings (e.g., *Flower* [130]), even without the presence of embodied avatars (e.g., *Bioharmonious* [45]). Players can also be the villain, as in *Oiligarchy* [91]. Finally, some games include narratives that are witnessed mostly passively (e.g., *Survive Global Climate Change* [113]). Narratives are not just engaging; they contribute to knowledge construction and can motivate learners [97].

Some stories, as suggested by the experts interviewed by Ouariachi et al. [107], offer multiple choices in a remarkably open system where events unfold in different locations (e.g., *Climate Health Impact* [111]) or randomly (e.g., *Upstream: Combat Climate Change* [123]). In total, 51.33% of the games are **simulating (14)**, i.e., they offer systems with multiple variables and outcomes. Many provide an open world to explore but no end goal (e.g., *Niche* [127]), while others offer both (e.g., *Eco* [53]; *Civilization VI: Gathering Storm* [49]). Some games simulate an environment with multiple options while being linear in their level structure and story (e.g., *Life of Pika* [35]). Meanwhile, non-simulating games provide single-solution puzzles with little space for flexible play (e.g., *Ziro* [72]).

5.1.3 Uncommon attributes. Scientists have a small role in the climate change public discourse [122]. This can also be seen in the small proportion of games that are **credible (4)** (33.33%), i.e., that cite external sources or present credible fictional characters. Some feature sustainability advisors (e.g., *Climate Challenge* [116]), real-world institutions (e.g., *World Rescue* [24]), scientists (e.g.,

Ciclania [64]), journalists, even opposing the player (e.g., *Carbon Warfare* [126]), superheroes (e.g., *Waste Avengers* [146]), engineers (e.g., *Plan it Green: Generation Station* [58]), or in-game political institutions and figures (e.g., *Fate of the World: Tipping Point* [118]). Nevertheless, most games, even those created by scientific organizations (e.g., NASA), do not specify their sources. Some do not require further backing, since they do not use real-world data (such as *Climate Kids Power Up!* [4]), but other games refer to facts and figures without an explicit source (e.g., *Koral* [17]).

Only 32% of the games are **achievable (1)**, i.e., players take climate change actions that are within their reach (32%), missing an opportunity for direct transference from the game to real life [107]. Achievable games depict plausible situations (e.g., *Future Delta 2.0* [44], where engaging in conversation and simple tasks can help local citizens to mitigate emissions and adapt to climate impacts) or directly gamify aspects of real life. However, the rest often present animals or other non-human living beings, fantasy actions in combination with fantasy characters or settings, decision-makers in extreme situations (e.g., *Climate Health Impact* [111]), characters in a situation unlike that of the average player (e.g., *3rd World Farmer* [47]), or villains (e.g., *The Greenhouse Effect is a Lie* [54]).

Meaningful (11) games (30.67%) show climate change impacts on biodiversity and humanity but suggest possibilities for action (e.g., *Flower* [130], where players revivify degraded environments and power renewable energy), while non-meaningful games refuse to add any dramatic, emotional weight to climate change. This can be due to the absence of narratives and characters, as is the case of *BlockMount* [70]. Some do contain dramatic events, but they are disconnected from climate change (e.g., *Bionic Heart* [145]), and others discourage action or pitch the player against humanity. While portraying climate change as an important issue could help people care to understand and act, there is no universal method for creating such emotional impact [107]. One way is to avoid persuading through fear and appeal to topics relevant for players, such as health [82, 96].

5.1.4 Rare attributes. Mutual goals can reinforce a sense of community and shared intention [133], but despite the potential of **social (15)** play in video games, this attribute remains largely unexplored: only 18.67% of the games included a social or multiplayer feature, which could foster social support and trust as recommended in the climate change communication literature [16, 96] through their player communities. Practical reasons can explain this generalized absence, from technological barriers to limited development resources and infrastructure. Social features range from simple social media affordances (e.g., share buttons) and leaderboards to few local multiplayer (e.g., *Owl Together* [120]) and online games, most of which are for entertainment and where climate change is not the main theme. Therefore, the social affordances in most of the games analyzed do not necessarily enforce or even encourage discussion about climate change topics. Games that blend the digital and the physical world have also been cited as possible developments [149], but mobile gamified solutions that encouraged real-world actions were either prototypes or largely inactive (e.g., *Habitat the Game* [37]). Still, online video streaming platforms offer ways to share games and science with communities without the need of in-game multiplayer features.

5.2 Findings on climate change engagement by purpose

When examined individually, significant differences between the two subgroups are found in seven attributes. Results suggest that serious games tend to directly connect players to climate change through positive and plausible actions, while entertainment games often present stories where climate change has a powerful impact on the world that the player inhabits. Thus, in the first case we tend to find closeness to climate change occurring through relatively simple challenges and direct experience, while entertainment games focus on narrative immersion but less frequently give

players a significant role in addressing climate change, especially one that reflects their real-life identity.

In detail, associations with a moderate size effect suggest a significant difference between the number of **efficacy-enhancing (5)** serious games and games for entertainment (74.31% versus 29.27%). Most serious games provide freedom of choice, inspiration and a sense that climate change can be confronted, but most games for entertainment often present post-apocalyptic worlds (e.g., *The Aquatic Adventure of the Last Human* [55]), do not focus on solutions (e.g., *BlockMount* [70]), or the player's role and actions are separate from climate change (e.g., *Bionic Heart* [145]). While 42.20% of the serious games are **achievable (1)**, only two for entertainment are: *Vegan Dating Simulator* [88], available for free online, and the commercial platformer *Lumino City* [103]. Thus, it is almost impossible to find an entertainment game that depicts quotidian climate-related actions. **Feedback orientation (7)** is also correlated with serious games (93.58% vs. 73.17%). In one out of four games for entertainment, the player takes no actions related to climate change or is (comically) encouraged to damage the environment (such is the case of *Tropico 5*'s Waterborne downloadable content [50]). The only attribute that is associated with games for entertainment is **narrative-driven (12)** (70.73% vs. 44.04%). This means that most games for entertainment present a progression of meaningful events related to climate change, even though sometimes without direct interaction (e.g., *The Eternal Castle [REMASTERED]* [78]).

Regarding weak associations, serious games favor **experiential learning (6)** significantly more (74.31%) than games for entertainment (53.66%). While most serious games are short and invite to retry (e.g., *Energy Lab* [141]), even when they present strategic gameplay (e.g., *City Rain* [48]), many entertainment games are complex and not only about climate change (e.g., *Democracy 3* [52]) or offer no space for experimentation related to the topic (e.g., *Forged Battalion* [109]). **Credibility (4)** is also weakly associated with serious games (38.53% vs. 19.51%)—credible games in both categories tend to feature reliable-looking human advisors, but external sources and supporting institutions can only be found in some serious games (e.g., *2050 Calculator* [134]). Finally, more serious games than games for entertainment were challenging (2) (81.65% vs. 65.85%). While some serious games were indeed too simple to be challenging, one in three entertainment games were either simple and unpolished (e.g., *Climate Change: Gravity Edition* [128]) or their challenges did not directly address climate change (e.g., *The Unclearness* [51]).

5.3 Player effects in the literature

Games that feature numerous engagement attributes can be found in auxiliary file 1. Some of these belong to the entertainment group, for example big-budget commercial strategy games such as *Anno 2070* [119] or *Civilization VI: Gathering Storm* [49] (12 attributes) or the more modest management and strategy games *Green City* [89] and *Green City 2* [90]. These can be wildly different in scope (from human history to recycling), play time (from minutes to hours) and in the way they integrate climate change in their stories and gameplay (from flavor text to constant meaningful decision-making). For these reasons, qualitative case-by-case examination provides valuable insight.

However, the only studies found that examine player effects use serious games. One example is *Future Delta 2.0* [44] (12 attributes), which has been found to increase concern and understanding of climate change, as well as a sense of excitement and preference over traditional classroom learning [8], through local visualization techniques. While lacking in concreteness, the game connects with players through achievability, is efficacy-enhancing, identity-driven, and promotes experiential learning. A previous version of another serious game from the list, *Super Energy Apocalypse: Recycled* [28] (12 attributes), resulted in player enjoyment, learning and interest. However, these promising observations were not accompanied by statistically significant knowledge improvements about

different kinds of power plants' energy production and air pollution levels when comparing pre- and post-game tests [29]. The game was designed using a procedural rhetoric perspective.

A qualitative study [43] found *Eco* [53] (12 attributes), an ambitious commercial educational simulation game, to enhance environmental knowledge through direct action in the game, simulation aspects (those actions having consequences) and social elements (specifically cooperation). All three elements (experiential learning, social elements, and simulation) were recognized in our analysis, while we observed a lack in concreteness due to the inclusion of multiple statistics and complex visualizations, an aspect that all participants but one seemed to ignore when recalling their game experiences. In addition, participants found the game's slow pacing and lack of flow to be barriers to immersion [43], which highlights potential issues with complex simulations. In other words, simulation seems to be able to help understand systems, but excessive meticulousness can also worsen the game experience for some players. Similarly, playing the first version of *Fate of the World: Tipping Point* [118] (10 attributes) resulted in some players learning about systems thinking, but the opaque game mechanics, the game's difficulty and its lack of help were perceived as major hindrances [137]. Here, we noted that the game lacks concreteness, favoring long texts and detailed numerical relationships between variables, while the complexity and punishing nature of the game require players to think very carefully before making the next move, which hinders experiential learning.

2020 Energy [135] (14 attributes), an educational browser game where the player must balance their actions' economic, environmental and social impacts, provides an excellent opportunity to warn about the gap between the potential and actual effects of games. A study conducted with US and Spanish secondary students reported a lack of statistically significant attitudinal impact when compared to a control group that did not play [104], although slight improvements in self-efficacy and willingness to adopt future sustainable behaviors were observed. While the game offers a significant challenge, players criticized its graphics and would have preferred more diverse challenges and mechanics. Thus, specific games will have different effects depending on populations and contexts, for example with young people used to highly immersive commercial games. In addition, if games are to be used in formal learning contexts, their use with other instruction methods can yield higher learning gains [148].

5.4 Implications and further research

This study provides a full overview of how the extant corpus of video games can engage players with climate change. Perhaps unsurprisingly, serious games aim to engage players with achievable and efficacy-enhancing goals, explicit climate challenges and feedback, credible sources, and experiential learning significantly more than entertainment games, while these provide more narratives. However, considerable data dispersion, overall low presence of some of these attributes, and the results of specific games, imply that entertainment games can have significant potential for climate change engagement even if that is not their goal. In practical terms, this supports the recommendation that while relevant, games' purpose should not be the only criterion when choosing to include or exclude games from research, favoring instead individual cases' systematic examination. In addition, a significant number of the serious games analyzed here could be overlooked due to their coming from unusual sources (e.g., game jams, small independent developers, or distributed through commercial distribution services such as Steam) instead of appearing in peer-reviewed scientific studies.

Our findings call for a broader perspective in future research, including mobile, VR, and entertainment games, searching for games beyond scientific literature, and conducting empirical studies using games for entertainment. We suggest that future studies analyze the effects of some of the examples covered in this article and discuss the possible links between engagement attributes and

empirical results. By specifically examining uncommon and rare attributes, or those that may be difficult to implement, future research will be better equipped to assess if a conscious effort should be made to use them more. In addition, separate consideration could be given to representations of greenhouse gas emissions' mitigation and adaptation to climate risks, in order to explore potential differences regarding engagement with these two topics. For professionals interested in climate change communication, this study offers an extensive analysis of games that they can use. For example, they may want to select games that are complete in terms of engagement modes, or those that present a specific attribute (e.g., social). For game creators, we also point at overlooked modes of engagement (credibility, achievability, meaningfulness and social features) that could be further developed. In addition, our commentary of how all features have been implemented in existing games can help as a state-of-the-art reference when designing their own games.

5.5 Limitations

Due to the list being as comprehensive as possible, the quality of the games included is diverse. Some are in active or inactive development but have been included because their state has been deemed playable and representative of their potential. At the same time, while the study has a will to be universal, games appear and disappear often, so both archiving efforts and periodical research are needed should knowledge stay current. In that sense, this study only guarantees the games' availability in the data collection phase.

Given that we did not discard any game based on purpose, the number imbalance between the two game types can be due to at least two reasons: either (a) there are not as many games for entertainment addressing climate change-related issues as there are serious games, or (b) games for entertainment addressing climate change-related issues are harder to find due to a lack of specialized websites or adequate tags in distribution platforms (most being related to e.g., genre, graphics style). Were the second true, it would constitute a further limitation.

Other limitations are related to the methods themselves. First, the games' purpose has been determined by exhaustively searching for publicly available texts, which cannot guarantee retrieving all existing relevant information. Second, the content analysis has been conducted by a single researcher, who represents the judgment of an experienced player and designer. As explained in the Methods section, various strategies [75] have been used to maintain the quality of the work. Third, this study examines potential for engagement, but does not examine these games' real-world effects. As seen, this potential can be realized or not depending on various factors outside of the games' design, whose assessment falls outside of the scope of this paper.

6 CONCLUSIONS

This study analyzed 150 video games representing climate change and accessible through the internet. A climate change engagement analysis has noted that most comply with the majority of expert recommendations. Nonetheless, credibility, achievability, meaningfulness, and social aspects are uncommon or rare. Developers may choose to focus on exploring these underrepresented engagement modes in order to investigate their engagement effects empirically. The study also suggests that serious and entertainment games tend to engage players with climate change through different methods, but the large variety of games in the sample suggests widening the lens of future research in order to detect previously ignored opportunities for video game-based climate change engagement and communication.

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