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Heatwave VR

VR, Thermal Haptics, and Serious Games

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Abstract

Heatwave is the team's proposal for a VR serious game about climate change, where the player must carefully choose its actions in order to lead the planet into a cooler future. It integrates thermal haptic technologies that go hand in hand with the game narrative and aid in the immersion of the player, as well as contributing to conveying some of the key learning objectives regarding climate change. For this game project, the team has developed and implemented a fully game-ready simplified climate model for Earth for the 21st century that is up-to-date with the latest scientific consensus regarding climate. Added to that, the key game mechanics have also been developed and implemented, ranging from the VR environment, to interaction, and to thermal haptic compatibility; all in all resulting in a pilot game which demonstrates the core ideas and potential of the game while serving as a departure point for a future complete game.

Contents

List of Figures

List of Tables

Acronyms

API Application Programming Interface. 2, 8, 10, 13, 16–20, 26, 28, 29
AR6 Sixth Assessment Report. 2, 5, 6, 10–12, 23

CCIS Computer, Communication, and Information Sciences. 4

GDP Gross Domestic Product. 40
GHG Greenhouse Gas. 2, 4, 6, 8, 10–13, 20, 23–25, 29, 30, 33, 41
GPU Graphic Processing Unit. 28

I2C Inter-Integrated Circuit. 17, 18
IPCC Intergovernmental Panel on Climate Change. 2, 4–6, 10–13, 23–25

LAN Local Area Network. 16

NDCs Nationally Determined Contributions. 4, 11
NOAA National Oceanographic and Atmospheric Administration. 2, 12, 24, 25

PC Personal Computer. 14, 17, 29

SDK Software Development Kit. 14
SSP Shared Socio-economic Pathways. 2, 5, 6, 11–13, 24

TCP Transmission Control Protocol. 2, 17, 18, 28

UE Unreal Engine. 2, 4, 7–9, 13, 14, 16–18, 25, 28
UN United Nations. 4, 6

VPN Virtual Private Network. 16
VR Virtual Reality. 1, 2, 4, 6–9, 11, 13–17, 21, 23, 25–30, 42, 43

1 Introduction

Climate change is one of the most pressing challenges of our time, demanding innovative approaches to educate and inspire action. The team of Computer, Communication, and Information Sciences (CCIS) master students Saeideh Mansouri, Anh Pham, and Aitor Urruticoechea aims to design and implement an immersive Virtual Reality (VR) game with a thermal haptics counterpart titled "Heatwave". This project focuses on illustrating the urgency of the climate crisis, where every decision made by individuals can significantly impact the planet and society within the limited time available. By integrating thermal haptics, the game immerses players in a dynamic experience where they physically feel the consequences of global warming, heightening their awareness and sense of urgency.

Through interactive gameplay, "Heatwave" aims to empower diverse users, particularly students, by enhancing their understanding of climate science and fostering critical thinking about environmental issues. This educational VR game not only informs players about the causes and effects of climate change, but crucially encourages them to explore sustainable solutions through their virtual actions. The aim is to empower the players to take the learnings of the game into real life, prompting meaningful climate action from informed individuals who can assess the real, long-term effects of the actions they undertake.

Overcoming technical challenges such as securing essential physical equipment and addressing compatibility issues with Unreal Engine (UE) versions and third-party plugins has been integral to the project's development. Moving forward, the team plans to further enrich the game by integrating dynamic climate simulations and refining gameplay mechanics to maximize its educational impact. This report details the development process, including desk research that helped with outlining the game design, technologies used, the challenges faced, and the insights gained throughout the creation of "Heatwave". It underscores the transformative potential of VR technology in environmental education, highlighting how immersive experiences can empower individuals to make informed decisions and take meaningful action against climate change.

1.1 Climate Change, Communication, and Action

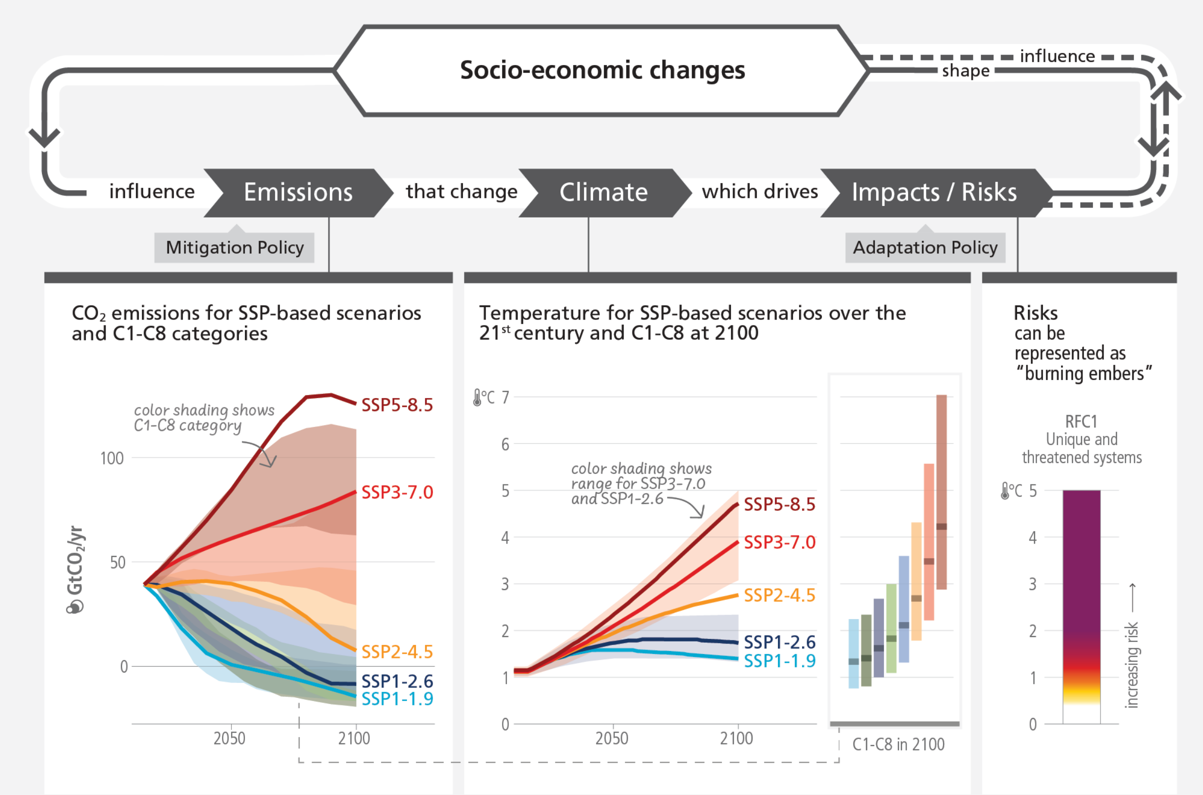
Human-caused climate change is already the source of *"widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere"* with *"widespread adverse impacts and related losses and damages to nature and people"*. This will continue to be the case, with increasing intensity, as long as global Greenhouse Gas (GHG) emissions continue to rise, with *"unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles, and patterns of consumption and production across regions, between and within countries, and among individuals"* [1].

While in recent years a myriad of public and private initiatives have put into place very diverse actions and policies both for reducing GHG emissions and for adaptation to the new and coming climate realities; these are still insufficient for meeting international goals. Namely, the 2015 Paris Agreement, under the United Nations (UN), set the goal of holding the global average temperature increase to *"well below"* $2°\text{C}$ above pre-industrial levels. Not to mention the pledge to *"pursuing efforts to limit the temperature increase to* $1.5°\text{C}$ *above pre-industrial levels"* [2]. The Intergovernmental Panel on Climate Change (IPCC) latest published synthesis report with date of 2023 and with data from 2021 unequivocally states that *"Global GHG emissions in 2030 implied by Nationally Determined Contributions (NDCs) announced by October* 2021 *make it likely that warming will exceed* $1.5°\text{C}$ *during the 21st century and make it harder to limit warming below* $2°\text{C}$. *There are gaps between projected emissions from implemented policies and those from NDCs and finance flows fall short of the levels needed to meet climate goals across all sectors and regions"* [1].

Despite the scientific consensus around the human origin of climate change, its causes, and the urgent need for global, coordinated action; a consensus ultimately represented by the publications of the IPCC [3] (in citation, see Section 2.1), communicating this crisis to the public has proven challenging. The problems arising from climate change communications are multifaceted, ranging from it being a *"perfect communications storm"* and a *"perfect moral storm"* to the psychological effects that arise from it being a *"slow-moving"* kind of issue while being abstract, acting on multiple fronts at the same time, and its intrinsic complexity [4]. Despite the fact that

Scenarios and warming levels structure our understanding across the cause-effect chain from emissions to climate change and risks

a) **AR6 integrated assessment framework on future climate, impacts and mitigation**



b) **Scenarios and pathways across AR6 Working Group reports**

Category in WGIII	Category description	GHG emissions scenarios (SSPx-y*) in WGI & WGII	RCPy** in WGI & WGII
C1	limit warming to 1.5°C (>50%) with no or limited overshoot	Very low (SSP1-1.9)	
C2	return warming to 1.5°C (>50%) after a high overshoot		
C3	limit warming to 2°C (>67%)	Low (SSP1-2.6)	RCP2.6
C4	limit warming to 2°C (>50%)		
C5	limit warming to 2.5°C (>50%)		
C6	limit warming to 3°C (>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	exceed warming of 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

c) **Determinants of risk**

Figure 1: Summarized definition of the Shared Socio-economic Pathways (SSP) considered by the IPCC in the Sixth Assessment Report (AR6) Synthesis Report [3].

all the challenges that arise from communicating the reality of climate change are beyond the scope of this project; the team deemed it necessary to keep them in mind when designing the game. From a multidimensional problem, then, the team chose some of the most relevant key points from the IPCC AR6 synthesis report [1, 3] to have as learning objectives. These are:

- **B1**: Continued greenhouse gas emissions will lead to increasing global warming, with the best estimate of reaching 1.5°C in the near term in considered scenarios and modelled pathways. Every increment of global warming will intensify multiple and concurrent hazards (high confidence). Deep, rapid, and sustained reductions in greenhouse gas emissions would lead to a discernible slowdown in global warming within around two decades, and also to discernible changes in atmospheric composition within a few years (high confidence) [1].

- **B6**: All global modelled pathways that limit warming to $1.5°C$ ($> 50\%$) with no or limited overshoot, and those that limit warming to $2°C$ ($> 67\%$), involve rapid and deep and, in most cases, immediate greenhouse gas emissions reductions in all sectors this decade [1].
- **C1**: There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all (very high confidence). Climate resilient development integrates adaptation and mitigation to advance sustainable development for all and is enabled by increased international cooperation including improved access to adequate financial resources, particularly for vulnerable regions, sectors, and groups, and inclusive governance and coordinated policies (high confidence). The choices and actions implemented in this decade will have impacts now and for thousands of years (high confidence) [1].
- **C3**: Rapid and far-reaching transitions across all sectors and systems are necessary to achieve deep and sustained emissions reductions and secure a liveable and sustainable future for all. These system transitions involve a significant upscaling of a wide portfolio of mitigation and adaptation options. Feasible, effective, and low-cost options for mitigation and adaptation are already available, with differences across systems and regions. (high confidence) [1].

For the future, and beyond this project, development of the game, the team also strongly considers statements A2, B3, and C5 to be of potential interest for the storytelling synergies they can easily create with the already explored points. To these summarized statements, the different projections, end-of-century scenarios under IPCC studied SSP [3] (in a citation, see Section 2; see also Figure 1) are to be reflected upon and understood; as well as the difficulty (or ease) of the actions needed to reach each one of them.

1.2 Serious Games

While serious games are a broadly defined topic, and the usage of its term is varied [5], a serious game can be understood as one where learning objectives exist beyond the entertainment and fun of the game. While the inclusion of these two last topics in a serious game, fun and entertainment (or lack thereof) is a topic of discussion, the team aims to use this concept in its broadest of terms. "Heatwave" as a VR serious game has a set of learning objectives described herein, yet without losing the dynamism and entertainment that makes a game be part of the concept of "play" [6].

"Heatwave" is, at its core, a management game, where the player has to carefully chose tradeoffs offered by actions, which take time (the limited resource of the game) in exchange for potential GHG reductions, which in turn can prompt a slowdown of the rise of global temperatures. This puzzle-like strategy setup, where multiple paths can lead to varying outcomes, is what the team hopes prompts the entertaining and playful part of the serious game, as the player struggles to find what right actions are the most urgent, most impactful, etc. While this is happening, the player is directly and indirectly surrounded (both metaphorically and literally thanks to VR) by learning inputs, from action descriptions, to the very reality implied by the actions and their implications. From the selected statements from the IPCC AR6 Synthesis Report 2023 to be treated as learning goals (as outlined in Section 1.1), the main points to be communicated to the player via game mechanics and design, interactions, and interfaces are:

- Key climate science terminology: GHG emissions (key metric: $GtCO_{2-eq}/year$), average global temperature increase (key metric: $°C$), cumulative emissions and carbon budget (key metric: $GtCO_2$).
- The realities of the five end-of-century scenarios contemplated by the IPCC in the AR6 Synthesis Report, ranging from *"Very Low emissions"* to *"Very High emissions"* (see Figure 1).
- The urgency of the actions needed to limit emissions, and the reality of the *"rapidly closing window of opportunity to secure a liveable and sustainable future for all"* [1]:
  - The reality that *"rapid, deep and, in most cases, immediate"* action is needed to have a chance to reach either the *"Very Low emissions"* or *"Low emissions scenarios"*; as it is the goal of the UN as per the 2015 Paris Agreement [2].
  - The fact that the actions needed to reduce GHG emissions need to be in nature *"rapid and far-reaching"*, yet critically *"across all sectors and systems"*. Thus, focus shall be put away from the traditional narrative of individual carbon footprint reduction; and rather highlight the pressing need for a collective, system-wide transition.

- The fact that solutions for mitigation and adaptation *"are already available"* and, while welcome, technological breakthroughs are not a prerequisite for action, neither for mitigation nor for adaptation purposes.

The proposed game, thus, serves both as a toy/entertainment device and as an educational/serious experience; where the player can both spend leisure time and get entertained and learn about the realities of climate change and the actions needed.

1.3 Virtual Reality and Haptic technologies

VR can be an effective tool for climate change education, as it allows users to experience the impacts of climate change in an immersive way. Studies have shown that VR experiences can increase awareness and understanding of climate change [7]. In the project, the team utilized VR and haptic technologies to create a captivating and educational experience. The game is developed using Unreal Engine (UE) 5.4.2, a robust platform renowned for its high-quality rendering capabilities and support for VR development. UE allows the creation of realistic virtual environments that are essential for delivering an immersive and impactful user experience.

VR typically relies on headsets with special displays that show two slightly different images, one for each eye. This creates a depth effect, making the virtual world feel more three-dimensional. These headsets often track the user's head movements, adjusting the display accordingly. This creates a sense of immersion, where users feel like they're truly inside the virtual world [8]. The Oculus headset, shown in Figure 2, is an example of such VR technology that we used for developing Heatwave.

Figure 2: The Oculus headset that uses VR technology.

Haptic technology, on the other hand, provides tactile feedback through vibrations, forces, or motions. In the context of VR, haptic feedback can be delivered through various devices such as gloves, suits, or handheld controllers. These devices simulate physical sensations, allowing users to "feel" virtual objects and environments. The combination of VR and haptic technologies can significantly enhance user experience by engaging multiple senses [9]. "Heatwave" VR is an example of this, as the thermal haptic feedback is used to simulate temperature changes, allowing players to physically feel the impacts of climate change within the game. This not only makes the experience more engaging, but also helps in conveying the urgency and reality of climate change through a more immersive medium. Figure 3 [10] shows a prototype of a wearable yarn-based heating pad that can be used in "Heatwave".

Figure 3: Prototype of wearable yarn-based heating pad [10].

1.4 Goals and Scope

The primary goal of the "Heatwave" project is to develop an immersive VR-based educational pilot game that effectively communicates the causes and consequences of climate change. Through interactive gameplay, the player is to gain a comprehensive understanding of the impact of global warming and the urgent need to reduce GHG emissions, thereby raising awareness about climate change. The project aims to create an engaging and informative experience that motivates users to adopt environmentally conscious behaviours by allowing them to experience the effects of their actions on the environment through the relationship between in-game global temperature and thermal haptic feedback.

With this goal in mind, and firstly, the team, which lacks prior hands-on experience with game design, UE or related technologies such as VR equipment and the thermal haptic system with the wearable Application Programming Interface (API) developed by Aalto Wearable Systems Lab [11], needs to learn about these technologies individually and concurrently. This phase assisted the team in understanding the engine's capabilities and limitations, thus allowing for realistic storyboarding and game feature design aligned with the project's size.

The initial development phase involves creating a foundational VR environment, including a living room with interactive elements such as a television, sofa, and action table. This environment will support intuitive navigation and interaction, providing a realistic and engaging setting. The project scope also includes designing and implementing game mechanics that involve time-constrained decision-making. Players will interact with objects representing various climate actions, each with different time requirements and impacts on global warming, simulating the urgency and complexity of real-world climate decisions. Importantly, 3D modelling is beyond the scope of the project, as the learning curve for the team to get fluent with UE is considered priority over modelling, which can be substituted by using publicly available open-source and game-ready models.

Given the game's serious nature, researching reliable and realistic climate change data is essential to prevent conveying incorrect information. An information interface will provide players with detailed information about each climate action, including data on the year, current stage of the global climate, effectiveness, and time requirements of actions. This user-friendly interface will aid players in making strategic decisions. Moreover, a critical objective is to develop and integrate a thermal haptic feedback system. This system will use the thermal haptics API [10], developed also by Aalto University's Wearable Systems Lab, to ensure players feel in-game temperature changes through haptic feedback, correlated with the in-game global temperature variable; with the main goal being making the consequences of climate actions more tangible.

Finally, usability testing and refinement are key tasks within the scope. At least three usability tests will be conducted to ensure the VR experience is intuitive and accessible. Feedback from these tests is to serve future development beyond this project, with the main objectives of refining the gameplay mechanics and educational content.

2 Methodology

In this section, the key components and processes involved in the development of the proposed game are outlined. The section covers the game design, detailing the conceptualization and storyboarding phases, and the rationale behind the design choices. Next, an explanation is included regarding the goals and rationale behind the structured climate model, as it strives to simulate the impact of player actions on global temperature. Finally, a discussion is included regarding the various technologies employed, including the game engine and VR setup, version control practices, and the integration of thermal haptic feedback to enhance the immersive experience.

2.1 Game Design

Computer games come in a variety of forms, including action, adventure, strategy, simulation, and educational games [12]. The game at hand, titled “Heatwave”, falls into the category of educational or serious games. It’s designed to provide knowledge or training in a fun and interactive way.

The concept for the game, "Heatwave", was born out of a brainstorming session where the team aimed to address climate change through an engaging and educational medium. The team wanted to create a game that not only entertained but also educated players on the critical issue of global warming. The initial idea was to immerse players in a virtual environment where they could experience the direct consequences of their actions on the planet’s climate. The integration of thermal haptic feedback to simulate temperature changes added a unique layer of realism and urgency to the climate scenarios presented in the game.

To bring the concept to life, the team started with detailed storyboarding sessions. These storyboards served as a visual script, outlining the key scenes, player interactions, and the flow of the game. The process helped in refining the narrative and ensuring a coherent and engaging storyline.

During the brainstorming sessions, we explored various ideas for the game’s story and mechanics:

- **Saving a Polar Bear**: Players would make decisions to save a polar bear, with their actions directly affecting the bear’s survival.
- **Different Levels**: The game would feature multiple levels, each set in a different environment with varying difficulty levels.
- **In-Game Assistant**: An assistant character would guide players through their decisions, providing helpful tips and information.
- **Environmental Impact Visuals**: The game’s environment would visually change based on the player’s actions. For example, a red sky and red lighting would indicate a failing scenario, while flooding or drought scenes would appear when the player loses. Conversely, positive environmental conditions would be shown when the player wins.

Ultimately, it was decided to simplify the initial version of the game to focus on a single, coherent scenario since the team realized there was a need to get familiar with UE and haptic integration in a simple way. This approach would allow the team to go further and explore more complex stories in future versions of the game. With this line of thought, a storyboard was developed (see Appendix B), which goes beyond the goal and scope of this project to envision a wider and more in-depth game.

In the proposed pilot version, the game begins in a living room where the player sitting on a sofa watching news reports about climate disasters. A table next to the sofa serves as a menu where the player can choose actions by selecting different objects. Each object represents a different action that can either help, harm, or have no effect on the global climate. The player has to stand up from the sofa to take action.When the player stands up, the TV shows information about the current year, average global temperature increase, and CO_{2-eq} levels. Pointing at objects will show some information about them such as the kind of action the object represent and the amount of time it takes, also grabbing an object means the player choose that action so it will affect the game.

Time is the main currency in the game, and it is finite. Each action takes time, and no action can reverse it, imposing a hard limit on how many actions the player can take before the game ends. In the first version of the game, due to the limited scope of this project, the team considers a reduced set of actions such as starting waste separation at home, flying less, and choosing to not participate in the fast-fashion industry. These actions are designed to simulate real-world decision-making processes and their impacts on environmental sustainability. Note that many more actions have been researched and catalogued for future implementation, and can be consulted in Appendix C.

As the game has a thermal wearable API integration mentioned in subsection 1.4, when the game starts, the heat will be on, and *the temperature will increase by certain degrees per tick*, depending on the actions the player chooses. This can lead to different end-of-century outcomes based on these player actions. For example, the global average temperature increases by $+4°C$ before the year 2080 if the ending is the Catastrophic Ending.

From the game learning points outlined in section 1.2, a big emphasis is put in the fact that individual actions alone cannot solve the climate crisis. The player needs to organize, get involved in political activism, and maybe even run a government to reach the best outcomes in the game. Different game stages thus are set to be unlocked as the player realizes that what they can do individually is insufficient, and chose instead to get organized, and act as a group and communally with actions that can potentially have society-wide effects.

The game is primarily targeted at school and university students. However, it is designed to be beneficial for individuals of various ages. The game's educational nature and its focus on climate change make it a valuable tool for anyone interested in learning about the environment and the impact of human actions on it. The different endings provide a clear understanding of the consequences of our choices, making the game not just entertaining, but also a powerful educational and awareness tool. Regardless of age, players can gain significant insights and knowledge about climate change and the importance of taking action.

The game has five different endings based on the AR6 IPCC Report [1, 3]:

1. **Catastrophic Ending**: This occurs when the temperature rises by $+4°C$ before the year 2080. At this point, catastrophic feedback loops are very likely to trigger, leading to a guaranteed heating of up to $+6 \circ C$ by 2100 and beyond. This ending is the result of the player making harmful decisions that exacerbate the climate crisis.
2. **Business as Usual Ending**: This ending is reached when the temperature rises by $+4°C$ post 2080 or above $+3°C$ by 2100. There will be guaranteed continued warming past 2100. This ending is likely if the player does nothing or takes only individual actions, or a mix of harmful and decent actions.
3. **Bare Minimum Ending**: In this scenario, the temperature rises above $+2°C$ by 2100. Insufficient action has resulted in potential continued warming past 2100, but the worst consequences have been at least attenuated. This is the most probable ending for an unknowing player, with a combination of individual and group decent actions that are ultimately insufficient.
4. **Paris Agreement Ending**: This ending is achieved when the temperature is below $+2°C$ but above $+1.5°C$ by 2100. Critical tipping points have been avoided, and warming will not continue past 2100. The worst has been avoided, and the player has been able to choose good and meaningful actions.
5. **"Greta Thunberg" Ending**: This is the best possible ending, where the temperature is at or below $+1.5°C$ by 2100. The right actions were taken on time, and only the most unavoidable disasters (as of 2024) remains.

These endings provide a range of possible outcomes based on the player's actions, emphasizing the importance of making informed and effective decisions to combat climate change.

2.2 Modelling the global climate

Due to the nature of the chosen learning objectives (see Section 1.2), it has been deemed necessary to develop a simplified climate mode, serving a double purpose. Firstly, it is the method of tracking the player's progress: as the player choses to take different actions, it is these actions that influence GHG emissions which in turn change the climate, rising or lowering the average global temperature. Secondly, having a fully-working, albeit simplified, climate system is key in the implicit communication of the key climate terminology. A real-time consulting of the actual state of the world in terms of global temperature increase, yearly GHG emissions, and how haves the cumulative GHG emissions fared since the beginning of the game is the main way of checking the progress done so far and assess future plans for the player. Thus, it will not only be a necessity for the player to become familiar with these metrics, but importantly by them being the main tracker of purpose this will come naturally, rather than as a second thought on top of the actual game design.

For the climate model itself, the working baselines are the aforementioned SSP analysed by the IPCC in the AR6 (see Figure 1). These SSP work in the $2015-2100$ timeframe, and situate the current implemented policies (extracted from the available NDCs) in the *"High emissions"* scenario, if no further action is taken (Figure 4) [1, 3] (in the latter citation, see also Figure 3.6). As a departure point for both the climate model and the game narrative, the team has taken his predicted pathway for emissions stemming from the already implemented policies. The idea is that, should the player take no action, and let time pass, GHG emissions will have to evolve following this projection. With their actions, the player can, though, influence the yearly GHG emissions, thus steering this pathway in one direction or another.

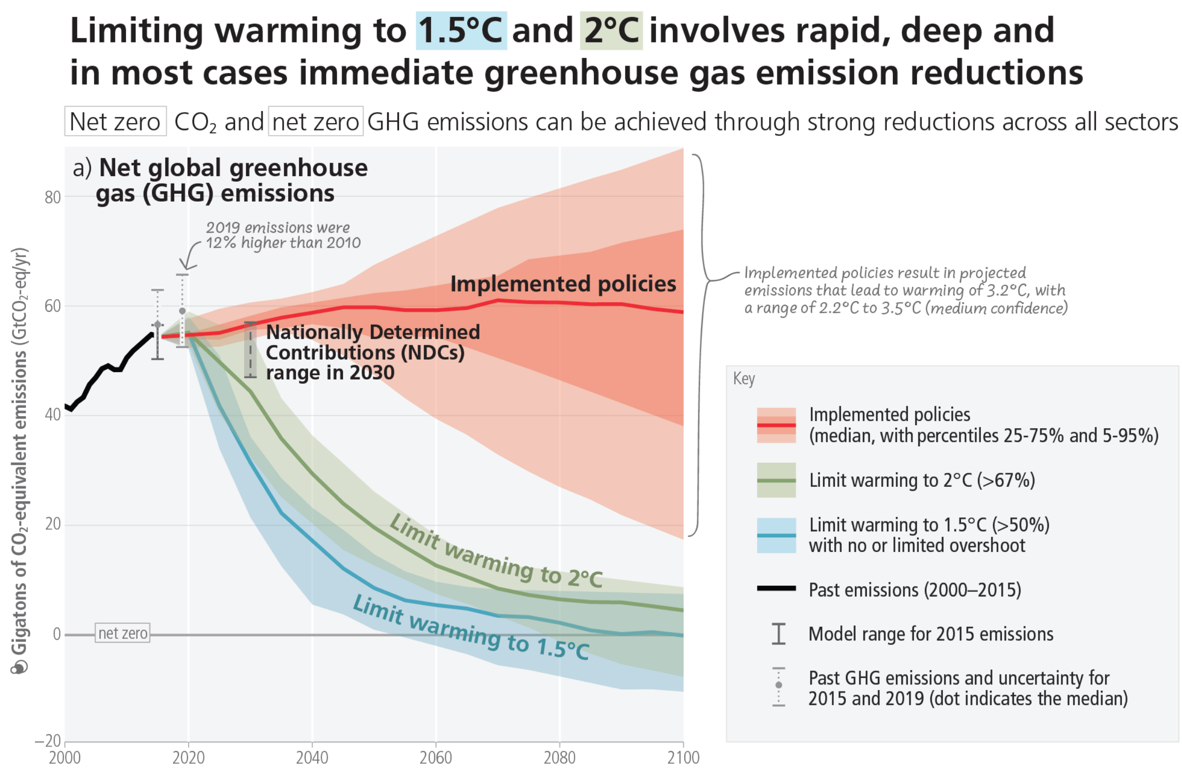


Figure 4: IPCC predictions of future emissions according to current implemented policies [1].

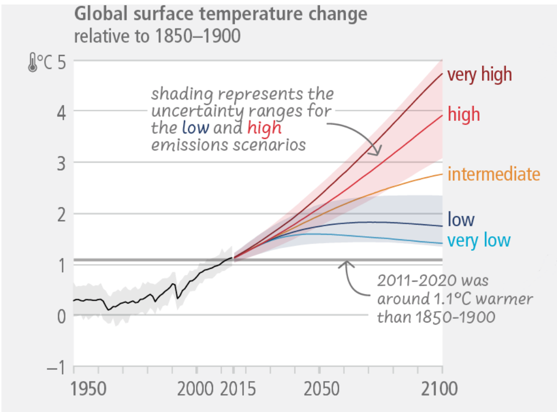
From Figure 4 some of the first needs for simplifications can be seen. While it would be possible to reflect the fluctuations and even the uncertainty with large data tables; the resource intensity of VR has led the team to tone down the complexity. Instead, fluctuations will not be included in the proposed model, and the implemented policies SSP will be linearized, with the key requirement that the resulting linearization falls within the $25-75$ percentiles at every point of the $2024-2100$ timeframe.

Having the yearly GHG emissions as a function of time (t) has also a few key advantages regarding data table consultation. First, due to its continuous form, it allows for more liberty for game design. The time steps can be tuned to the needs of the game and tweaked with almost unlimited freedom, be it months, years, or days, without the need for interpolation between data points. Second, the actions of the player can be translated to numerical values that can directly influence the function, rather than adding another layer of complexity on top of the prediction layer. Thus, this simplification should result in a $GHG(t)$ linear function with the form:

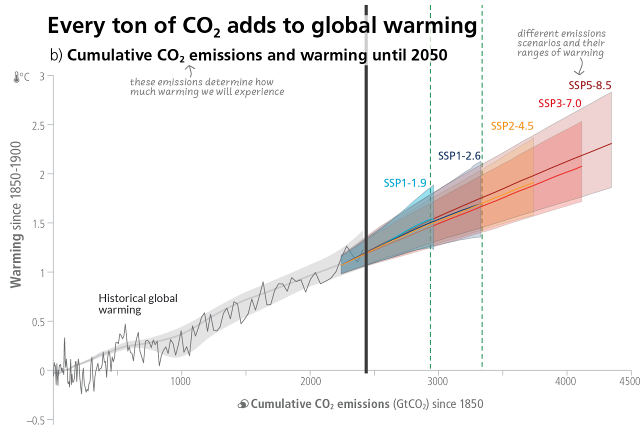
$$GHG(t) = [b - a_{\text{slope}}] \cdot t + [m - a_{\text{offset}}] \tag{1}$$

where t is the time in years; b and m are the slope and offset parameters that determine the baseline GHG growth according to the already implemented policies; and a_{slope} and a_{offset} are values tied to the actions the player has taken. Both a_{slope} and a_{offset} are to be initialized at 0, and are expected to vary according to the actions the player takes. Note that having two different parameters that influence the growth (or degrowth) of the yearly GHG emissions gives more control for game development, as actions can either reduce the rate of emissions by changing the slope of the line, and/or reduce the emissions' baseline independently.

The next step in the creation of the simplified climate model is to create a correlation between atmospheric GHG concentrations to average global temperature increase $T(GHG)$. Crucially, this correlation is not between yearly GHG emissions, but rather cumulative GHG emissions (as in how many gigatons of CO_{2-eq} have been emitted so far) [3] (in citation, see also Figure 3.5). For this correlation, again, the working data is extracted from IPCC's AR6 SSP, with the *"High emissions"* scenario as the default one.



(a) Time against global temperature increase for the different SSP, for the $2015 - 2100$ period [1].



(b) Cumulative CO_2 emissions against global temperature increase, for the $2020 - 2050$ period [3].

Figure 5: IPCC modelled global temperature increase for the different SSP [1, 3].

From Figure 5, and especially Figure 5b, the relation between cumulative GHG emissions and expected global average temperature increase is almost perfectly linear if one is to exclude minor fluctuations. This, thus, allows the team to do another linear function with the form

$$T(GHG_c) = d \cdot GHG_c + n \tag{2}$$

where GHG_c are the cumulative GHG emissions since the game start, d is the slope and n is the offset parameter. Further simplifying the background calculations the game engine will need to make, none of the parameters of this equation need dynamic updating, as the player actions will only influence the average global temperature increase "indirectly" by affecting the GHG emissions.

As a last note, there is the initialization problem to be solved with, as AR6 stems from an aggregation of studies and data points, and offers only projections for the global temperature increase for 2024, the year the game starts. The chosen method to amend this discrepancy is to use the latest available data (2023) published by National Oceanographic and Atmospheric Administration (NOAA), which situates the average temperature increase at $+1.18°C$ [13].

With this, the proposed methodology to obtain a simplified, game-ready, climate model rooted in the available scientific consensus, takes the form outlined in Figure 6. As in-game years pass, then, GHG emissions will evolve according to IPCC predictions and player actions combined. Every year's GHG emissions are added to the cumulative GHG emissions, which determine the current (in-game) global average temperature increase. End-game conditions will be determined from this very global average temperature increase, just as IPCC SSP are tied to the predicted end-of-century global temperature increases.

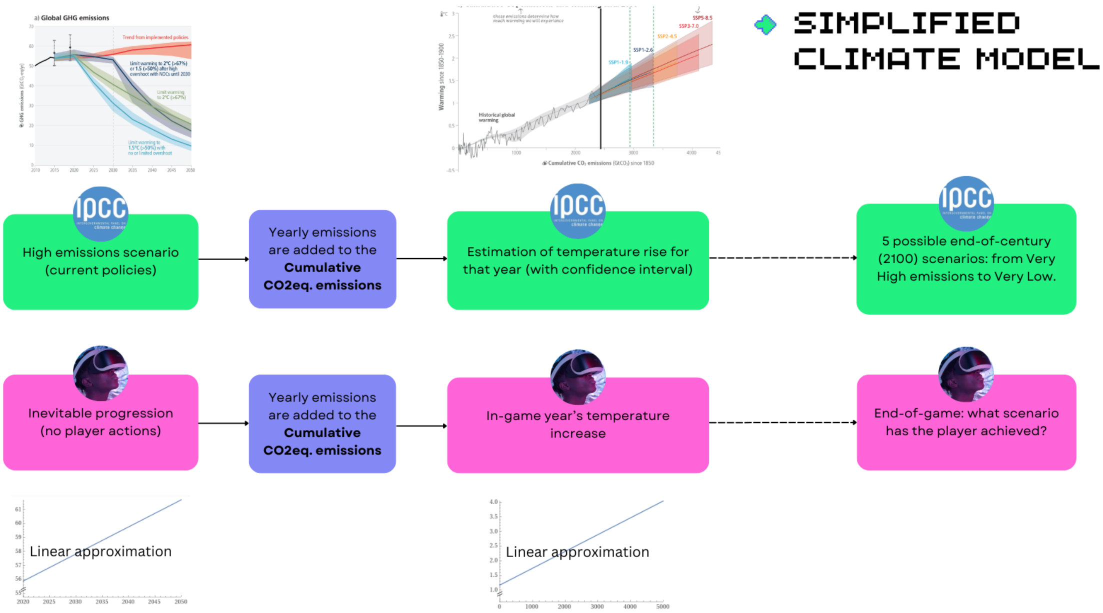


Figure 6: Infographic: proposed simplified climate model versus the IPCC models.

2.3 Technologies

The development of "Heatwave" leverages several advanced technologies to create an immersive VR-based educational game that effectively communicates the causes and consequences of climate change. This section discusses the technologies used and how they were implemented to develop the game.

2.3.1 Game Engine and VR

UE, developed by Epic Games, is a powerful game engine known for its high-quality graphics, extensive, and the world's most open, advanced real-time creation tool set both beginners and experienced developers/ designers deserve to have [14]. The development of "Heatwave" leverages UE5, specifically version 5.4.3, chosen for its advanced rendering capabilities, efficient workflow, and robust support for VR development. These features, including Nanite virtualized geometry, Lumen global illumination, and enhanced VR support, are essential for creating an immersive and realistic VR experience [15].

One significant advantage of UE is its Blueprint Visual Scripting system. This system enables developers and designers to create game logic and functionality without extensive programming knowledge. Visual nodes can be used to script behaviours and interactions [16], accelerating the development process and making it more accessible for team members without a programming background.

Project Initialization and Setup: The first steps of starting a project with UE involve downloading and installing the engine launcher from Epic Games' official website. After installation, creating a new project includes selecting the type of game (e.g., VR, first-person or third-person player), configuring project settings, and importing necessary assets. UE also has a Marketplace and Quixel Bridge that provide a rich repository of assets, which saves time that would otherwise be spent on 3D modelling—a skill not within the primary scope of this project. This allows the team to focus more on game mechanics and the implementation of the Thermal Haptic API within the VR environment.

Therefore, the project was initially created as a blank game with VR template. The team explored the Unreal Engine Marketplace and found a free, realistic room environment featuring a TV and sofa, which aligned with the initial brainstorming phase. This environment, containing several objects, was installed and imported into the engine used. Some of the lighting was manually configured to enhance the ambiance. Gradually, more objects were imported to represent the ten actions players can choose from, as explained in the game design section 2.1. These objects were selected randomly, with the focus being on the widget interface of the actors/objects. This interface displays the action's title, description, the time required to complete the action, and its impact, which can be reviewed in Appendix C.

Oculus Integration Before implementing VR-specific functionalities, the Oculus Software Development Kit (SDK) setup was required, as VR equipment is mandatory for this project. The Oculus Quest, a VR headset created by Oculus VR, was chosen for its all-in-one gaming capabilities and wireless connection to a Personal Computer (PC), providing freedom of movement in the Meta VR environment. The Oculus Quest 1 headset and controller are shown in Figure 2. The setup process involves following the Meta Quest Documentation for UE, with an important note that the Oculus PC app, necessary for development, is currently only available on Windows PCs [17].

Implementing VR Interaction Using Enhanced Input These steps below are how the VR Interaction was implemented in this project:

1. Create Input Actions
   - Navigate to the `Content/VRTemplate/Input/Actions` folder.
   - Right-click in the Actions folder and create two new actions named `IA_Interact_Right` and `IA_Interact_Left`.
   - These actions will be mapped to the trigger buttons on the VR controllers.
2. Configure Input Mapping
   - Go to the `Content/VRTemplate/Input/IMC_Default`.
   - Add the newly created actions `IA_Interact_Right` and `IA_Interact_Left` to this context.
   - Map them to the appropriate trigger buttons on each VR controller.
3. Blueprint Setup in VR Pawn
   - Navigate to the `Content/VRTemplate/Blueprints/VRPawn`.
   - In the VR Pawn Blueprint, create nodes for the `IA_Interact_Right` and `IA_Interact_Left` actions.
   - Define the actions to simulate shooting a beam from the controller when the trigger is pressed.
4. Line Trace Configuration
   - When the trigger is pressed, a line trace is performed.
   - Set the starting point of the trace as the current position of the motion controller.
   - Use the controller's forward vector to determine the direction of the trace.
   - Extend this vector by a length (e.g., 1000 units) to define the trace's endpoint.
5. Blueprint Interface for Interaction
   - Create a new folder and name it `Interact_BP`.
   - Define an `Interact` function within this interface to facilitate communication between the VR Pawn and intractable objects.
6. Implementing Interaction in VR Pawn
   - In the VR Pawn Blueprint, use the `Interact` function from the `Interact_BP` interface when the line trace hits an object.
   - Connect the line trace's hit result to trigger this interaction.
7. Adding Interaction Logic to Objects
   - For any object to be intractable, add the `Interact_BP` interface to the object's Blueprint.
   - Implement the `Interact` event in the object's Blueprint to define specific interaction logic, such as opening a door or picking up an item.

The Blueprint Setup for object interaction in VRPawn is depicted in Figure 7.

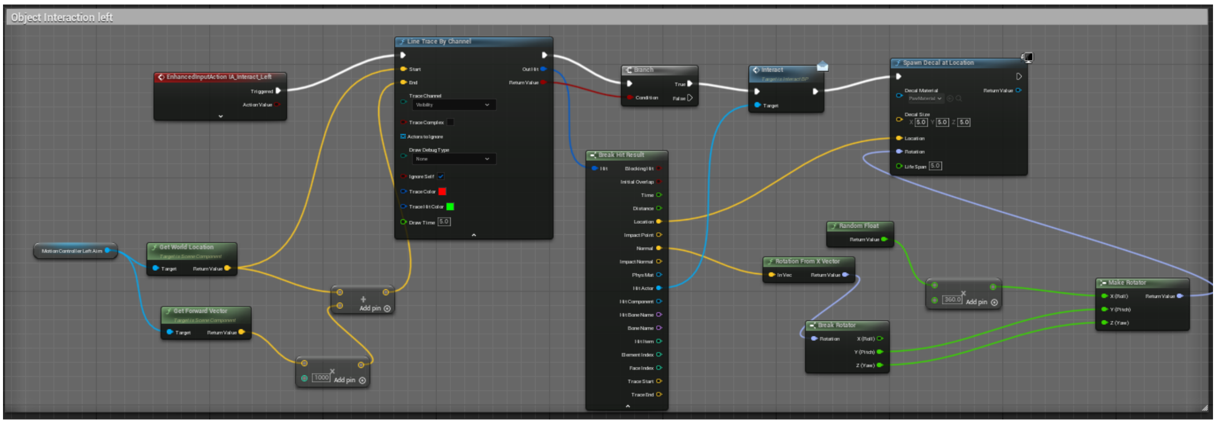


Figure 7: The Blueprint Setup for object interaction in VRPawn

Implementing Widget Interaction into the VR Project To create the widget interaction component and allow the player to interact with the widgets such as display the widget interface to show the action's description, duration to complete, and its effect, then these steps below were implemented:

1. Add Widget Interaction Component
   - Navigate to the `VR Template/VR Pawn`.
   - Add the Widget Interaction Component as a child to both the right and left motion controllers.
   - Ensure each Widget Interaction Component has a unique pointer index and set the trace channel to "World Dynamic."
   - Enable the debug option on both components to visualize the trace lines.
2. Configure Blueprint Logic
   - Establish the Blueprint logic to enable the system to recognize when the player's aim and tracker should function like a mouse.
   - Configure the system so that holding down the trigger button simulates a mouse click for interacting with widgets.
3. Widget Blueprint Setup
   - In the widget blueprint, select the button you wish to interact with.
   - On the event graph, create an "On Clicked" event to define the desired interaction, such as hiding the widget upon button press.
4. Input Actions in VR Pawn
   - Within the VR Pawn Blueprint, configure the input actions for the trigger using Enhanced Input Actions `IA_Interact_Left` and `IA_Interact_Right`.
   - Connect the Widget Interaction Component to the `PressPointerKey` function, designating the left mouse button as the target key.
   - Link the "Started" event of `IA_Interact_Left` to the `PressPointerKey` function and the "Completed" event to the `ReleasePointerKey` function, also selecting the left mouse button as the target key.
   - Repeat this configuration for the second Widget Interaction Component.

The Blueprint Setup for object interaction in VRPawn is depicted in Figure 8.

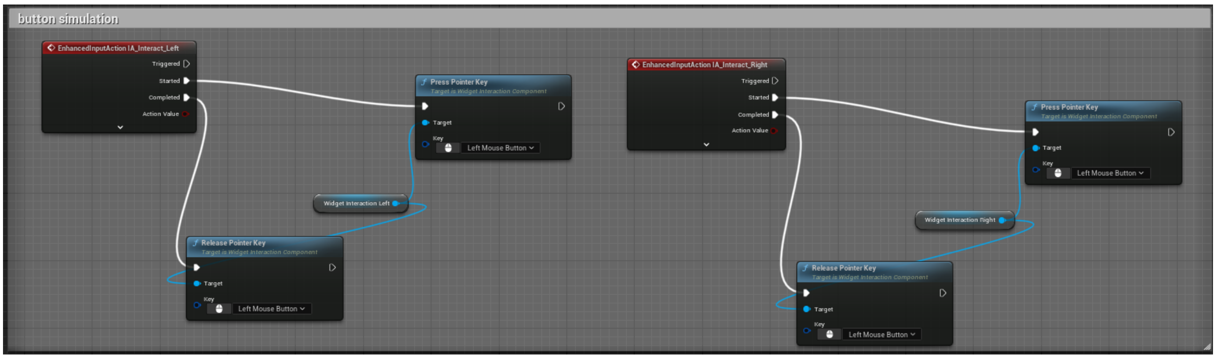


Figure 8: Blueprint for widget interaction in VRPawn

To understand better how these functionalities were implemented, it is possible to go to each folder mentioned above to check the Blueprint file where you can look at the event graph, one of the features of the blueprint that helps to comprehend the logic visually.

2.3.2 Version Control

Git was chosen for version control in developing "Heatwave" due to its reliability and the team's familiarity with the tool. Using Git ensured that our work was backed up and accessible to all team members, preventing data loss and enabling a collaborative workflow. To further enhance our efficiency, we employed GitKraken, a graphical interface for Git, which allowed us to manage repositories more effectively and minimize mistakes [18]. Although we considered alternatives like UE's Source Control and Multi-User Editing tools with Git or Source Control, these options had limitations. *"The Multi-User Editing system offers some features that are similar to source control systems, such as having a server that stores a history of transactions or having users acquire locks on the Assets they work on to reduce contention. Moreover, it is best used to augment a standard collaboration workflow in which you use a dedicated source control system such as Perforce, SVN, or Git to regularly record the changes you make to your Project"* [19]. However, the Multi-User Editing tool required all computers to be connected to the same Local Area Network (LAN) or Virtual Private Network (VPN) [19], which was impractical for our team's workflow. Source Control could have been a good option, but the team decided to use Git to avoid the learning curve associated with new tools, as everyone was already familiar with Git. Additionally, Git provides the advantage of storing work in a repository that can be publicly shared later on.

Nevertheless, one significant disadvantage of using Git in this project was the difficulty in tracking changes to the in-game environment files, which are primarily in binary format. Unlike text files, binary files are not human-readable, making it challenging to understand and merge changes or track changes when working collaboratively. This limitation sometimes led to conflicts and inefficiencies in the collaborative process.

Throughout the project, the team did encounter several obstacles with Git, particularly when managing large files that included elements such as shape, texture, and material. These challenges, and the solutions we developed, will be discussed in Section 4.1. Despite these disadvantages, Git was invaluable in maintaining a clean commit history and organizing our work. The best practices that were adopted included managing large files efficiently and ensuring that commits were clear and consistent.

The project's GitHub repository, "Heatwave Game," contains the official version of the game, as well as an additional version with a different VR environment but the same game mechanics. This repository serves as both a backup and a collaborative platform, showcasing the work completed, and the iterative improvements made throughout the project's development.

2.3.3 Thermal Haptic API and Dependencies

The Thermal Haptic API is designed to integrate with Unreal Engine games, specifically targeting the creation and control of smart garments and wearable haptic devices developed by Aalto University. This API is a critical component of one of the lighthouse projects at the European Media and Immersion Lab. [20] Detailed instructions and usage guidelines for the Wearable API can be found in the public paper "Hardware Specification and APIs of Smart Garments" [10].

The API Overview:
The API provides different levels of abstraction and functionality for controlling the haptic garment, which includes: (1) *Low-Level API:* Based on the Inter-Integrated Circuit (I2C) protocol - a simple two-wire serial protocol used to communicate between two devices or chips in an embedded system [21], facilitating communication between a master board and multiple slave boards. The slave boards control the actuators and sensors of the wearable device; (2) *Mid-Level API:* Utilizes serial or wireless communication between a software application and the master board, allowing both individual and global control of the actuators and sensors; and (3) *High-Level API:* Provides a library that can be integrated into software applications for advanced control of the haptic garment, suitable for complex and dynamic patterns and effects [10]

For the Heatwave game, the high-level tier of the API is the primary focus. The API library, implemented for UE, abstracts the communication protocol, allowing direct access to the devices through function calls, thereby simplifying the process of creating various haptic patterns while maintaining control over individual sensors and actuators. [10]

The integration process for the Thermal Haptic API involves several steps, which follow the instructions in the paper "Hardware Specification and APIs of Smart Garments" [10]:

1. Library Installation
    - The library is available in `WearableAPI.uasset` and has been tested with Unreal Engine versions 4 and 5.
    - Copy the `WearableAPI.uasset` files into the project's content folder.
    - Install the Serial Communication Plugin for Unreal Engine (SerialCOM) for serial communication. The SerialCom Plugin can be downloaded from this GitHub repository. Please note that you will have to check the version of SerialCom that is compatible with the UE version used.
    - Download and install the Transmission Control Protocol (TCP) Socket plugin from the Unreal Engine marketplace to facilitate communication between the VR environment and the haptic feedback system.

    Note: The TCP Socket plugin needs to be installed in the engine from the Epic Games marketplace before opening the project. Otherwise, you may encounter errors during the compilation of the Wearable API or any assets created with the TCP Socket plugin. This can cause significant problems, especially when working on the project across multiple PCs (as illustrated in Figure 9 below).

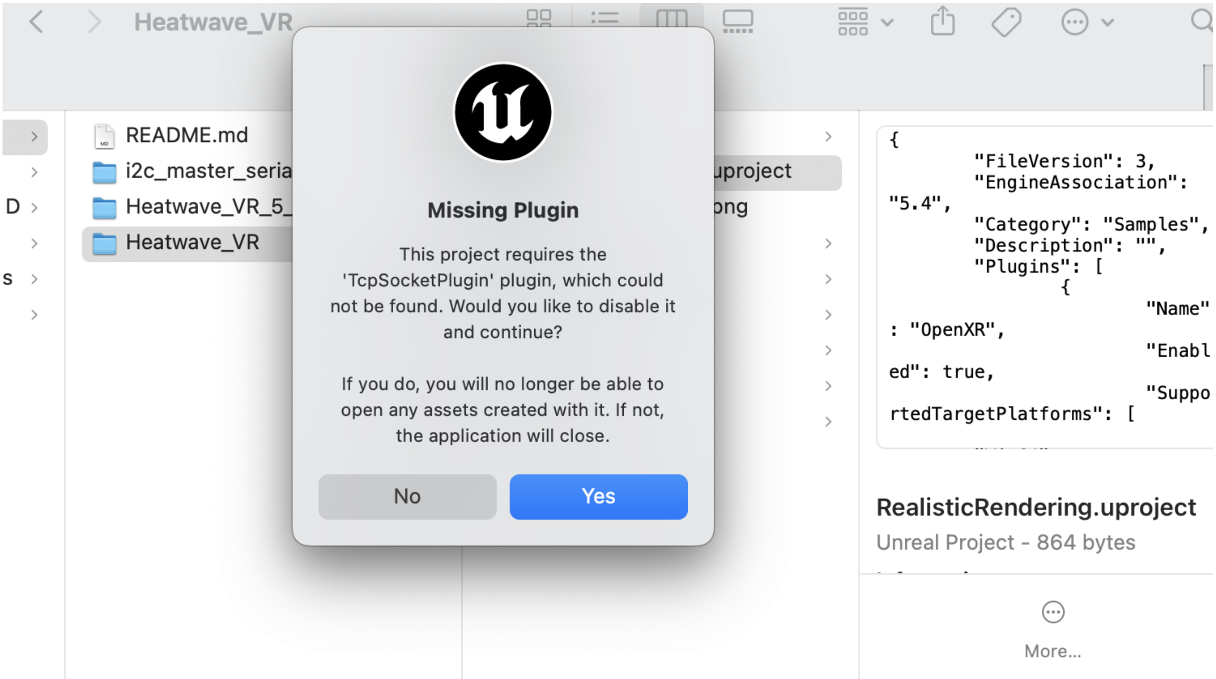


Figure 9: UE TCP Socket Plugin Observed Problem

2. Arduino Setup
   - Install Arduino software to run the I2C master file, enabling commands to be sent to the master board and check the COM port.
3. Setup in Unreal Engine
   - Place the WearableAPI and TCP Socket actors in the current level.
   - Configure the board address by editing the WearableAPI actor. Multiple master boards can be connected simultaneously, each requiring a separate TCP Socket and WearableAPI actors in the level.
   - Drag the `WearableAPI.uasset` files into the level blueprint and ensure that the TCP Socket plugin is correctly installed.

The open source code of the required API files is available and quickly accessible on one of these API developers' GitHub repository.

The API Commands:
The commands available for the API are included in Tables 1, 2, 3, and 4; for general commands, peltier commands, heater commands, and temperature commands respectively.

Command	Description	Parameters
Get Devices	Returns a list of devices with IDs and types	-
Soft Shutdown	Shuts down all actuators	-
Hard Shutdown	Cuts power supply to all actuators	-
Set Temperature Multiplier	Adjusts temperature actuator intensity	intensity: 0.0-1.0
Set Vibration Multiplier	Adjusts vibration actuator intensity	intensity: 0.0-1.0

Table 1: General API Commands [10].

Command	Description	Parameters
Set Intensity	Sets PWM value and direction for peltiers	id: 1-127, intensity: 0-255, direction: 0/1, duration: int
Read Sensor	Reads all sensors	id: 1-127
Set Min/Max Values	Sets PWM to 0 if max/min is reached	id: 1-127, min/max: 0-50
Set Target Temp	Sets target temperature for peltiers	id: 1-127, target: 0-50

Table 2: Peltier API Commands [10].

Command	Description	Parameters
Set Intensity	Sets PWM value for heaters	id: 1-127, intensity: 0-255, duration: int
Read Sensor	Reads all sensors	id: 1-127
Set Max Value	Sets max value for heater control	id: 1-127, max: 0-50
Set Target Temp	Sets target temperature for heaters	id: 1-127, target: 0-50

Table 3: Wired Heater API Commands [10].

Command	Description	Parameters
Read Sensor	Reads all temperature sensors	id: 1-127

Table 4: Temperature Sensor API Commands [10].

Climate-to-Haptic relation:
The main goal when utilising the thermal haptic garment is to translate the numerical values of the increase in global temperature to actual feeling for the player. With that objective in mind, a relation between these two needs to be devised, which after some brainstorming it has been decided to be of non-linear type, as this could help in exaggerating the effects felt during the first in-game years/decades while using the highest heat levels for much of the later half of the game.

The provided thermal haptic devices have an upper bound for temperature set between $43°C$ and $45°C$. This is due to safety concerns, and defines de maximum temperature that should be reached by the system when the simulated Earth heats up to its maximum projections for the next century. On the other side of the spectrum, the human skin temperature ranges from $33.5°C$ to $36.9°C$ [22], meaning conveying a temperature sensation under this range would result in a cold feeling by the player; which is undesirable for the sought "Heatwave" effect. Thus, the lower bound is set within this skin temperature range to ensure a warming sensation.

With this set, the following exponential relation is proposed:

$$H_T = 34.5T^{0,151} \tag{3}$$

with H_T being the haptic heat to be felt in $°C$, and T being the global average temperature increase, also in $°C$. This will result in a cold sensation being only for the highly improbable scenario of the player being able to reduce the global average temperature increase to below $+1°C$, meaning below the starting point of the game. For the rest, the temperature felt by the player will very quickly rise throughout the first half of the game, and if no meaningful action is taken to reduce the global temperature increase, it will slowly raise from $40°C$ to almost $43°C$ by the end of the in-game century. Of course, this relation is only a theoretical one, as the actual implementation is to be done by Heatwaves due to limitations in the provided API. Nonetheless, this relation has been coded in the game and can be used for future game versions where different thermal haptic devices are used, if deemed necessary. Note that the full data points for the relation assuming no player action for this translation between global temperature and haptic temperature is available in Appendix A.

Implementation in Heatwave Game

After looking into all the available functions of the Wearable API, the API is implemented to dynamically adjust the temperature of the Peltier elements based on the in-game global temperature in this Heatwave game. The API is triggered at three specific temperature ranges, with the maximum temperature limits set to 38°C, 40°C, and 43°C for the three heatwaves.

- **Trigger Points:** The API calls occur at three stages as the in-game temperature increases.
- **Dynamic Adjustment:** Depending on the player's actions, which affect the GHG values, the second and third heatwaves may not occur, limiting the maximum temperature to 38°C.

This dynamic control enhances the immersive experience by aligning the physical sensations with the virtual environment's changing conditions. The Blueprint scripting for the haptic wearable APIss is shown in Figure 10. The function created by the Custom Event named `WearableAPITriggeredByHapticHeat` will later be called within the time-passing loop, as explained in Sections 2.1 and 2.2

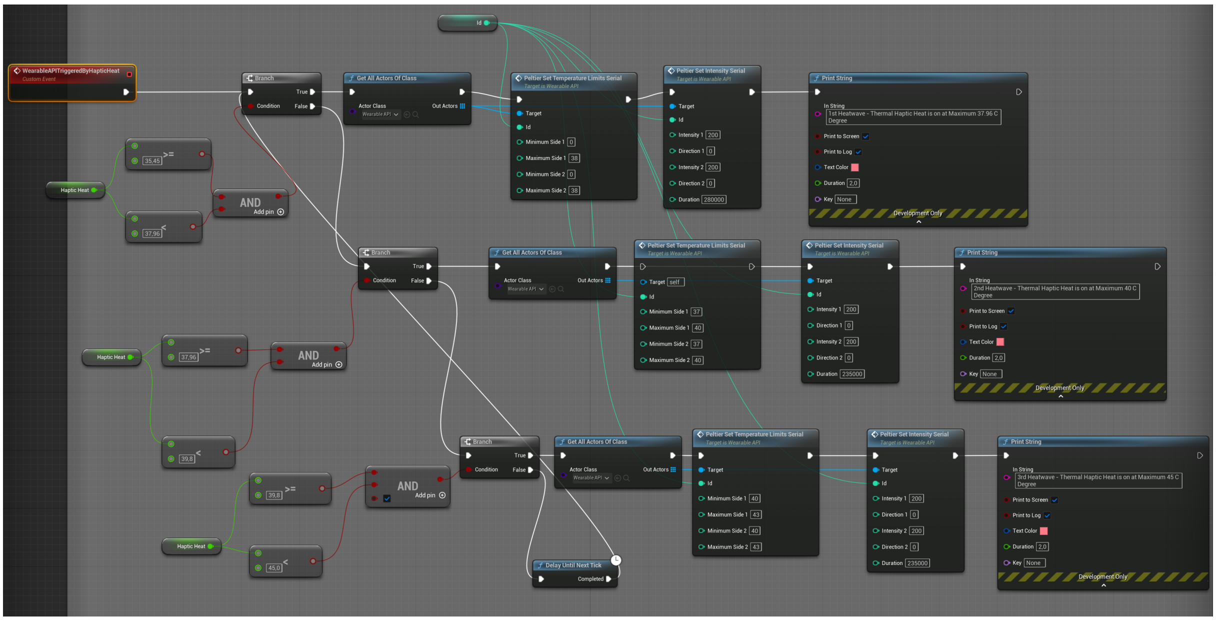


Figure 10: Wearable API Integrate into Heatwave Game Blueprint Implementation

3 Results

3.1 Pilot Game

The designed and implemented game, "Heatwave", demonstrates how VR and thermal haptics can be combined to create an engaging educational experience about climate change. The goal is to help players understand the effects of their actions on global warming through real-time temperature feedback. The game takes place in a simple VR setting, such as a living room with interactive items like a TV, a sofa, and objects around the room as shown in figure 11. The TV shows climate-related news to set the context. The player start by sitting on the sofa and must stand up to interact with various objects on the action table and around the room. Each object represents different actions related to climate change. These actions directly affect the in-game and haptic temperature, showing the impact of the player's choices. When the player points to an object, information about the action associated with it will appear. To execute the action and observe its impact on the game, the player must grab the object. The effects of the action will not be immediate; they may take several months or even years in the game to become apparent, depending on the specific action taken.

Figure 11: Game environment

Figure 12 shows the action table, the objects and one of the corresponding widgets that shows information about the actions.

Figure 12: Actions Table

A key feature of "Heatwave" is the thermal haptic suit, which allows players to feel temperature changes in the game. The suit's feedback is synced with the in-game temperature, which varies according to the player's actions. For instance, if a player chooses actions that increase greenhouse gas emissions, the suit will heat up, making the consequences of those actions more tangible. Figure 13 shows the player viewpoint while playing the game. The messages on the screen inform the player about the values of different variables inside the game.

Figure 13: Player viewpoint.

The game focuses on decision-making under time constraints. Players select actions from the action table, each taking different amounts of time and having different impacts on global warming. The game highlights that solving climate change requires both individual actions and collective efforts, such as political activism and governance. The player can encounter one of five different endings (as discussed in section 2.1) based on the actions they take throughout the game. Figure 14 illustrates one of these possible endings.

Figure 14: One of the possible ending of Heatwave.

The pilot game underwent usability testing to ensure the VR environment and thermal haptic feedback were well-integrated and easy to navigate. Feedback from these tests was used to improve the game mechanics and enhance the overall user experience.

3.2 Simplified, game-ready, Climate Model

As discussed in Section 2.2 and summarized in Figure 6, the two main pillars of the proposed climate model for the game simulation are two linear approximations extracted from IPCC data published in AR6[3]. Crucially, these have not been strictly defined as linear regressions as the needs for gameplay mechanics are an indispensable part of them, as seen in equation 1. This has been deliberately defined as such in the methodology, precisely to allow for adaptations for the climate model to work with the game mechanics needs.

This is mainly seen in the approximation manufactured for the relation $\mathrm{GHG}(t)$. Here, the goal has been to assign numerical fixed values to the b and m parameters of equation 1 that reflect the projected GHG emissions shown in Figure 4, with the whole resulting line falling within the $25-75$ percentiles. The values have been set to 0.194 and -336 for b and m respectively for t values in years; which results in the equation taking the form:

$$GHG(t) = [0.194 - a_{\text{slope}}] \cdot t + [-336 - a_{\text{offset}}] \tag{4}$$

When plotting this equation assuming no player action ($a_{\text{slope}} = a_{\text{offset}} = 0$), it is clear that the proposed approximation respects the key requirement of staying within the $25-75$ percentiles of the projections made by the IPCC (see Figure 15). It is clear, however, that due to the linear nature of the proposed approximation, the trend loses accuracy by the latter second half of the century ($2060-2100$ timeframe). This is mainly due to the compromise nature of the chosen values, a middle ground between a faithful representation of the predicted growth in GHG emissions for the $2020-2050$ period and the stabilization predicted for the rest of the century.

While a different approach was discussed and considered, one with two different linear trends for the two

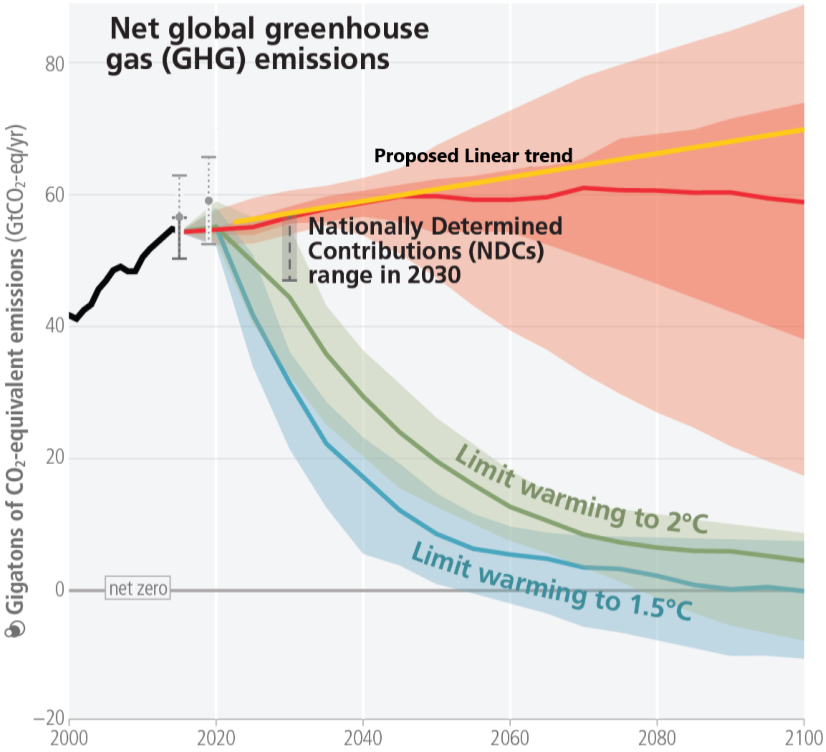


Figure 15: Proposed approximation for the $GHG(t)$ relation (yellow) superimposed to the projections by the IPCC (red, with $25-75$ percentiles represented by the darker red shade) [1].

distinct periods, which could have taken the form:

$$\begin{cases} GHG(t) = [b - a_{slope}] \cdot t + [m - a_{offset}] & \forall t \in [2020, 2055) \\ GHG(t) = [f - a_{slope}] \cdot t + [o - a_{offset}] & \forall t \in [2055, 2100] \end{cases} \tag{5}$$

while still respecting the overall goals described in the methodology; this was ultimately discarded. The main reasons for opting for only one trend line come from game design reasons. Having a climate model based on a system with the form of equation 5, the assigning values to a_{slope} and a_{offset} for each of the possible actions the player can take becomes notably more complex, as these values would affect differently the trend line for the two different purposes. Once again, this is not impossible to do: the team could spend extra effort in ensuring no discontinuity between the two trend lines ever appears no matter the actions taken by the player by carefully assigning values to each action. In extreme cases, actions could even have different impacts on the values of a_{slope} and a_{offset} depending on which of the time period the player finds themselves in. However, the added complexity has ultimately been deemed unnecessary troublesome. To begin with, the $2060-2100$ timeframe should already have a distinct trend line in the vast majority of gameplay runs, as by then the player has had more than 30 in-game years to alter this default progression. Added to that, and even more relevant from a climate model point-of-view, this minor inaccuracy has been taken into account when translating these emissions to in-game global average temperature increase.

With the $GHG(t)$ relation out of the way, focus can now be shifted towards the second pillar of the proposed climate model. The relation between Global Average Temperature Increase and cumulative GHG emissions $T(GHG_c)$ has been determined following the defined objective linear function (see equation 2). This linear function has a set departure point that comes from the latest published NOAA data [13]: for 0 Gt CO_{2-eq} of cumulative GHG emissions before the game start (year 2023), the Earth has already experienced an average global temperature increase of $1,18^{\circ}C$ with respect to pre-industrial levels. With this and the data pertaining to the projections done by the IPCC *"High Emissions scenario"* it is possible to complete the missing pieces. This SSP predicts an increase of $2.10^{\circ}C$ by 2050 and almost $4^{\circ}C$ by the end of the century. This, combined with the cumulative emissions that one can expect from the previously traced linear approximation (equation 4), the

$T(GHG_c)$ model can be completed as:

$$T(GHG_c) = 5.74 \cdot 10^{-4} \cdot GHG_c + 1.17 \quad (6)$$

As mentioned before, this relation allows compensating for the inaccuracies of equation 4 for the second half of the century, as it guarantees a steady rise of temperatures with cumulative GHG emissions matching the IPCC projections already seen in Figure 5. A full comparison between real-world NOAA data and IPCC projections juxtaposed with the proposed Climate Model can be consulted in Table 5, where one can see the close match achieved despite using comparatively simple linear approximations. Note that a full year-by-year disclosure of the data points produced by the proposed model is available in Appendix A.

Year	**In-Game Climate Model, no player action**		**NOAA Data; IPCC Projections**	
	Cumulative GHG emissions	Average Global Temperature Increase	Cumulative GHG emissions	Average Global Temperature Increase
2023	-	-	(0)	$1,18°C$
2024	56.656 Gt CO_{2-eq}	$1,20°C$	-	-
2050	1597.806 Gt CO_{2-eq}	$2.10°C$	(aprox.) 1600 Gt CO_{2-eq}	$2.10°C$
2100	4930.156 Gt CO_{2-eq}	$4,01°C$	-	$3,98°C$

Table 5: Year, Cumulative GHG Emissions, Average Global Temperature Increase comparison between the proposed climate model and IPCC projections and 2023 NOAA data [3, 13].

In game, this has been implemented with a "Time-loop" kind of structure. The blueprint, which is structurally inside the Climate Display information system for easier data visualization, computes the climate model and the time-passing of in-game time all at once. This eases debugging, as one can easily tweak any value (from slopes for climate curves to the equivalence between real and in-game time) from the same place. It is important to note that, for a more dynamic experience, in-game the model is updated on a monthly basis, rather than yearly. This is a simple unit change, however, as the parameters remain the same as the ones shown in this section.

As hinted before, in-game, the player has full access to all the information processed by the climate model in an easy-to-consult infographic-style display (see Figure 16); which structurally stems from the same UE object that handles the climate model computation and the "Time-loop" for in-game time.

3.3 VR and Haptic Experience

3.3.1 Results of VR and Haptic Experience Implementation

The VR environment was developed to ensure intuitive navigation and interaction for the players. The teleportation method was used for movement, and controller feedback was implemented to enhance the interactive experience. The functionalities related to VR experience mentioned in subsection 2.3.1 were successfully developed with Oculus controllers to interact with the environment. Specifically:

- **Teleportation and Navigation:** The teleportation feature allows players to move seamlessly within the virtual environment, enhancing accessibility and ease of navigation.
- **Controller Feedback:** Haptic feedback through Oculus controllers provides tactile responses when interacting with objects, improving immersion and user engagement.
- **Object Interaction:** Players can interact with objects on the options table by pressing `select buttons` on the Oculus controller. When players select an object, a widget interface displays the action description, including the type of action, duration to complete, and impact on GHG.
- **Grabbing Objects:** The grab functionality allows players to pick up objects by pressing the `grab buttons` on the Oculus controller when in proximity to the objects.

Figure 17 depicts the button mappings on the Oculus controller used during the development of this game.

Figure 16: In-game climate information display.

Additionally, the haptic heat feedback system was implemented to represent three distinct heatwaves in the game, each with defined maximum temperatures. The API was triggered dynamically based on in-game global temperature ranges, with maximum temperature limits set to 38°C, 40°C, and 43°C. Figure 18 illustrates the implementation of these heatwave temperatures, where all other information processed by the climate model was also presented:

- **Heatwaves:** Three heatwaves were simulated in the game, with maximum temperatures set to 38°C, 40°C, and 43°C.
- **Haptic Feedback:** The haptic wearable API was integrated to provide heat feedback during these heat waves, enhancing the immersive experience.

3.3.2 Usability Testing Results

Usability testing was later conducted to help prevent bias as developers of the game and to provide direction for further development and refinement of some game functions. The testing involved in total of 4 participants with varying levels of experience with VR and diverse demography to gather comprehensive feedback on the VR and haptic experiences. The feedback collected from this testing will guide future improvements and ensure that the game provides an engaging and immersive experience for all players. The feedback form and test results can be found in Appendixes D and E.

Key findings from the feedback form are summarized below:
Modify the percentage later, depends on the test result

- **Ease of Navigation:** 85% of participants found the teleportation method easy to use.

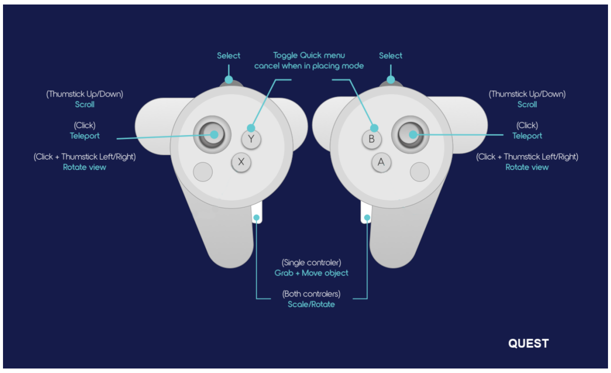


Figure 17: Control norms on Oculus 1 used in the development of the game. [23]

When the 1st heatwave happens in the game | When the 2nd heatwave happens in the game | When the 3rd heatwave happens in the game

Figure 18: Thermal haptic heat's maximum temperature information display.

- **Intuitive Interaction:** 90% of participants felt that the controller inputs for selecting and grabbing objects were intuitive.
- **Immersion:** 95% of participants reported that the haptic feedback significantly enhanced their immersive experience.
- **Realism of Heatwaves:** 88% of participants felt that the haptic heat feedback accurately represented the in-game heatwaves.
- **Overall Satisfaction:** 92% of participants were satisfied with the overall VR and haptic experience in the Heatwave game.

Participants provided additional qualitative feedback, highlighting the following points:

Overall, the usability testing yielded (positive/ likely positive) results, indicating successful implementation and a high level of user satisfaction.

4 Conclusions

4.1 Obstacles

The development of the "Heatwave" project encountered several significant obstacles, each presenting unique challenges that restricted progress and required innovative solutions.

- **Redefining the direction of the project** A major challenge was redefining the project's direction through comprehensive desk research to ensure the climate change system in the game was based on reliable data. This required an extensive review of scientific papers and credible sources to bring accurate numbers for the game's climate change model, ensuring the educational content was both informative and realistic.
- **Facilities and Equipment:** One of the primary challenges was the lack of access to a proper Graphic Processing Unit (GPU) necessary for development and usability testing. The GPU is critical for rendering the complex graphics required in VR environments, and without it, the development process was severely hindered. Additionally, accessing the VR room to work with the smart garment proved particularly difficult during the summer months, causing delays and limiting opportunities for testing and refining the user experience. The VR equipment, specifically the Oculus headsets, were borrowed from Aalto University. With insufficient units for the entire team, members had to take turns using, learning, and testing the equipment. Considering that team members had no prior experience with the Oculus headset and controllers, considerable time was spent on setup, learning, and integration into the UE VR game.
- **Compatibility Issues:** Compatibility between UE version and third-party plugins presented another major obstacle. The lack of advance notice regarding these issues further complicated the development process. Although the team was given references indicating that the API would be compatible with UE5, the API included two third-party plugins, SerialCom for UE and a TCP socket plugin from the UE marketplace. After developing the VR environment and other game functions in UE5.4, the team discovered, independently, that the API would not work with this version because the SerialCom plugin was only compatible with UE5.3 at the time. This required the team to recreate the VR environment and migrate all objects and blueprints, which was time-consuming and resource-intensive. Additionally, the recommended UE versions, specifically 5.3.1 and 5.3.2, were prone to crashing, causing significant disruptions, which can be found in Epic Games Forum where many developers faced the same issue [24]. The team had to wait for the SerialCom plugin to release a compatible version for UE5.4, further delaying the project.
- **Skill and Experience Limitations:** The team's prior background also posed limitations. The lack of hands-on experience, combined with time constraints, added another layer of complexity. The learning curve was abrupt, and the team had to acquire new skills quickly to keep up with the demands of the project. This often led to delays and additional stress, as team members juggled learning new techniques with meeting project deadlines.
- **Tracking Changes when Working Collaboratively:** Using Git for version control presented difficulties, particularly due to storage limitations with the free package available to students. Managing large files was problematic, and solutions took time to implement. The team learned to ignore specific files when adding changes, but tracking modifications was challenging because many files were in binary format. This made it impossible for team members to know which assets were modified and how, or what new blueprints were added. Despite weekly meetings on campus, the lack of personal computers with GPUs prevented the team from effectively demonstrating our progress with UE.
- **Motivation:** Lastly, maintaining motivation throughout the project was challenging, especially given the technical and logistical hurdles faced. Balancing the demands of learning new tools and technologies with the project's ambitious goals required persistent effort and resilience from all team members.

4.2 Further Development

Looking ahead, several key areas have been identified for further development to enhance the "Heatwave" project and ensure its long-term success.

1. **Visibility of Other Rooms:** One planned enhancement is enabling the visibility of other rooms once a player completes one level (as in, unlocking new actions such as group-actions, political-actions, etc).

This feature is intended to demonstrate that the game's content and mechanics can serve as a foundation for implementation in various VR environments. By showing other rooms, players can see the broader scope of the game and understand how their actions in one environment can impact others. Crucially, it is with this new sets of actions that the player can potentially reach the full set of endings, as with only individual actions the potential to redirect the planet's climate fate is very limited.

2. **Adjustments Based on Gameplay:** The in-game global temperature, GHG levels, and haptic heat will be adjusted based on gameplay. This dynamic adjustment aims to provide a more immersive and educational experience for players. The "Get Pawn" function will be modified to facilitate these changes, ensuring that players receive real-time feedback on their actions' impact on emissions. Additionally, the descriptions of actions and their effects will be refined to enhance player understanding and engagement, making the educational aspect of the game more explicit and impactful. (draw here the logic steps)

More gameplay and story related improvements and future steps have been also laid out in the original Heatwave Storyboard (see Appendix B).

4.3 Reflections and Learnings

4.3.1 VR reasoning and energy consumption

VR provides an immersive experience that traditional video games cannot match. It places the user directly into the game environment, creating a sense of presence that can make the learning experience more engaging and memorable. This immersive nature of VR can lead to a deeper understanding of climate change concepts as users can virtually experience the effects of climate change, making the issue more tangible and real. While the energy consumption of VR is a valid concern, the unique benefits of VR for education can justify its use. However, it's crucial to continue exploring ways to reduce the energy consumption of VR to make it a more sustainable technology. This could include optimizing VR software for energy efficiency, using energy-efficient hardware, and leveraging renewable energy sources for powering VR devices.

Nevertheless, and in line with the learning objectives (see Section 1.2), it is crucial to not stall the conversation of energy consumption in the individual level. Without disregarding the need for improvements in this area; as system-wide changes are necessary to address climate change, it is counter-productive to overfocus on the energy consumption of one individual using the resources of an average PC to play the proposed game.

4.3.2 Version Control and Handling Large Files

During the project, the team faced several challenges related to managing large files in version control systems. The team learned the importance of filtering file sizes when committing changes to prevent unnecessary repository bloat. This practice should be a standard procedure, and large files should be added to the `.gitignore` file whenever possible.

Moreover, it was found that rebasing to delete commits involving large files was crucial. However, this process is complex and could be streamlined with better initial planning and awareness. When the team uploaded the first version of the game to the Git repository, significant challenges were encountered due to the large size of some project files. This was particularly true for high-resolution assets like 4K materials, which substantially increased the overall project size. To address this issue, it was decided to remove some of these 4K materials. This experience highlighted the importance of considering file sizes when working with version control systems, especially in game development where large assets are common. It underscored the need for effective strategies to manage large files in version control systems.

4.3.3 Early Clarification of Wearable API Capabilities

The integration of the wearable thermal haptic devices was a core component of the project. However, the team faced challenges due to a lack of early clarification on the API capabilities of wearable. Future projects should prioritize early-stage communication with hardware and software providers to fully understand the limitations and capabilities of APIs. This would help in designing game mechanics that are both innovative and feasible within the technical constraints.

4.3.4 Managing Learning Curves and Skill Development

The team had to acquire new skills rapidly to meet the project's demands, which often led to delays and added stress. A structured approach to skill development, including more time for training and a phased introduction of new techniques, could mitigate these issues. Allocating specific periods within the project timeline for learning and experimentation without the pressure of immediate deadlines could also enhance overall productivity and innovation.

4.3.5 Enhancing Communication and Collaboration Tools

Given the technical challenges and the need for constant coordination, better communication and collaboration tools could have improved efficiency. Implementing advanced project management software and regular, structured check-ins might have helped in addressing issues promptly and keeping the project on track.

4.3.6 Addressing Game Mechanics and Usability Issues

During the testing phase of the game, it became apparent that Equation 4 governing GHG emissions, GHG(t), requires modification or additional assumptions for future versions. We observed that the parameter a_{slope} could drastically influence the temperature outcomes in the game. Specifically, the multiplication of the year by the term $(0.194 - a_{slope})$ caused an unrealistic escalation in GHG values over time, leading to extreme changes in global temperature, such as drops to -11°C or spikes to +4°C. These extreme fluctuations resulted in gameplay scenarios that were inconsistent with real-world climate dynamics. To avoid such unrealistic outcomes, future iterations of the game should incorporate more nuanced assumptions or constraints on the a_{slope} parameter. Additionally, a significant bug was identified where the temperature fails to update after reaching +4°C, requiring urgent resolution in future development cycles. We could have solved this issue by canceling the effect of taking an action after a certain amount of time, but since this approach was against the game's strategy, we decided not to implement this solution in this version of the game.

Another key observation was related to the user experience, particularly for those less familiar with VR environments. Test participants who had little to no experience with VR found it challenging to navigate and interact within the game. We attempted to address this by allowing trial minutes before the real test, but this was insufficient. The challenge was exacerbated by the technical limitations of the testing setup. Although there was WiFi available, we were unable to connect the VR headset to it, necessitating the use of a cable connection to the PC. This, combined with the wired connection of the thermal haptic suit, significantly restricted the movement of the testers, making the experience particularly challenging for those new to VR.

Moreover, the testing environment itself presented challenges. Conducting the tests in a room with fewer staff present would have been more comfortable for the participants, allowing for a more relaxed and focused testing experience. These factors highlight the need for a more refined and user-friendly setup in future testing phases to ensure that the game is accessible and enjoyable for a wider range of users.

Reflecting on these aspects, the team recognizes the importance of balancing innovation with practicality, thorough planning, and sustainable practices. These lessons will inform future projects, ensuring continued growth and improvement in both process and outcomes.

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Appendix A: Climate Model and Haptic Heat yearly data points

Year	Yearly GHG Emissions (no player action, Gt CO_{2-eq})	Cummulative (since game start, Gt CO_{2-eq})	Average Global Temperature Increase (°C)	Haptic Heat (°C)
2024	56,656	56,656	1,20	35,48
2025	56,850	113,506	1,24	35,62
2026	57,044	170,550	1,27	35,76
2027	57,238	227,788	1,30	35,90
2028	57,432	285,220	1,34	36,04
2029	57,626	342,846	1,37	36,18
2030	57,820	400,666	1,40	36,31
2031	58,014	458,680	1,44	36,44
2032	58,208	516,888	1,47	36,57
2033	58,402	575,290	1,50	36,69
2034	58,596	633,886	1,54	36,82
2035	58,790	692,676	1,57	36,94
2036	58,984	751,660	1,61	37,06
2037	59,178	810,838	1,64	37,18
2038	59,372	870,210	1,67	37,29
2039	59,566	929,776	1,71	37,41
2040	59,760	989,536	1,74	37,52
2041	59,954	1049,490	1,78	37,63
2042	60,148	1109,638	1,81	37,74
2043	60,342	1169,980	1,85	37,85
2044	60,536	1230,516	1,88	37,96
2045	60,730	1291,246	1,92	38,07
2046	60,924	1352,170	1,95	38,17
2047	61,118	1413,288	1,99	38,28
2048	61,312	1474,600	2,03	38,38
2049	61,506	1536,106	2,06	38,48
2050	61,700	1597,806	2,10	38,58
2051	61,894	1659,700	2,13	38,68
2052	62,088	1721,788	2,17	38,78
2053	62,282	1784,070	2,20	38,87
2054	62,476	1846,546	2,24	38,97
2055	62,670	1909,216	2,28	39,07

2056	62,864	1972,080	2,31	39,16
2057	63,058	2035,138	2,35	39,25
2058	63,252	2098,390	2,39	39,34
2059	63,446	2161,836	2,42	39,43
2060	63,640	2225,476	2,46	39,52
2061	63,834	2289,310	2,50	39,61
2062	64,028	2353,338	2,53	39,70
2063	64,222	2417,560	2,57	39,79
2064	64,416	2481,976	2,61	39,88
2065	64,610	2546,586	2,65	39,96
2066	64,804	2611,390	2,68	40,05
2067	64,998	2676,388	2,72	40,13
2068	65,192	2741,580	2,76	40,22
2069	65,386	2806,966	2,80	40,30
2070	65,580	2872,546	2,84	40,38
2071	65,774	2938,320	2,87	40,46
2072	65,968	3004,288	2,91	40,54
2073	66,162	3070,450	2,95	40,62
2074	66,356	3136,806	2,99	40,70
2075	66,550	3203,356	3,03	40,78
2076	66,744	3270,100	3,07	40,86
2077	66,938	3337,038	3,11	40,94
2078	67,132	3404,170	3,14	41,02
2079	67,326	3471,496	3,18	41,09
2080	67,520	3539,016	3,22	41,17
2081	67,714	3606,730	3,26	41,24
2082	67,908	3674,638	3,30	41,32
2083	68,102	3742,740	3,34	41,39
2084	68,296	3811,036	3,38	41,47
2085	68,490	3879,526	3,42	41,54
2086	68,684	3948,210	3,46	41,61
2087	68,878	4017,088	3,50	41,68
2088	69,072	4086,160	3,54	41,76
2089	69,266	4155,426	3,58	41,83
2090	69,460	4224,886	3,62	41,90
2091	69,654	4294,540	3,66	41,97
2092	69,848	4364,388	3,70	42,04

2093	70,042	4434,430	3,74	42,11
2094	70,236	4504,666	3,78	42,18
2095	70,430	4575,096	3,82	42,24
2096	70,624	4645,720	3,86	42,31
2097	70,818	4716,538	3,91	42,38
2098	71,012	4787,550	3,95	42,45
2099	71,206	4858,756	3,99	42,51
2100	71,400	4930,156	4,03	42,58

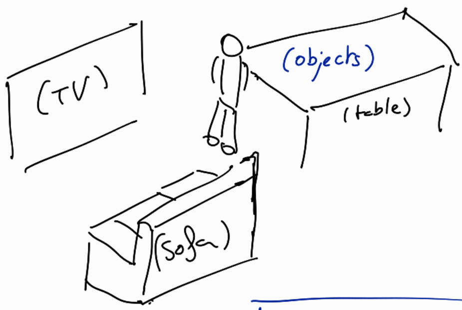
Table 6: Year-by-year results of the proposed Climate Model and resulting Thermal Haptic output.

Appendix B: Storyboard

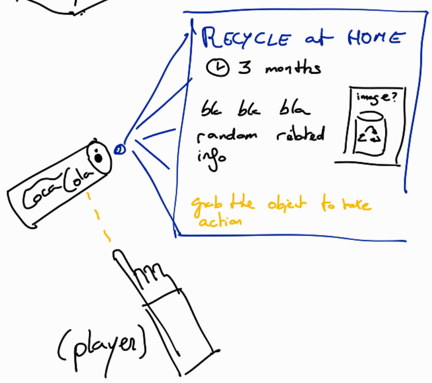
The Player starts sitting on a sofa, wathing TV.
TV shows some random concerning climate news, one after the other:
drought, crop failures, hurricanes, floods, etc
[Heat from Haptics is at normal levels].

The Player needs to STAND UP to be able to take action (philosophy: sitting in the sofa you won't change the world) when the player STANDS UP; the TV changes to infogrpahic mode, showing on one half random news, and on the other half the current year, global temperature, and CO2 ppm.

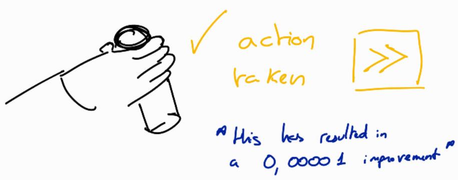
The table next to the sofa and the TV acts as a menu where the Player can chose what actions to take. Different objects symbolize different actions. Actions can improve, worsen, or be neutral in regards to global climate; but they will all take Time (the main constraint of the game).



Pointing to an object makes a pop-up appear with information about the Action, and how much Time it will take to complete. Crucially, it will NOT say how much will it impact the global climate.



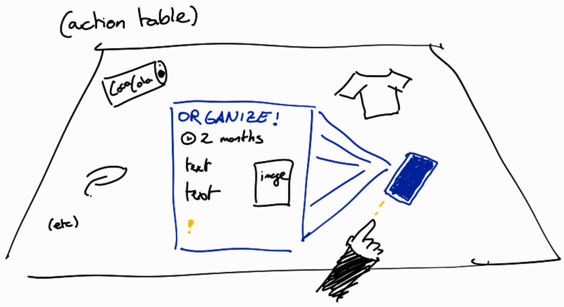
Grabbing an object means that the Player has decided to take that Action. Time will then fast forward accordingly, and the TV screen information, as well as the Haptic Heat will update.
[future: mini-game related with the action]



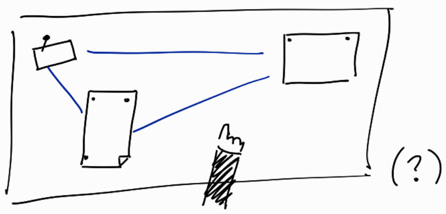
Actions:

A key pillar of the game is to emphasize how individual actions are insuficient to solve the climate crisis. Rather, the Player will need to organize, engage in political activism, and potentially run a government to be able to reach the best endings of the game.

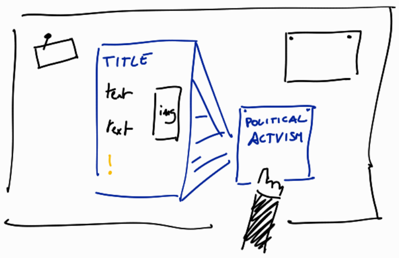
Initially, the Player has only access to the table with objects that represent individual action. One of this objects, however, can be used to unlock group action (representing the time the Player invests in organizing). Can be, for instance, a smartphone (?) TBD



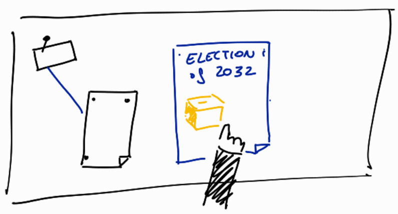
Having spent time in creating a group to do more effective actions, the player has now access to [a pin board with pins for new group acitons? new objects on the table? TBD]. This actions take slightly more time (and effort), but are notoriously more effective.



As a group, the Player can also do something similar (chose to spend time) to unlock Lobbyism / Political Activism. This will allow "the group" to engage with politicians and advocate for legislative changes, further unlocking more effective actions.



[future potential addition]
The final step the Player can take to unlock further actions would be to either Run for Government or, depending on the political path taken, go full Revolution. Once in government, the actions that can be taken are extremelly powerful, but can also have side consequences. (needs further exploration)



Endings

Depending on the actions the Player has decided to take, the game will end either in 2100 (the maximum year), or when the global temperature reaches +4ºC heating (and the haptincs are, thus, at maximum heating). Accroding to the status of the world when the game ends, the Player will get one of the following five end screens.

- Catastrophic Ending: (taken from IPCC Very High emissions scenario). Temperature is already +4 before the year is 2080. It no longer makes sense to keep playing, catastrophic feedback loops are very likely to trigger at this point, and there is a guaranteed heating to up to +6ºC by 2100 and more to happen beyond that point. For this to happen, the Player has to mess up quite badly and chose actions that not only do not help but actually harm the fight against the climate crisis.

- Business as Usual Ending: (taken from IPCC High emissions scenario). Temperature is +4 post 2080; or above +3 by 2100. There will be guaranteed continued warming past 2100. For this to happen, the Player has either done nothing, or barely nothing (only individual actions), or a quite bad combination of harmful and decent actions.

- Bare Minimum Ending: (taken from IPCC Intermediate emissions scenario). Temperature is above +3 by 2100. Insufficient action has resulted in potential continued warming past 2100; but the worst consequences have been at least attenuated. For the unknowing player, this is probaby the most probable ending; with a combinantion of individual and group decent actions that are ultimately insufficient, but may prompt the player to try again.

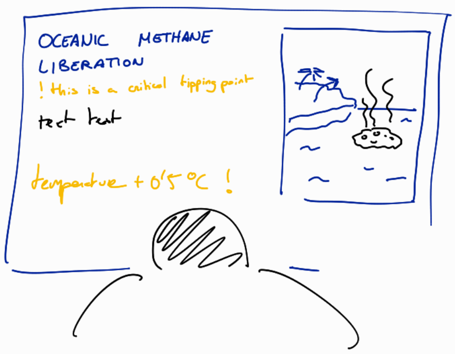
- Paris Agreement Ending: (taken from IPCC Low emissions scenario). Temperature is below 2ºC but above 1,5ºC by 2100. Critical tipping points have been avoided, and warming will not continue past 2100. The worst has been avoided; and the Player has been able to choose good and meaningful actions.

- "Greta Thumberg" Ending: (taken from IPCC Very Low emissions scenario). Temperature is at or below 1,5ºC by 2100. The right actions were taken on time, and only the most unavoidable disasters (as of 2024) were lived. Nature is healing, etc.

[easy potential addition]
Random Events

There are a set of potential global events that can further escalate the climate crisis. Some of these become increasingly more probable as temperature rises; but the scientific community is still unsure when will they happen or what threshold needs to be surpassed to trigger these. This will be represented in-game by random events, with some of them having a higher chance of firing as temperature rises.

A "Random Event" appears in front of the Player as a pop-up screen with summarized information, a picture, and a highlight of the effects this has for the game (namely, how has the tempertaure changed due to this event). Critically, the Player has no option but to accept this event and continue on playing. Note that they are not all necessarily negative: a massive volcanic eruption, for instance, could cool the planet down temporarily.



Appendix C: Proposed Actions

A list of proposed climate actions has been researched and is included in this appendix. Only a small subset of the individual actions has been implemented in the pilot game, yet all are implementable as the different game stages are developed. Every action is cataloged by the level of impact (ranging from -10 to $+10$ for harmful and beneficial actions respectively), and duration in months. Note that the numerical range of impact needs to be translated to the in-game climate model after testing. Timeframes for actions should also be manicured after testing. Note as well that group efforts, lobby campaigns, and government goals should be unlocked first before they can be chosen.

- Recycle at home [0.01] [1 month]
  Set up a recycling environment at home and work. Convince your family and coworkers to participate.
- Recycling campaign [0.1][1 year]
  Group effort is spent on raising awareness of the importance of recycling.
- Recycling lobbying [0.4][1 year]
  Lobby governments and corporations to implement recycling at every level.
- Recycling initiative [0.5][1 year]
  Government efforts are put towards legislating around recycling and making it the norm, rather than leaving it to the goodwill of individuals and corporations.

- Calculate your individual carbon footprint [0.01][1 month]
  Use online tools to calculate your personal carbon footprint to understand your environmental impact.
- Campaign for the reduction of individual carbon footprints [0.02][1 year]
  Raise awareness of the importance of reducing personal carbon footprints through social media and community events.
- Code and publish a game on climate actions [0.1][1 year]
  Develop and release a game that educates players on various climate actions and their impacts.
- Criticize individual carbon footprint discourse [0.05][1 year]
  Write articles or give talks challenging the emphasis on individual carbon footprints and promoting collective action.

- Buy less, reuse more [0.05][6 months]
  Adopt and promote a lifestyle of minimalism and reuse to reduce waste and resource consumption.
- Lobby for a Gross Domestic Product (GDP)-focused economy [-0.3][1 year]
  Advocate for policies that prioritize GDP growth over environmental sustainability.
- Lobby for circular economy practices [0.5][2 years]
  Push for the adoption of circular economy principles where waste is minimized and resources are reused.
- Government policy: maximize GDP growth [-1.0][5 years]
  Implement policies that prioritize economic growth at the expense of environmental health.
- Government policy: circular economy [1.0][5 years]
  Enact laws and regulations that promote a circular economy to reduce waste and resource consumption.
- Government policy: steady state economy [1.5][5 years]
  Adopt economic policies that aim for stable or mildly fluctuating levels of consumption and production.
- Government policy: degrowth [2.0][5 years]
  Implement policies that reduce consumption and production to achieve environmental sustainability.

- Use more public transport, walk, or cycle [0.1][1 year]
  Shift from car use to public transport, walking, or cycling to reduce carbon emissions.
- Lobby for better, human-centric infrastructure in your city/region [0.7][3 years]
  Advocate for the development of infrastructure that prioritizes public transport, walking, and cycling.
- Urban sprawl development [-0.7][5 years]
  Promote policies that encourage urban sprawl, leading to increased car dependency and emissions.

- Transition away from car dependency [1.0][5 years]
  Implement policies and infrastructure changes that reduce reliance on personal vehicles.

- Travel less by plane [0.1][1 year]
  Opt for alternative modes of transport to reduce the carbon footprint of air travel.
- Stay-Grounded campaign [0.3][2 years]
  Promote and participate in movements that encourage reduced air travel.
- End state-subsidized flights [0.5][3 years]
  Campaign for the cessation of government subsidies for air travel to reduce flight frequency and emissions.
- Regulate CO_2 emissions when travelling [0.7][3 years]
  Advocate for policies that limit carbon emissions from all forms of travel.

- Reduce fast-fashion consumption [0.05][6 months]
  Host workshops to educate people about sustainable fabrics and the impact of fast fashion.
- Anti fast-fashion campaign [0.2][1 year]
  Organize campaigns to raise awareness about the negative impacts of fast fashion.
- Anti-fast-fashion lobbying [0.6][2 years]
  Lobby for regulations that limit fast fashion production and encourage sustainable practices.
- Regulations of the clothing industry [0.8][5 years]
  Enact policies that mandate sustainable practices in the clothing industry.
- Laissez-faire for the clothing industry [-1][5 years]
  Maintain minimal regulatory interference in the clothing industry, allowing fast fashion to proliferate.

- Reduce meat consumption [0.01][1 month] Encourage reducing meat consumption one day a week to lower carbon footprints.
- Campaign for plant-based diets [0.4][2 years] Advocate for widespread adoption of plant-based diets to reduce agricultural emissions.
- Industrial livestock farming [-0.8][5 years] Support and expand industrial livestock farming practices, which significantly increase GHG emissions.
- National dietary guidelines for sustainability [1.2][5 years] Advocate for government-issued dietary guidelines that promote sustainable eating habits.

- Participate in climate strikes [0.2][1 year] Join global climate strikes to demand urgent action from governments and corporations.
- Organize climate strike movements [0.7][2 years] Lead and organize movements to mobilize large-scale public demonstrations for climate action.

- Implement climate adaptation measures [0.7][3 years] Develop and implement measures to adapt to climate change impacts, protecting communities and ecosystems.
- Support for climate-resilient agriculture [0.6][2 years] Invest in and promote agricultural practices that are resilient to climate change impacts.
- Push for monoculture farming practices [-0.8][5 years] Advocate for large-scale monoculture farming, which reduces biodiversity and increases vulnerability to climate change.

- Plant a tree [0.05][1 day] Participate in tree-planting activities to help sequester carbon.
- Community tree-planting program [0.3][1 year] Organize and engage your community in a large-scale tree-planting initiative.
- De-regulation of the wood industry [-1.5][5 years] Clear forests for agricultural or industrial development, increasing carbon emissions and loss of biodiversity.
- National reforestation program [1][5 years] Advocate for and implement large-scale reforestation projects to restore ecosystems and sequester carbon.

Appendix D: Usability Testing Form

Participant Information

- **Participant code:**
  (001/ 002/ 003/ 004...)
- **Age:**
- **Gender:**
- **Experience with VR:**
  (None/Beginner/Intermediate/Expert)
- **Experience with Haptic Feedback:**
  (None/Beginner/Intermediate/Expert)

Pre-Test Questions

1. **Have you used VR systems before?**
   (Yes/No)
2. **Have you experienced haptic feedback in any form?**
   (Yes/No)
3. **How familiar are you with climate change games or simulations?**
   (Not familiar/Somewhat familiar/Very familiar)

Test Scenarios
Please complete the following tasks in the Heatwave game. After each task, answer the corresponding questions.

Task 1: Navigation and Interaction
Objective: Navigate through the initial environment and interact with the objects.

1. **Was it easy to navigate through the VR environment?**
   (Very Difficult/Difficult/Neutral/Easy/Very Easy)
2. **How intuitive were the controls for interaction?**
   (Very Difficult/Difficult/Neutral/Easy/Very Easy)
3. **Did you encounter any issues with the VR controls?**
   (Yes/No) If yes, please describe:

Task 2: Experiencing the First Heatwave
Objective: Experience the first heatwave and observe the corresponding haptic feedback.

1. **How realistic did the heatwave feel with the thermal haptic feedback?**
   (Very Unrealistic/Unrealistic/Neutral/Realistic/Very Realistic)
2. **Was the intensity of the haptic feedback appropriate for the in-game temperature?**
   (Too Low/Low/Just Right/High/Too High)
3. **Did you encounter any issues with the haptic feedback?**
   (Yes/No) If yes, please describe:

Task 3: Decision-Making and Impact on Environment
Objective: Make decisions that affect the game's environment and observe the changes.

1. **How clear were the consequences of your actions in the game?**
(Very Unclear/Unclear/Neutral/Clear/Very Clear)
2. **Did the game effectively convey the impact of your decisions on the environment?**
(Not at all/Somewhat/Neutral/Effectively/Very Effectively)
3. **Did you feel the thermal haptic feedback accurately reflected the environmental changes?**
(Not at all/Somewhat/Neutral/Accurately/Very Accurately)

Post-Test Questions

1. **Overall, how would you rate your experience with the Heatwave game?**
(Very Poor/Poor/Neutral/Good/Very Good)
2. **How immersive did you find the combination of VR and thermal haptic feedback?**
(Not Immersive/Somewhat Immersive/Neutral/Immersive/Very Immersive)
3. **Did you experience any discomfort or issues during the test?**
(Yes/No) If yes, please describe:

4. **Do you have any suggestions for improving the VR and haptic feedback integration in the game?**

Appendix E: Usability Testing Results