

Developing a Video Game from a Prototype

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GOMES DA COSTA, Beatriz. *A 3D Pipeline for 2D Pixel Art Animation*. Bachelor's Thesis. Universitat Politècnica de Catalunya, 2023. Also available at: <http://hdl.handle.net/2117/392235>.
HEIKKINEN, Olli. *Hi-Bit Pixel Graphics – The New Era of Pixel Art*. Bachelor's Thesis. Tampere: Tampere University of Applied Sciences, 2021.
MOREIRA, Rodrigo D.; COUTINHO, Flávio; CHAIMOWICZ, Luiz. Analysis and compilation of normal map generation techniques for pixel art. *21st Brazilian Symposium on Computer Games and Digital Entertainment (SBGames)*. Natal: IEEE, 2022. p. 1 – 6. DOI: 10.1109/SBGAMES56371.2022.9961116.
SÁNCHEZ, José Luis González, et al. Playability: analysing user experience in video games. *Behaviour & Information Technology*, 2012, vol. 31, iss. 10, p. 1033 – 1054. DOI: 10.1080/0144929X.2012.710648
ULAŞ, Ekber Servet. *Virtual environment design and storytelling in video games*. PhD Thesis. 2013. DOI: 10.1386/mv-cr.4.1.75_1.

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ABSTRAKT

Práce se zaměřuje na návrh a tvůrčí proces vývoje ekologické pixel artové videohry *Revenant Earth 2*. Cílem je navázat na základy prozkoumané v mé bakalářské práci, kde vznikla jednoduchá demoverze hry, a přiblížit ji hotovému, hratelnému produktu.

První kapitola se zaměřuje na analýzu hráčské zpětné vazby a poznatků z vývoje demoverze. Druhá kapitola obsahuje hlubší výzkum fungování klimatu a ekosystému ze souvisejících vědeckých materiálů, a pojednává o adaptaci těchto poznatků na zábavné a edukativní herní mechaniky. V posledních kapitolách práce dokumentuje estetickou a tematickou rešerši, vývoj samotné hry, použité technologie, a cesty k dalšímu rozvoji projektu.

Klíčová slova: videohra, ekologie, pixel art, životní prostředí, game design, herní vývoj, výzkum, věda o klimatu

ABSTRACT

The thesis focuses on the design and creative process of developing an ecological pixel art video game, *Revenant Earth 2*. The aim is to build on the foundations explored in my bachelor thesis, where a simple demo of the game was created, and bring it closer to a finished, playable product.

The first chapter focuses on analysing player feedback and insights from the development of the demo. The second chapter includes in-depth research on climate and ecosystem functioning from related science and discusses the adaptation of these findings to create fun and educational game mechanics. In the final chapters, the thesis documents the aesthetic and thematic research, the development of the game itself, the technologies used, and the pathways to further developing the project.

Keywords: video game, ecology, pixel art, environment, game design, game development, research, climate science

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INTRODUCTION

This diploma thesis focuses on my design and creative process while developing the video game *Revenant Earth 2* – a pixel-art adventure game focusing on environmental themes in a realistic sci-fi setting. The goal of this project is to build upon the foundation explored in my bachelor thesis¹ – which was aimed at creating a simple demo version of the game – and bring it closer to a finished, playable product.

During the two years since creating the demo version in 2023, I have presented the game at numerous industry and public events and collected substantial amounts of player feedback. One of the key goals of the thesis is to analyse and adapt this player feedback for the next iteration of the game. Besides player feedback, I have also compiled a series of personal remarks and ideas during playtesting of the demo. These are also listed and considered in the thesis.

A major avenue for improvement over the original demo is in-depth scientific research into ecosystems and climate, resulting in more accurate environmental mechanics based on real-world principles. This allows the game to serve not only an entertainment purpose but also educate players and bring attention to contemporary challenges associated with climate change. Game design according to research results focuses on developing engaging game mechanics that still accurately represent reality, without getting overly constrained creatively.

The resulting video game, *Revenant Earth 2*, places the player in the role of a climate engineer, using near-future technologies combined with biological processes to restore the ecosystem of planet Earth after it has been destroyed. Its development considers in-depth scientific research, educational aspects, technical innovations, and paths to releasing the game to market, such as on the Steam online games store.

¹ MAREK, *Videohra Revenant Earth*, 2023.

1 THE INITIAL STATE OF THE PROJECT

My 2023 bachelor's thesis concluded with releasing a limited demo called *Revenant Earth*. In this chapter, I briefly describe this demo, its goals and features, and analyse if some of its approaches have been successful. This will then be used as a guideline for directing the second iteration of the game.



Figure 1: Screenshot from the current version of the demo, *Revenant Earth* (own elaboration)

1.1 Overview of the demo

The demo *Revenant Earth* is a side-scrolling pixel art sandbox game set in the future following a climate catastrophe. The player is tasked with exploring the polluted planet Earth and gathering resources, which are used to engage in the main mechanic of the demo: Planting trees to reduce environmental pollution. This pollution affects the player character in a direct way: any movement actions (walking, running, jumping etc.) in a polluted area will deduct oxygen from the player, possibly leading to the death of the character if oxygen is not replenished in time.

The other major danger in the demo are aggressive robotic enemies, which roam the world and attack the player on sight, forcing them to either flee or engage in combat.

The pixel-based environment is extensively simulated and dynamic – the player may add or remove terrain pixels of varying materials, such as soil, rock, sand, or water. These materials interact with each other (water soaks into soil), the physics system (sand falls and

forms piles), the placeable trees (trees require sufficiently watered soil to grow) and the player character (movement is blocked by solid walls of rock or soil and slowed by moving in water). The player can place or remove terrain in a very freeform way similar to drawing on a digital canvas. Removing terrain of any type grants the player a resource called “Material”, while adding terrain deducts this resource. “Material” is also used when planting trees and building structures.

The demo has no win state or conditions, but the game communicates direction of what could be considered player success: Planting enough trees to remove pollution in every part of the game map and eliminating all the enemy robots.

The only losing state is when the player character dies due to low health or oxygen, at which point the player must restart the game from scratch, as there is no progress saving system.

Technology-wise, the demo runs in the web browser supported by technologies like HTML, TypeScript and the PIXI.js library.

1.2 Player feedback

The demo version of *Revenant Earth* was presented to the public at two video game events, *GameDev Connect 2024* and *Game Access 2024*. Players had the opportunity to try the game and provide verbal feedback, which was collected and compiled into a list of remarks. It is important to note that feedback collection was not structured or comprehensive in any way, and as such the compiled feedback only serves as a rough guiding point for further development.

Table 1 presents an overview of player feedback, including direct suggestions for improvement, feature requests, or expressed enjoyment or dissatisfaction with elements of the game. Repeated suggestions of a similar nature by different players have been merged in the data, with a subjective estimate of the number of times reported.

Table 1 Player suggestions from two game events

Suggestion / feedback	Rough number of times reported
Add a practical intro / tutorial explaining the game's controls	15
Remove unskippable introduction dialogue	10
Enjoyed the visuals of the game	10
Add a game-over / fail state, ability to restart	8
Show clear warnings when low on health, oxygen or energy	8
Add a win / success state, game score	8
Enjoyed the plant / base management gameplay	8
Make it easier to avoid enemies and combat	6
Enjoyed the terrain editing gameplay	6
Enjoyed the visual feedback of removing pollution	6
Visualise where player structures can be placed	5
Found it difficult to move the character	5
Show clear warnings when in a dangerous or polluted area	5
Add a language selection option	5
Improve grass behaviour, so that it spreads naturally	5
Enjoyed the combat gameplay	5
Enjoyed the environmental context	5
Improve UI workflow, such as closing unused panels	3
Clarify the player's available resources	3
Add a species selector when planting seeds	3
Implement an online multiplayer mode	3
Visualise predicted projectile paths during combat	2
Add more biomes	2
Add more player buildings	2
Add animals	2
Add a tougher "boss" enemy	1
Add game modding capabilities	1

(source: own elaboration)

1.3 Successful elements

Collected feedback indicates that many players enjoyed the visual direction and art style of the demo, often appreciating the scenery before even engaging in any substantial game mechanics. While there are still many ways to update and improve the visual style of the game world, the general style could be considered a success.

One of the game mechanics that received positive feedback from the players was the concept of tree planting – some players considered this relaxing and creative, enjoying also the process of taking care of the plants, despite it being unnecessary in some versions of the demo. Players expressed a desire for more plant variety and a more detailed growth process, as well as the addition of animals.

A part of the player base also reported enjoying the sandbox aspect of terrain manipulation in the game – often chaotically reshaping the terrain at large scales, rendering the game world untraversable by the player character. Despite the player approval of the sandbox system, this poses significant challenges to a smooth flow of gameplay and may need to be reconsidered.

1.4 Unsuccessful elements

One feature that players consistently avoided during the playtesting of the game was the dialogue system. This system introduces story, characters and conversations in a purely text form, which saw players quickly losing attention and trying to skip past the dialogue sequences. In some instances, players abandoned playing the game altogether before the dialogue sequence could finish. This could be considered a major flaw of the demo's design and should be addressed by reimagining the story in a more visual, interactive way – possibly using cutscenes. These cutscenes could reveal the story of the game throughout gameplay, instead of providing the majority of it as exposition at the beginning, which could increase player engagement.¹

¹ GUTIÉRREZ et al., *Supporting Narrative Design in Video Games: Proposal and Case Study with an Educational Video Game: Proposal and Case Study with an Educational Video Game*, 2024.



Figure 2: Screenshot from the game *Hades* (2020), which distributes multiple story cutscenes throughout a playthrough as rewards for completing each round of the game. Screenshot by Supergiant Games through Polygon¹.

The sandbox terrain system mentioned earlier is not only unrealistic but works mostly against the game's narrative – the player is through this system encouraged to exploit and mine the environment for material gain, something that the game's themes aim to criticise in the first place. Therefore, despite players expressing enjoyment of this mechanic, it may need to be reevaluated, perhaps with terrain manipulation being restricted and in-game resources being primarily gained in an alternative, environmentally friendly way. There should, though, remain a choice for the player to make in how to approach resource gathering. Seeing consequences of environmentally damaging decisions can be a helpful learning tool to influence players' behaviour in real life. ²

Another point that players struggled with in the demo was the free-roaming enemies, whose difficulty and persistence in pursuing the player put heavy emphasis on intense combat gameplay. While the danger of well-equipped aggressive enemies to a nearly unarmed player is something I would like to keep in the game, it is an intrusive mechanic in its current form. A potential solution could see the enemy robots relegated to specific areas which the player has to consciously decide to visit, or give the player a deterrent which, while not defeating the enemies outright, could help avoid combat until the player feels comfortable dealing with it.

¹ SUPERGIANT GAMES, *Hades*, 2024.

² FENG, *How Game Ecology Drives Player Choices in Strategy Video Games: An Environmental Determinism Perspective: An Environmental Determinism Perspective*, 2024.

1.5 Going forward

While the initial demo of *Revenant Earth* proved successful in achieving some of its goals and received generally positive feedback from the players, there are many ways to improve on the introduced game mechanics and concepts.

The main goal of these changes and improvements will be to create a more coherent gameplay loop that integrates well with the setting and story. Game mechanics will be revised to better represent real-world environmental principles and challenges. Expanding the game world of *Revenant Earth 2* with a background story and referencing contemporary real-world issues according to research will help players understand the depicted events in the context of topics they encounter in common public discourse.

This can in the future be used as a framework for introducing a greater amount of content into the game, in the form of environments, quests, storylines and player progression tools.

2 RESEARCH ON CLIMATE CHANGE AND CLIMATE RESTORATION

While the initial demo had mechanics relating to environmentalism, they were implemented with a simplistic and naïve approach that doesn't map well to the issues and solutions employed in the real world. Solving climate issues was essentially reduced to planting enough trees in various map locations. However, player feedback showed that a degree of simplification helped make the topic of climate restoration more approachable and attractive in a game setting. *Revenant Earth 2* - while it is still a game set in a fictional world, dealing with climate engineering in an exaggerated, easy-to-grasp setting - has a strong focus on more accuracy in climate portrayal than the demo. Simpler game elements like plants and ground fertility are based more closely on how individuals and agencies interact with the climate in the real world, while more speculative aspects like large-scale climate engineering, reintroduction of extinct species and weather manipulation, offer more space for creative interpretation – but existing scientific research and ecological principles are still relevant as a starting point.

This section of the paper outlines some scientific research on several aspects of *Revenant Earth 2*'s setting and gameplay and discusses how they can be adapted into engaging game mechanics.

2.1 The setting

A major aspect that may undergo revision is the setting, premise and story that frames the game's goals and motivations. The original setting imagines a near future where – after decades of exaggerated worsening of climate change – humanity is forced to leave planet Earth and live in space, in greatly reduced numbers. The various ecosystems on Earth are entirely collapsed and life is non-existent in most regions. Visually, landscapes become hot, reddish deserts with a dusty atmosphere, intended to remind players of the uninhabitable planet Mars. Any life seen in the game is brought in by the player's actions, and ecosystems must be artificially sustained at first. A major source of harm is presented in environmental pollution, which can be removed from the air by filters and plants before allowing sustained presence of the player. The main danger to the player is lack of oxygen, which is presented to be closely linked to the absence of plants and the necessity of using air tanks due to air pollution.

From a storytelling and art direction perspective, this setting is visually striking and communicates the state of a climate catastrophe very clearly. The core mechanic of pollution is a very clear concept to explain and is easy to portray using devastated scenery and unnaturally coloured air.

However, the premise of life entirely disappearing from most of the Earth's surface implies an extremely destructive disaster that likely would not result from only the effects of climate change alone. The concept of ecosystem collapse, in reality, is not the complete disappearance of life, but rather a transformation into another ecosystem and a shift in which species dominate an area.¹ For instance, as described by Aladin and Potts, the Aral Sea draining collapsed the former aquatic and marine ecosystem, but it was replaced by desert and saline lake ecosystems, with newly introduced invasive species². The actual problems caused by these new ecosystems are the extinction or displacement of original species, decrease in habitability for humans, and impacts on agriculture or water supply.

In *Revenant Earth 2*, the setting is revised to include signs of some ecosystems still being present, although rudimentary and not capable of supporting human life. Water isn't entirely absent at the start of the game, although the terrain is still initially a mostly dry desert. This also allows for new avenues in art direction, as the ruined human-made structures found around the game world can show signs of damage by water, plant roots and other fauna, which makes for more interesting environments visually and is more consistent with what the audience may read as an abandoned, post-human landscape. In gameplay, pre-existing life includes scattered patches of dry grass, a limited range of soil biota – making it more plausible to introduce new plant species – and an implied presence of microorganisms.

The composition of the atmosphere has also been revised: in the demo, the air was depicted as having no breathable oxygen, which is a highly implausible scenario even in the case of mass destruction of plant life on Earth³. Oxygen content is no longer tracked in *Revenant Earth 2*, instead the main danger to the player is presented by air pollution, high temperatures and harsh weather, which are real-world problems that people in impacted communities have to deal with⁴. This is part of the general aim to bring the game's depiction of the environmental crisis closer to the real ecological challenges of today.

¹ KEITH et al., *Scientific foundations for an IUCN Red List of Ecosystems*, 2013.

² ALADIN a POTTS, *Changes in the Aral Sea ecosystems during the period 1960–1990*, 1992.

³ KEELING et al., *Impacts of Changes in Atmospheric O₂ on Human Physiology. Is There a Basis for Concern?*, 2021.

⁴ LAKHANI, *Nearly half of Americans breathing in unsafe levels of air pollutants – report*, 2025.

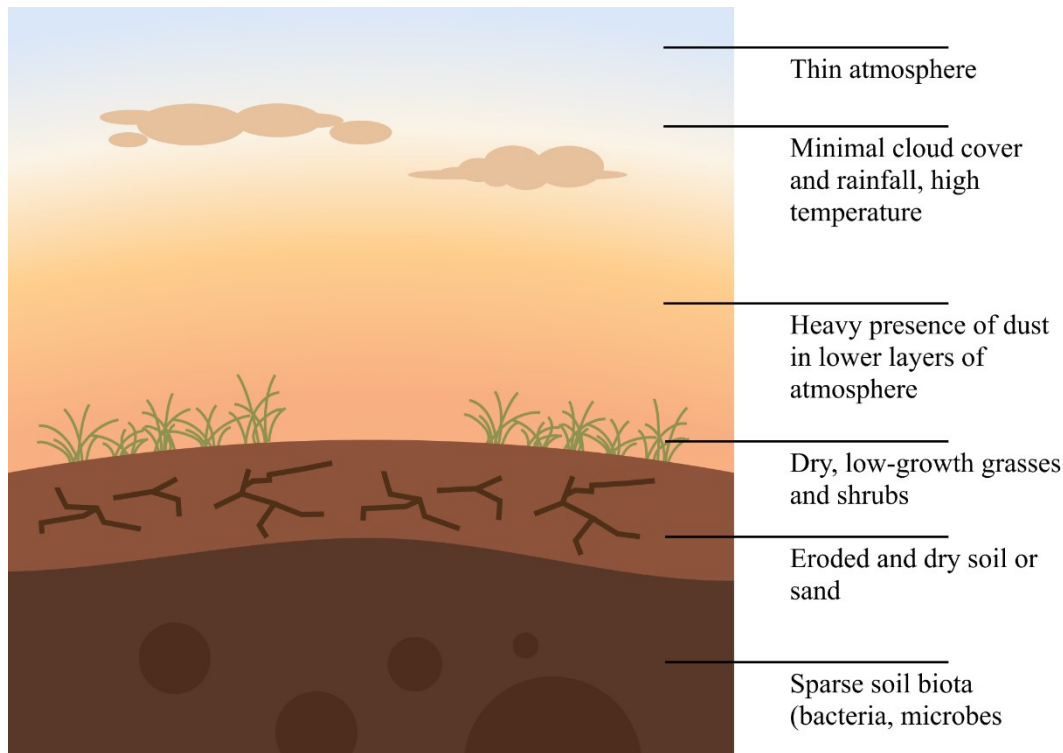


Figure 3: Diagram of the initial ecosystem state in *Revenant Earth 2* (own elaboration)

2.2 Environmental pollution

One point of inaccuracy in the original demo has been the mechanic of pollution. It is not further described beyond being harmful to the player and has a very simplistic interaction – plants can clean it from the air locally, which does not affect or propagate to neighbouring locations, and there is no visible source of the pre-existing pollution on the map.

2.2.1 Air pollution

In real-world ecosystems, pollution is defined much more specifically. Air pollution usually consists of: ¹

- particulate matter, such as dust, smoke and soot
- gases, such as nitrogen dioxide (NO₂), carbon monoxide (CO), sulphur dioxide (SO₂) or ozone (O₃)
- acidic deposition (acid rain) caused by presence of sulphates and nitric oxides in the atmosphere
- lead (Pb)

¹ VALLERO, *Fundamentals of air pollution*, 2014.

Its main harmful effect is on humans and animals, and while plants can be directly damaged by exposure to pollutants like ozone, they may be more affected by its secondary effects, such as acidic deposition from rain and sunlight reduction caused by sulphates or particulate matter. An engaging game mechanic may be found in the concept of acid rains, which will have a higher prevalence with increased air pollution and provide a dynamic weather event that the player must react to.

2.2.2 Ground pollution

Ground or soil pollution primarily consists of: ¹

- heavy metals such as mercury (Hg), arsenic (As) or lead (Pb)²
- chemicals such as solvents from industry
- fertilisers and pesticides from agriculture
- petroleum products
- radionuclides (radioactive particles) and nuclear debris

Ground pollution is closely related to water pollution, as water is the main transport vector for most of these pollutants and is also in turn affected by the presence of pollutants in surrounding soil. Heavy metals, especially, tend to have a widespread effect on marine ecosystems³, where they get deposited in organisms and travel through the food chain, acting as neurotoxins at high concentrations. This also significantly affects human populations that rely on marine ecosystems as a main source of food.

2.2.3 In-game portrayal

Since the gameplay of *Revenant Earth 2* takes place inland and places emphasis on depicting terrestrial ecosystems, implementation will mainly focus on tracking air and ground pollution, with water as a contributing factor rather than an entire system to manage.

Compared to the demo, air pollution in *Revenant Earth 2* has a less profound direct effect on plant life⁴, instead harming the player while contributing secondary effects such as sunlight dimming and acid rain. In general, it is visually depicted as dust and smog in the

¹ MIRSAL, *Soil pollution*, 2008.

² ANWETING et al., Evaluating the Concentration of Pb, Hg, Co, V, As, Fe, Cu, Cd, Cr, Mn, Ni, and Zn and their Potential Sources in Soil from Two Abattoirs in Itu and Ikot Ekpene Local Government Areas of Akwa Ibom State, *Nigeria*, 2024.

³ HÄDER et al., *Anthropogenic pollution of aquatic ecosystems*, 2021.

⁴ *Air, Animals, and Plants*, 2025.

atmosphere, with the most intense visuals inspired by real-world incidents of heavy air pollution, such as Delhi in 2024, as seen in Figure 4. It is also significantly more globalised, and air quality changes propagate to the entire game region, highlighting the importance of comprehensive solutions.



Figure 4: *Cows and buffaloes graze on fields on the banks of the polluted Yamuna river on a smoggy morning in New Delhi, India, November 5. Photo by REUTERS, Anushree Fadnavis¹*

Ground pollution in *Revenant Earth 2* is depicted mainly as heavy metals and chemicals that strongly impact plant growth and health, possibly even leading to plant death through phytotoxicity. The effect on the player is less profound than air pollution. During the game's development, I also considered a mechanic of gathering useful materials from pollutants after the player cleans them from the environment.

As further described in Chapter 4 (Development process), the two main layers – air and ground – have been designed to influence each other in multiple ways such as weather and evaporation, creating a reactive ecosystem that feels complete even without the player's involvement.

¹ FADNAVIS, *Delhi shrouded in toxic smog*, 2024.



Figure 5: Sydney Harbour Bridge during a red dust storm. Photos from real-world incidents like this serve as important visual reference when developing *Revenant Earth 2*.
Photo by John Byrne at Wikimedia Commons¹

2.3 Energy and temperature

Among the most widely discussed topics in climate science – and perhaps the most publicly visible – is the issue of global warming.² Generally, global warming is driven by an increase in atmospheric greenhouse gases like carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), which trap energy (heat) in the Earth's atmosphere. The main sources of these gases are the burning of fossil fuels, industrial processes, and land-use changes such as deforestation – which releases previously sequestered carbon back into the atmosphere. As concentrations of these gases rise, more heat is retained within the atmosphere rather than radiated into space, leading to a gradual increase in average global temperatures³. The inflows and outflows of heat energy between various parts of the Earth's atmosphere and surface can be illustrated using the concept of an energy budget, as seen on Figure 6.

¹ BYRNE, *File:SHB-Red-Dust.jpg - Wikimedia Commons: SHB-Red-Dust.jpg - Wikimedia Commons*, 2025.

² LINEMAN et al., *Talking about Climate Change and Global Warming*, 2015.

³ MASSON-DELMOTTE et al., *Climate change 2021: the physical science basis: the physical science basis*, 2021.

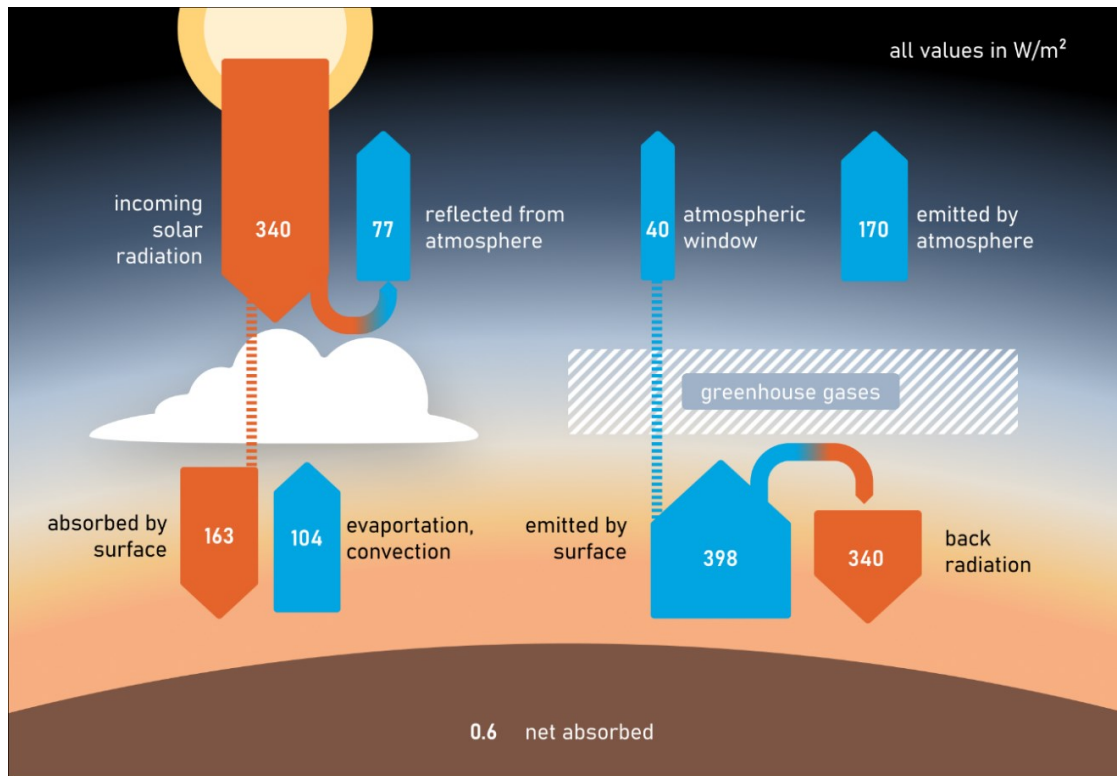


Figure 6: A simplified diagram of the “energy budget” of Earth.
(own elaboration using data from NASA¹)

All heat flux is calculated in Watts per square meter, or W/m^2 . This indicates the amount of energy received or lost over time for every square meter of Earth’s surface. When net **heat energy** is deposited into an object (in this case Earth’s surface), its **temperature** increases inversely proportional to its heat capacity.

The diagram on Figure 6 shows that the two main ways in which the surface of the Earth gains heat energy are absorbing solar radiation and receiving reflected radiation from greenhouse gases in the atmosphere. Since incoming solar radiation is constant, it is apparent that the main factor driving changes in the temperature equilibrium is indeed an increase in greenhouse gas concentrations in the atmosphere.

In climate science, the actual long-term temperature increase calculation includes a wide array of additional factors like cloud albedo², surface albedo, radiation heat loss according to the Stefan-Boltzmann law³, feedback effects and differences in the various

¹ *What is Earth’s Energy Budget? Five Questions with a Guy Who Knows - NASA, 2023.*

² Albedo is the proportion of radiation energy reflected to energy absorbed, objects with a higher albedo appear brighter as they reflect more light. The average albedo of the Earth is about 0.3, compounded from the high albedo of clouds, snow and ice, and the low albedo of oceans, urban surfaces and forests.

³ Stefan-Boltzmann law states that the thermal radiation emitted from a surface is equal to the fourth power of its temperature multiplied by the Stefan-Boltzmann constant ($\approx 5.670 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \times \text{K}^4}$).

materials constituting the Earth. A value that combines the total effect of these factors is known as climate sensitivity¹ and describes how much the global temperature will rise following a doubling of the atmospheric CO₂ concentration over pre-industrial levels. Pre-industrial levels are estimated at 260 parts per million (ppm), while the current levels² are around 427 ppm. It is expected that the CO₂ concentration could rise to over a 1000 ppm in the worst-case scenario³, resulting in a global temperature increase of 5 to 7 degrees Celsius, assuming climate sensitivity at 3°C per CO₂ doubling.

In the game design of *Revenant Earth 2*, temperature/heat is a newly introduced mechanic which was not present in the demo. Its inclusion is possibly the most important mechanical change, as almost all other in-game climate variables are linked to or directly depend on simulating temperature. Notably, temperature influences soil erosion, wildfire probability, plant health, water evaporation and thus rainfall, habitability, and wind intensity. Its importance is highlighted, as global temperature is the main general indicator of the player's progress and success. The main way for the player to control environmental temperature, as outlined in Figure 6, is capturing and sequestering greenhouse gases present in the atmosphere. A secondary, complementary approach is also offered, by which the player can artificially promote cloud formation in order to increase the planetary albedo and reflect more heat back into space. This is further described in section 2.5.4.

2.4 Plants in climate restoration

Just as much as the previously described technical and physical aspects climate change, plants are a crucial topic both from a practical and symbolic perspective. They both significantly affect and are affected by changes in the climate, act as bioindicators, phytoremediators, and importantly also as carbon sinks. Currently, it is estimated that about 500 gigatonnes (Gt) of carbon are currently stored in living plant life alone⁴, with an additional 1500 to 2000 gigatonnes stored in soil, mainly through past decomposition of dead plant matter⁵. In addition to that, plants in forest ecosystems capture around 15.6 gigatonnes of carbon every year⁶. Much of this stored carbon is also susceptible to processes such as deforestation by humans or forest fires, which release stored carbon back into the

¹ What is 'climate sensitivity'?, 2025.

² Carbon Dioxide Concentration | NASA Global Climate Change, 2025.

³ Climate Change: Atmospheric Carbon Dioxide: Atmospheric Carbon Dioxide, 2024.

⁴ NEUFELD, *Visualizing Carbon Storage in Earth's Ecosystems*, 2023.

⁵ SMITH, *Soils as carbon sinks: The global context: The global context*, 2006.

⁶ NASA Satellites Help Quantify Forests' Impacts on Global Carbon Budget - NASA, 2023.

atmosphere. Annually, this releases about 8.1 Gt of CO₂, significantly decreasing the net carbon capture potential of forests to 7.6 billion Gt per year.

Plants are also some of the forefront victims of intensifying climate change. They are integrated within complex ecosystems and can be very sensitive to changes within their environments. Plant growth and health is influenced by temperature, water availability and soil quality, and many species struggle or go extinct when these factors reach critical levels. As soils erode and hold fewer nutrients and less moisture, plant populations are reduced and forested areas recede in a process known as desertification¹. This can enter a positive feedback loop, where the reduced plant cover further contributes to soil erosion, slowly expanding arid areas over formerly fertile soil. Many plant species also depend on pollinators such as bees or other insects, and disruptions in those populations may pose a great risk to reliant plants.

The symbolism of plants is also important and generally helps players understand the game's focus on ecology and climate. This was the core principle behind the main mechanic in the demo of *Revenant Earth*, and most environmental interactions were simplified down to planting trees to clean up environmental pollution. However, gameplay overly focused on plants as problem solvers could invite misconceptions as to the role of plants in realistic climate restoration efforts.

A common misconception, also present in the original demo game, is that plants convert atmospheric CO₂ through photosynthesis in more or less constant amounts throughout their lifetime. In fact, plants photosynthesise and store carbon the most during growth periods, when it is needed as a source of energy for new cell development. This is measured as an increase in the dry mass of the plant (excluding water), which is almost entirely constituted of photosynthesised carbon molecules. This means that as plants get older and their growth rate slows, their carbon capture rate will slow and they will act more as passive carbon storage in terms of the carbon cycle². Plant growth rate could also slow or stop due to insufficient soil nutrition or moisture, meaning that even with abundant sunlight and healthy leaves, a plant might not uptake and store a significant amount of carbon from the atmosphere.

¹ IBERDROLA, *DESERTIFICATION*, 2021.

² BIELCZYNSKI et al., *Leaf and Plant Age Affects Photosynthetic Performance and Photoprotective Capacity*, 2017.

In *Revenant Earth 2*, this is portrayed in the form of an interesting innovation in game mechanics – in order to get the most out of plants as CO₂ sinks, players have to ensure their plants are not only in good health, but also actively growing and increasing in dry mass through providing adequate growing conditions. When a plant stops growing naturally, for instance due to slow age, the player may opt to permanently sequester this plant's carbon through converting it into biochar and depositing in soil. Biochar and other carbon capture techniques are further described in the following section 2.5.3.

Figure 7 shows the results of a study¹ modelling relative growth rates of four trees over time and attained volume show that growth can significantly slow down with age. Note that as this is relative and not absolute growth rate, a horizontal line would actually mean an *increase* in total volume grown per year. However, even when taking this into account, the graph indicates absolute growth slowing down over time.

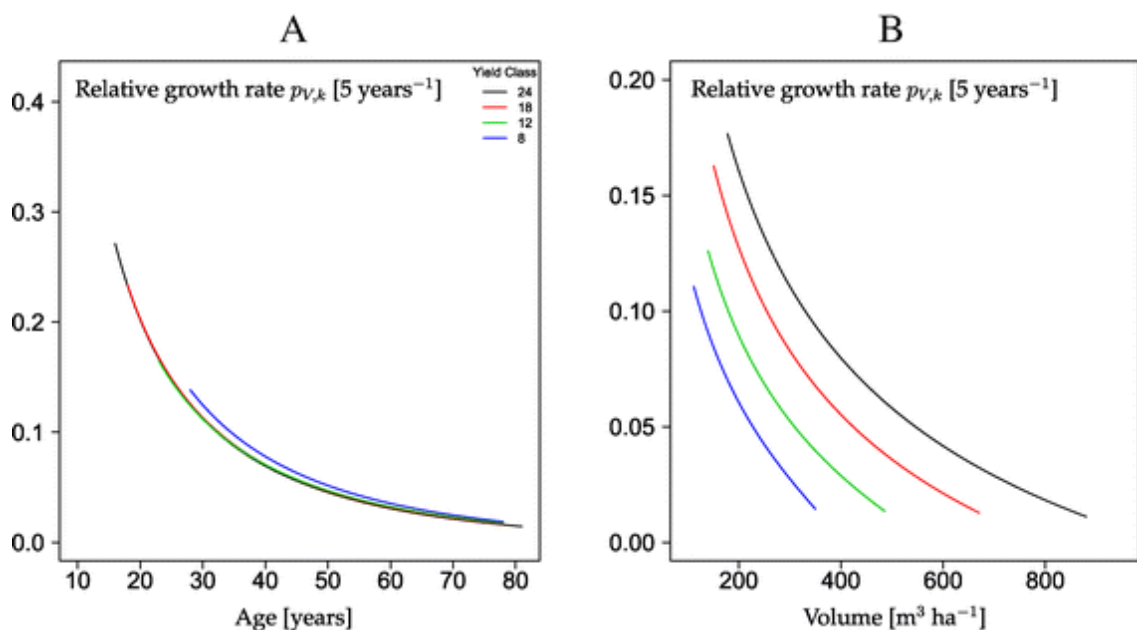


Figure 7: Relative growth rates of four trees modelled using the using the Chapman-Richards growth function².

Another key role of plants besides capturing atmospheric carbon, and perhaps more important during the early stages of ecosystem restoration that the game's initial setting focuses on, is stabilising soil, preventing erosion, fixing nutrients to soil and providing a base that other parts of the new ecosystem can thrive on. According to Espeland and

¹ POMMERENING a MUSZTA, *Methods of modelling relative growth rate*, 2015.

² POMMERENING a MUSZTA, *Methods of modelling relative growth rate*, 2015, s. 5.

Kettenring¹, plants “alleviate the impact of rapid onset effects” such as droughts or floods, by increasing soil water retention or reducing wind velocity and erosion. In the game’s setting, droughts, floods, desertification and unpredictable weather patterns are among the most important challenges for the beginning player, and careful plant selection is crucial to establishing an ecosystem capable of resisting these effects. Plant species especially valuable for this role are sometimes called *pioneer species*, signifying that they meet several criteria for surviving in harsh conditions, reclaiming land, and improving the conditions for other species to thrive in the area.

As a key to understanding the ecological strengths and weaknesses of plant species, it is important to note the most important soil properties and nutrients that constitute what is known as *soil fertility*². Besides carbon (C) and water, plants also need other nutrient elements to grow and reproduce: nitrogen (N), phosphorus (P), and potassium (K) are the three main nutrients. Some other key elements are sulphur (S), calcium (Ca), magnesium (Mg), or iron (Fe), among others. Some plant species and their symbiotic bacteria can help fix and deposit these elements into the soil or prevent their drainage from eroded soil.

2.4.1 Pioneer species

While there are countless species of plants with various degrees of viability for the pioneer role, some stand out either for their exceptional properties, or for their prominence in the discussion of land reclamation. This section outlines some suggested species and their possible roles in restoring an ecosystem, with the additional consideration of their use in a video game, and therefore a need for the species to be recognisable and sufficiently diverse in their properties.

¹ ESPELAND a KETTENRING, *Strategic plant choices can alleviate climate change impacts: A review: A review*, 2018.

² WEIL a BRADY, *The Nature and Properties of Soils. 15th edition*, 2017.



Figure 8: Sea buckthorn (*Hippophae rhamnoides*). Photo by Svdmolen at Wikimedia Commons¹

Sea buckthorn (*Hippophae rhamnoides*) is a shrub species common in Europe and Asia has many desirable properties for water and soil conservation² and is capable of thriving in harsh, arid environments. It can withstand temperatures from -43°C to $+40^{\circ}\text{C}$ or even $+55^{\circ}\text{C}$ in extreme cases³, making it ideal for cold, arid environments but also capable of surviving hotter climates. It resists droughts, salinity and poor soil properties, and functions as an atmospheric nitrogen fixer thanks to a symbiotic relationship with the bacteria genus *Frankia* – greatly improving soil fertility over time⁴. In game, this species of shrub could be one of the first complex plants the player utilises and could complement species like mosses and grasses in the initial stages. An interesting property of the Sea buckthorn is that it bears edible fruit – potentially supporting animal life in addition to the previous benefits.

¹ SVDMOLEN, *Hippophae rhamnoides-01 (xndr).JPG* - Wikimedia Commons, 2025.

² RONGSEN, *Seabuckthorn - A multipurpose Plan Species for Fragile Mountains*, 1992.

³ ENESCU, *Sea-buckthorn: a species with a variety of uses, especially in land reclamation*, 2014.

⁴ BRAȘOVAN a CODREA, *Data on Coal Dumps Retrieving in Petroșani Basin Using Sea Buckthorn (Hippophae Rhamnoides)*, 2008.



Figure 9: Fire moss (*Ceratodon purpureus*). Photo by Claire Halpin at The British Bryological Society¹.

Fire moss (*Ceratodon purpureus*) is a species of moss known for its extraordinary resistance to pollution and poor soil quality². It thrives in dry, sandy and disturbed soils, burned ground, and urban rubble. It helps stabilise soil and retain water in areas with extremely harsh conditions. In game, it could serve as an initial colonisation plant in areas with heavy pollution or low moisture – serving as a first step in the preparation of areas for further development.



Figure 10: Silver moss (*Bryum argenteum*). Photo by Illinois Wildflowers³.

Other moss species, such as *Bryum argenteum*, *Funaria hygrometrica* and *Tortula muralis* could exist as in game alternatives to this moss with a similar function and performance, but different visual appearance, with green and silver colours.

¹ HALPIN, *Ceratodon purpureus* - British Bryological Society, 2023.

² RICHARDSON, *The biology of mosses*, 1981.

³ *Silver Moss (Bryum argenteum)*, 2017.

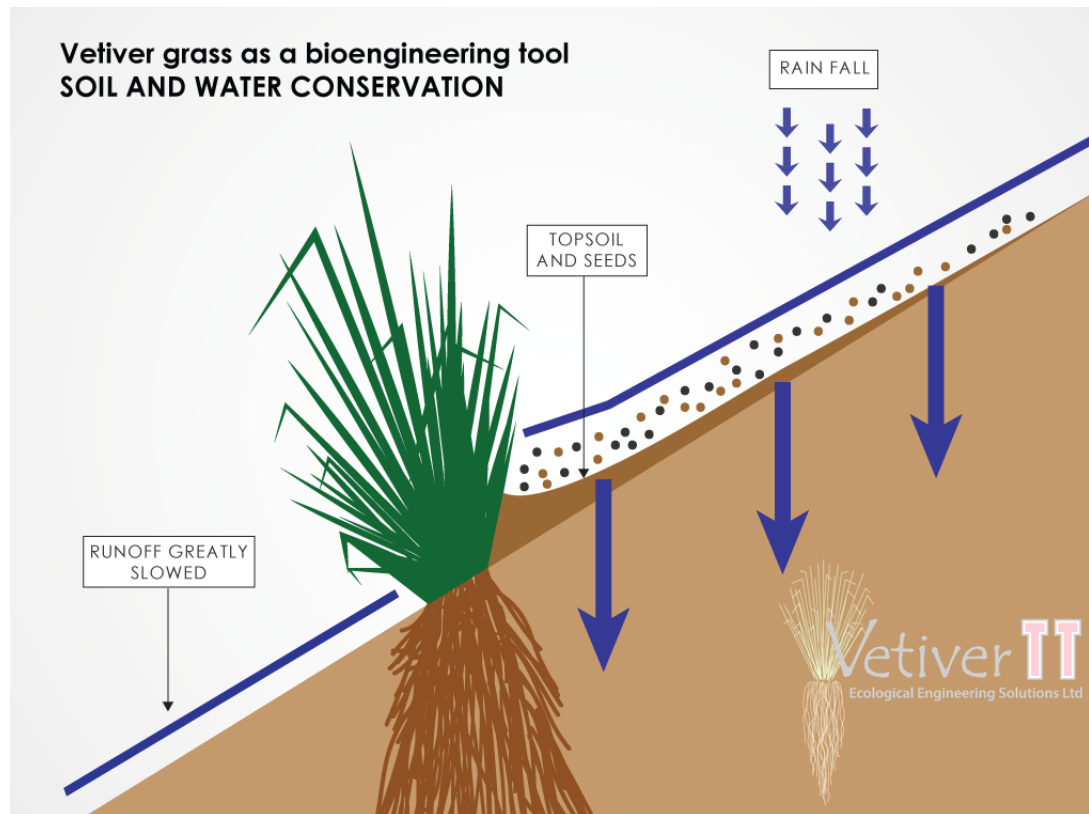


Figure 11: Vetiver grass and its contribution to soil stabilisation. Source: The Vetiver Network West Indies¹.

Vetiver grass (*Chrysopogon zizanioides*) is a perennial grass species with excellent erosion control properties. Its roots may reach deeper than some trees² and stabilise the soil. Compacted soils may also be penetrated and loosened by the roots of this grass, improving their quality and water infiltration. Vetiver grass prefers sandy soils and is tolerant to drought, salinity, and floods. Its ideal temperature range is +15°C to +55°C, meaning it is better suited for hot regions and may perish in excessively cold weather. A technological system of soil conservation called the Vetiver System has been developed around this plant, consisting of hedgerows of vetiver grass planted on eroding slopes. It may reduce rainfall runoff by as much as 70%³. In game, it could be useful in especially eroded soil where pollution is low to moderate, and also function as a fast-growing source of biomass in later stages.

¹ *The Vetiver System (VS) - The Vetiver Network West Indies*, 2019.

² TRUONG et al., Vetiver Systems Application, *Technical Reference Manual. The Vetiver Network International*, 2008.

³ COUNCIL, *Vetiver Grass: A Thin Green Line Against Erosion: A Thin Green Line Against Erosion*, 1993.



Figure 12: Black poplar (*Populus nigra*) in Poland. Photo by Kenraiz at Wikimedia Commons¹.

Poplars (*Populus*) are a genus of trees that include the subspecies of poplars, aspens and cottonwoods. They grow very fast for their mass and are useful in climate restoration in multiple roles². The poplar is suitable for phytoremediation (capture of pollutants from the environment) and can store harmful pollutants in its trunk such as industrial solvent chemicals or trace elements of heavy metals. Thanks to its fast growth, the poplar can quickly capture and store atmospheric carbon, which can be harvested in short growth cycles and permanently stored using methods such as biochar. However, poplars are quite vulnerable to heat, droughts and pests, meaning that in the context of game progression in *Revenant Earth 2*, they may be utilised as high-performance plants in later stages, after basic soil stabilisation and restoration has been performed.

There are many more species viable for the role of *pioneer species* besides the ones described in this section. However, the outlined selection of one shrub, moss, grass and tree species provides a base array of plants with interesting differences that could form the core selection within the in-game environmental progression system of *Revenant Earth 2*. Their specific implementation into game mechanics is further discussed in chapter 4.

¹ KENRAIZ, *Populus nigra* kz1 - Wikimedia Commons, 2025.

² DOTY et al., *Enhanced Degradation of TCE on a Superfund Site Using Endophyte-Assisted Poplar Tree Phytoremediation*, 2017/09/05.

2.5 Technology in climate restoration

As Earth's ecosystems degrade and the climate undergoes anthropogenic shifts, the changes may reach a point where restoration through purely natural means is no longer possible or sufficient. To alleviate this issue, technological approaches are being developed that complement or enhance natural restoration processes. They range from directly supporting and managing plant species to stand-alone mechanisms like direct air capture of CO₂ or influencing weather patterns¹.

However, technological processes can also work in the opposite direction, acting as a source of pollution, greenhouse gases, and requiring extensive resource extraction. The existence of climate change itself can be attributed to technological advancements and the resulting industrial development², and even in modern attempts to mitigate its effects, new technological solutions can introduce unintended consequences or deepen existing environmental problems.

In the context of the near-future science fiction game setting of *Revenant Earth 2*, established, newly introduced and speculative technology represents a significant portion of the player's toolset for restoring the climate. Within the story of the game, humanity becomes existentially reliant on technology while living in space, while self-replicating technology occupies the nearly lifeless surface of planet Earth and presents a danger to human attempts at exploration. The game portrays speculative, large-scale efforts such as terraforming, climate engineering and weather manipulation, some of which are analysed in this section.

2.5.1 Terraforming, climate engineering and ecological restoration

The idea of terraforming describes deliberate, large-scale hypothetical efforts to transform environments of other planets on a massive scale, in order to bring those environments closer to that of Earth, making them habitable for humans or other terrestrial life³. It is an idea in the realm of science fiction, as no real-world efforts of this magnitude are currently being planned or considered, with doubts as to whether they're even possible. In a sci-fi video game, however, terraforming presents an interesting theme. A twist that *Revenant Earth* puts

¹ ROYAL SOCIETY a ROYAL ACADEMY OF ENGINEERING, *Greenhouse gas removal*, 2018.

² LYNAS et al., *Greater than 99% consensus on human caused climate change in the peer-reviewed scientific literature*, 2021.

³ BEECH, *Terraforming: the creating of habitable worlds: the creating of habitable worlds*, 2009.

on the idea is that within the game's story, partial terraforming is being applied not to other planets in space, but to Earth itself – to make its environment more habitable as it once was.

Related terms to terraforming include climate engineering and ecological restoration¹ - the latter implies a much more realistic scope and viability than terraforming and is more frequently discussed in academic works and policymaking. *Ecological restoration* is a current process practiced in areas with damaged or degraded ecosystems and aims to create conditions that support a natural return of the ecosystem to its historic trajectory². In contrast, *climate engineering* directly aims to influence environments and ecosystems to reach a desired state within shorter timescales, using technologies like direct air capture, cloud seeding or planetary albedo modification. This approach requires far more resources, funding and research, and comes with additional risks – artificial modification of ecosystems can backfire in unpredictable ways.

In contrast with more grounded natural processes, while mostly a theoretical concept, climate engineering presents a stronger theme for a video game like *Revenant Earth 2* – both as a more attractive exploration of ideas, and as a better fit for the fast-paced time scale of a game. Care will be taken during development to ensure that technologies portrayed in game are still within the realm of plausibility and to prevent the creation of “magic solutions” using speculative future technology. Players should be able to see and test the effectiveness of various climate restoration approaches, and not all of them need to be portrayed as effective and safe.

2.5.2 Harmful technology

While *Revenant Earth 2* is set in the future and depicts speculative technologies, it still is intended to relate in-game events and principles to current issues in the real world. A key climate issue today is the continued release of greenhouse gases, pollutants and waste into the environment. As seen on Figure 1Figure 13, the main contributor to emissions by far is the energy sector, particularly energy for industrial purposes and fuels for transport. Most climate change mitigation scenarios require as a first step a significant reduction of the world's greenhouse gas emissions, and offsetting of the relatively low volume of remaining emissions, to reach so-called carbon neutrality or “net zero” emissions. However, if a widespread reduction in emissions is not achieved, all proposed climate restoration methods

¹ JACKSON a HOBBS, *Ecological restoration in the light of ecological history*, 2009.

² *Restoration Resource Center What is Ecological Restoration?*, 2025.

(such as carbon capture, forest planting, ocean fertilisation) will not be capable of offsetting the net emissions below neutral level, meaning climate change would continue to worsen.

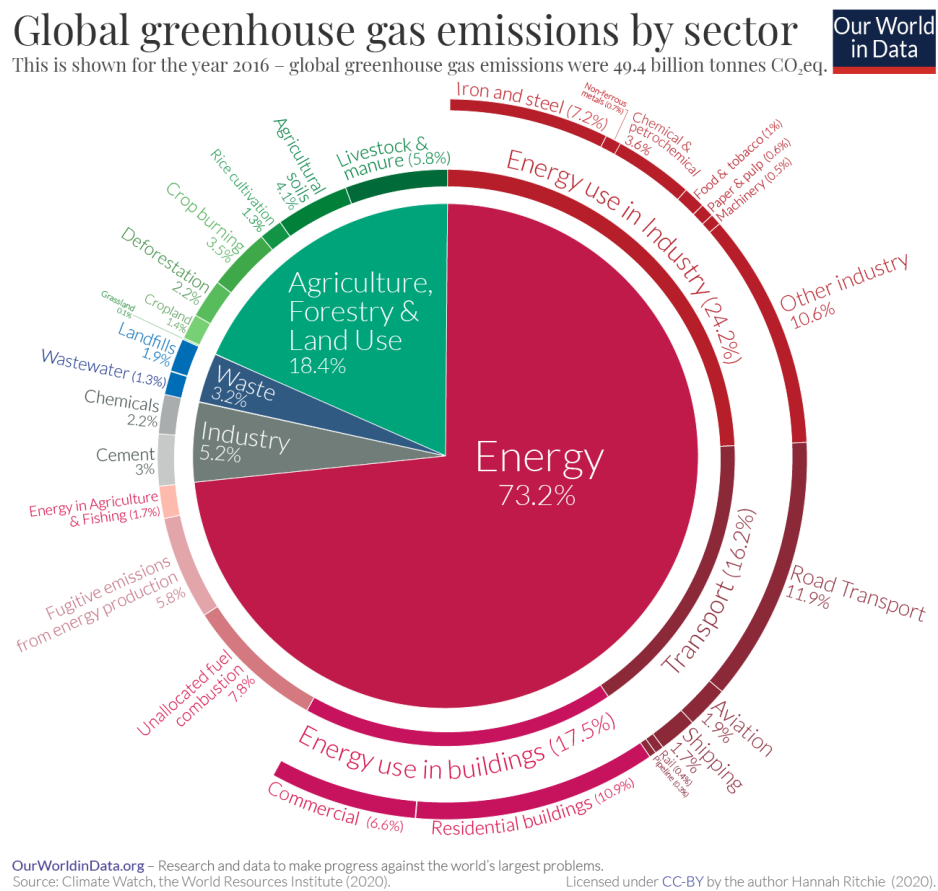


Figure 13: Global greenhouse gas emissions by sector. Graph and data by Hannah Ritchie at Our World in Data¹.

In the scenario presented in *Revenant Earth 2*, human population on Earth is practically non-existent, which would conceivably also reduce active greenhouse gas emission sources to near zero. While this is a realistic consequence of the presented scenario, it is lacking from a game design and educational perspective: the player's path to resolving residual climate change effects would be dramatically different from the real-world path global society needs to take to tackle this crisis. A source of active CO₂ emissions and pollution present in the game world would challenge the player to first make steps towards stopping those emissions, before engaging in more novel, restorative activities. An in-game narrative element that can satisfy this role is the presence of robotic enemies, which has already been established in the first iteration of the game. This narrative is expanded in *Revenant Earth 2* to depict evolving and self-replicating robotic enemies based in automated factories from times of human

¹ RITCHIE, *Sector by sector: where do global greenhouse gas emissions come from?: where do global greenhouse gas emissions come from?*, 2020.

settlement. The robotic factories are set up to produce unnecessary products for companies that are no longer present or manufacture more copies of military robots that act as enemies to the player. They operate without consideration for their environmental effects and thus represent heavy polluting industry that continually reverses the player's climate restoration efforts until dealt with. The player may try to destroy or disable them directly – or alternatively replace their energy supply to run on renewable methods to avoid confrontation. This mechanic is further discussed in chapter 4.

2.5.3 Carbon capture

As the main greenhouse gas component of climate change, atmospheric CO₂ is the focus of many mitigation strategies. The most common and natural way of capturing carbon is through photosynthesis in plants, as described in section 2.4 above. However, technological methods to reduce or capture carbon emissions can be deployed to enhance natural processes or substitute them in situations where plants would struggle or prove impractical. Their effectiveness is usually limited by material or power requirements, and most are prohibitively expensive to deploy at meaningful scales – but they are being utilised and continuously developed today, with the promise of increased efficiency in the near future. In the fictional setting of *Revenant Earth 2*, these substitutes are particularly attractive, as complex plants initially struggle in the harsh conditions. The player can thus progress in reversing the temperature anomaly while the local ecosystems are still largely dysfunctional.

This section is an overview of some prominent carbon capture technologies with a comparison of their current viability and their viability within the game world of *Revenant Earth 2*.



Figure 14: A direct air capture plant. Concept art by Carbon Engineering¹.

Direct Air Capture (DAC) is the process of extracting diffused CO₂ from ambient air using chemical processes, separating this CO₂ and storing it away while releasing the rest of the captured air into the atmosphere². It functions using a variety of sorbent materials that bind CO₂ onto themselves chemically or mechanically. These can include hydroxide solutions, resins or metal-organic frameworks. After capturing, heat, pressure, or humidity changes are applied to release the bound pure CO₂ and reuse the sorbent. Captured carbon can then undergo long term storage or utilisation in industrial processes like synthetic fuels. DAC has been successfully deployed by companies like Climeworks and Carbon Engineering. However, the process is very energy intensive³, requiring up to 2 MWh per ton of captured CO₂. This brings the cost to about \$600 to capture one ton of CO₂, which is a barrier to extensive deployment – but as atmospheric concentrations of CO₂ increase, the process of DAC gets more efficient. In comparison, it only costs about \$40 to \$60 in burned coal or natural gas to emit one ton of CO₂ – illustrating the economic difficulty of offsetting current carbon emissions without first reducing them. A benefit in comparison with planting trees as a carbon capture method, about 50 trees are required for similar capacity as one DAC

¹ Carbon Engineering | *Direct Air Capture of CO₂* | Home, 2023.

² HERZOG, *Direct Air Capture*, 2022.

³ MAZZOTTI et al., *Direct air capture of CO₂ with chemicals: optimization of a two-loop hydroxide carbonate system using a countercurrent air-liquid contactor: optimization of a two-loop hydroxide carbonate system using a countercurrent air-liquid contactor*, 2013.

plant (roughly 1 ton per year). The land area taken up by deploying DAC is also dramatically smaller than the land area needed to plant trees of equivalent CO₂ capture capacity.

In *Revenant Earth 2*, DAC is a moderately expensive, energy-intensive technology available to the player to build as a complementary addition to plants early in the game, quickly reducing the worst of the initial levels of CO₂ before they can be stabilised using other methods. Players need to build accompanying renewable energy infrastructure such as wind turbines and solar panels to power DAC, and their in-game material cost means that only a small number of units are available in the first stages of gameplay. Further use of DAC is an optional approach for players who may be more interested in experimenting with technological solutions to climate change, rather than managing a growing forest. However, it does not replace plants for purposes such as stabilising soil, moderating wind and improving soil fertility.



Figure 15: Biomass pyrolysis plant. Photo by Beston Pyrolysis Plant¹.

Biomass pyrolysis is the controlled thermal decomposition of biomass (such as harvested wood, leaves etc.) without the presence of oxygen to prevent burning². The resulting product is called **biochar**, a form of charcoal that is very stable and can be stored indefinitely. This process complements plants as a CO₂ capture method: after plants attain sufficient mass by growing and absorbing atmospheric CO₂, they are harvested and processed rather than being left to decompose or burn – which would release much of the CO₂ captured by the plant back

¹ Biomass Pyrolysis Plant - Sustainable Biochar Production, 2025.

² AU - WILSON et al., Producing, Characterizing and Quantifying Biochar in the Woods Using Portable Flame Cap Kilns, 2024.

into the atmosphere. By processing them through pyrolysis, all of the plants' carbon is instead separated and outputted as biochar. The land cleared up by the harvested plants can then be used for a new growing cycle, continuing to capture atmospheric carbon.

When added to soil, biochar can improve soil quality and fertility, giving it a double use besides capturing carbon. This makes it a beneficial technique in agriculture and small-scale farmers can utilise biochar kilns to produce biochar at low costs. Benefits include increased water retention, erosion mitigation, and reduced methane emissions from soils¹.

In *Revenant Earth 2*, the player can build biochar kilns or biomass pyrolysis reactors, then harvest surrounding plants and process them while planting new ones to continue sequestering CO₂. These technologies are energy- and cost-efficient and slightly improve nearby soil quality, but require the player to have already sufficiently grown plants in the area, making the method quite slow and more useful as a component of repeated, long-term growth cycles. Unlike DAC, the direct benefit is relatively small, while the supportive role is much more important. Use of biochar is optional in-game, but without it plant growth will eventually reach a limit and as plants start to decompose or catch fire, their progress in capturing carbon will be reversed.



Figure 16: BECCS plant in Stockholm, Sweden. Photo by Beccs Stockholm².

Bioenergy with Carbon Capture and Storage (BECCS) is a related concept to biochar. Similarly, it processes biomass, but unlike the previous method of pyrolysis, biomass is burned with the presence of oxygen. This does not produce a stable compound like biochar, but the volatile reaction of burning can be utilised for energy production. The combustion process emits CO₂ in gas form, but the gas is captured and stored before it can escape into

¹ WANG a WANG, Preparation, modification and environmental application of biochar: A review, 2019.

² WRETBORN, About Beccs Stockholm - Beccs Stockholm, 2025.

the atmosphere, preventing emissions. A BECCS power plant converts the heat generated from burning into clean electricity, potentially replacing the need for fossil fuel electricity generation. BECCS is usually done on a much larger scale than biomass pyrolysis and does not output any agriculturally valuable materials – however it has the same benefits of processing grown plants instead of letting them decompose¹. Resulting captured CO₂ is compressed in gas form and stored underground.

In *Revenant Earth 2*, the utility of BECCS is limited – the player has initially very little need for larger amounts of electric energy, therefore a full-scale BECCS power plant would not fill a particular need – especially compared to small-scale biochar with agriculturally useful outputs. The construction of an entire power plant is also out of scope of the game, where player construction is generally limited to deploying compact, pre-packaged technologies. However, a theoretical smaller-scale, portable BECCS power plant could provide interesting utility as a power source for a DAC device.

Many more technologies exist and continue to be developed in the field of carbon capture, but the three prominent ones featured above constitute a solid foundation for presenting such technologies in-game, while fitting into the gameplay patterns in *Revenant Earth 2*. Potential future development of the game could consider carbon capture technologies such as ocean alkalinity enhancement, the Fischer-Tropsch process or mineralisation.

2.5.4 Weather manipulation

Besides contemporary, commercially deployed technologies for managing climate change, there are more ambitious projects that could directly influence weather patterns at large scale, with potential benefits of great magnitude for targeted ecosystems. Some have been deployed at smaller scale already, while some are in the realm of theory². In the sci-fi near future setting of *Revenant Earth 2*, these technologies are made available to the player, who can experiment with their use and consequences. Weather manipulation technologies, despite having specific stated benefits, can also carry drawbacks and unintended consequences. Both these aspects and the in-game value of some technologies is described in this section.

¹ GOUGH a UPHAM, *Biomass energy with carbon capture and storage (BECCS or Bio-CCS)*, 2011.

² COUNCIL et al., *Critical issues in weather modification research*, 2004.



Figure 17: Hygroscopic salt flares released below a cloud during a routine cloud-seeding mission on January 31, 2024 in Al Ain, United Arab Emirates. Photo by Andrea DiCenzo at Getty Images through NBC 6 South Florida¹.

Cloud seeding is the process of dispersing small particles with specific properties in the atmosphere above a specified area, with the goal of inducing cloud formation and subsequent rain or snow. The particles act as condensation nuclei, points around which water vapour already present in the atmosphere can start condensing, creating a basis for clouds that can then continue growing by natural condensation. The particles usually utilised are silver iodide (AgI), potassium iodide (KI) or salt (NaCl). The effectiveness of cloud seeding is unclear according to current research², with some research suggesting the effect is negligible or none, while others claim it can increase precipitation by up to 15%³. Nevertheless, it is commonly practiced at small scales today, with the goal of either inducing desirable rain or preventing undesirable rain at a later point in time. Aesthetically, it presents an interesting concept for a fictional setting, with hypothetical future technology bringing its effectiveness above negligible levels. A point of concern for both the current and the hypothetical future implementation is that the particles used for cloud seeding could act as pollutants, especially if used repeatedly over the same area.

In game, cloud seeding is available to the player as an early technology when weather patterns are still unstable, as a possible source of water for the initial plant colonies and a way to trigger early rain to avoid disastrous floods later on. However, every use of cloud seeding in *Revenant Earth 2* also increases the air pollution, potentially harming the very

¹ SETH BORENSTEIN, *Did cloud seeding lead to unprecedented floods in Dubai?*, 2024.

² *Cloud Seeding Technology: Assessing Effectiveness and Other Challenges: Assessing Effectiveness and Other Challenges*, 2025.

³ JANET PELLEY, *Firm footing for cloud seeding*, 2022.

plants the rain is supposed to support. While the effectiveness is brought up from current disputed levels, it is up to the player to weigh the utility of this speculative technology against its costs and drawbacks.

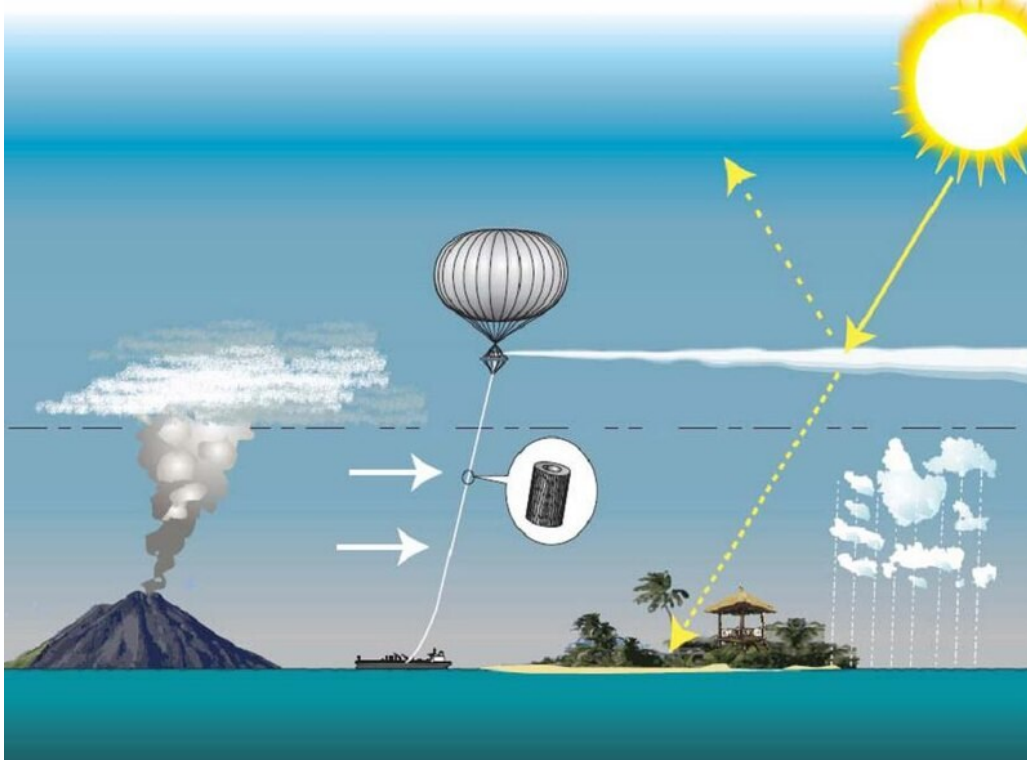


Figure 18: An illustration of stratospheric aerosol injection being deployed, and its simplified effects. Graphic by Hughhunt at Wikimedia Commons¹.

Stratospheric aerosol injection (SAI) is a hypothetical climate engineering technique related to cloud seeding, although with a different aim. It consists of releasing aerosols such as sulphur dioxide (SO_2) or hydrogen sulphide (H_2S) into the stratosphere (the second lowest layer of the atmosphere, about 10-50 km above ground), forming bright mist and fog that increase the Earth's albedo, thus reflecting more sunlight into space resulting in a cooling effect on the surface below. SAI can be compared to the natural process of large volcanic eruptions, which cover large areas of the atmosphere in dust and aerosols, temporarily cooling the planet by up to 0.5°C in historic cases. It can provide a fast and relatively cost-effective way to lower global temperatures, mitigating the global warming symptom of climate change². However, SAI does not contribute to alleviating the root causes of global warming, nor does it counteract or remove greenhouse gases from the atmosphere in any

¹ HUGHHUNT, *SPICE SRM overview.jpg* - Wikimedia Commons, 2011.

² HALSTEAD, *Stratospheric aerosol injection research and existential risk*, 2018.

way¹. Therefore, it is not a sustainable method to combating climate change, rather a potential temporary measure to be complemented by a more robust climate restoration strategy. There are also concerns about side effects of disrupting global weather patterns and introducing new air pollutants – potentially harming ecosystems in unpredictable ways².

In *Revenant Earth 2*, stratospheric aerosol injection is a technology available to the player as a temporary ability, rapidly reducing the temperature in the game world for a time. This can be useful during extreme weather events, or to protect early plants from excessive heat. Similarly to cloud seeding, every use of SAI also has negative consequences, which the game models as increased air pollution and reduced effectiveness of photosynthesis and solar panels due to less available sunlight.

In summary, weather manipulation technologies in *Revenant Earth 2* present a way to experiment with unusual, hypothetical scenarios and technologies, and provide the player with engaging ways to directly affect the environment at a large scale. The instability and scientific uncertainty of these techniques is also reflected with drawbacks, ensuring that they do not become trivial “silver bullet” solutions to in-game climate challenges.

¹ HULME, *Climate change: Climate engineering through stratospheric aerosol injection: Climate engineering through stratospheric aerosol injection*, 2012.

² HUYNH a MCNEILL, *The potential environmental and climate impacts of stratospheric aerosol injection: a review: a review*, 2024.

3 RESEARCH ON RELEVANT CURRENT GAMES

This chapter overviews a selection of currently published games that relate to the concept *Revenant Earth 2*, either by sharing the genre, thematic and topic of climate change, or by being prominent artistic inspirations in innovative pixel art. Significant research on related works has already been done in 2023 during my bachelor thesis for the previous iteration of *Revenant Earth*. Due to many of those findings still being current and relevant in 2025, this chapter seeks to avoid redundancy and serves mostly as a briefer update on any newly developed works with this subject matter, or findings that were previously omitted or missed.

3.1 Games depicting climate restoration or climate themes

3.1.1 Terra Nil

(Free Lives, 2023)



Figure 19: Gameplay of *Terra Nil* (2023)

Terra Nil is one of the most prominent video games with ecological themes currently on the market. It is a strategy game where players are tasked with restoring ecosystems from barren wastelands using buildings placed on tiles. It features management of water, soil, energy, plants and animal life. An interesting aspect of its gameplay is that the player must carefully deconstruct and recycle their buildings after completing a level, thus encouraging responsible climate management with a minimal footprint.



Figure 20: The newly updated world map in *Terra Nil* (2023)

While *Terra Nil* was already mentioned in the bachelor thesis for the first iteration of *Revenant Earth*, and served as inspiration for the demo, it remains one of the leading examples of modern climate games and continues to be updated by its developers. A major update, titled *Vita Nova*¹, was released in June 2024, introducing a deeper system of interactions with animals, animal migration mechanics, and a new world map displaying overall game progress and available levels.

The 3D game map of *Terra Nil: Vita Nova* is of particular interest to me while developing *Revenant Earth 2*. It takes the form of a planetary globe, divided into regions that represent the individual game levels available to play. It combines multiple layers of information into one view: level selection, restoration progress and ecosystem info for each level, and a combined overall metric of game completion titled “Restoration progress”. As players restore ecosystems in each region, they can see their progress visually reflected on the planet view, gradually getting greener and more colourful instead of the initial desaturated brown colour. I considered a similar approach for *Revenant Earth 2* for a future scenario where the game contains multiple playable regions set on a fictionalised Earth map.

¹ *Terra Nil* - 🖱️ THE TERRA NIL VITA NOVA UPDATE IS HERE! 🖱️ - Steam News, 2024.

3.1.2 Plan B: Terraform

(Gaddy Games, 2023)



Figure 21: The planetary view in *Plan B: Terraform* (2023)

Plan B: Terraform is a large-scale resource management strategy game focused on the concept of terraforming. It presents a scenario where humanity is facing a climate catastrophe on Earth but takes the approach of relocating to another planet instead of trying to salvage Earth. The player is tasked with terraforming and adapting this new planet to better suit human settlement, transforming it from an arid planet resembling Mars to a living world with greenery, water and a functioning ecosystem. While it has strong climate engineering themes, the environment of a new, uninhabited planet means that many of the approaches depicted are dramatically different from those applicable to Earth. For example, while climate management techniques on Earth focus on reducing greenhouse gas emissions and cooling the planet down, *Plan B: Terraform* instead has the player *increase* greenhouse gas emissions to warm up the exoplanet's cold atmosphere. The game simulates temperature, weather, river flow and ocean formation, vegetation, as well as a growing human population living on the planet while it's being terraformed.

Despite the difference to Earth in depicted goals and techniques, the game still places emphasis on environmentalism and responsible development, and models environmental changes using the same scientific basis that applies to Earth.



Figure 22: The detailed view in *Plan B: Terraform* (2023)

An aspect of this game that was particularly interesting to me during development of *Revenant Earth 2* is depicting large-scale climate engineering efforts and their consequences on an entire planet. Even though a technology may not be directly applicable or beneficial to real-world Earth, it is still interesting to experiment with and can provide players with insight into real-world climate principles. The game's tiered approach to the climate engineering process, which slowly introduces new mechanics and complexities, was also an inspiration for the game progression of *Revenant Earth 2*.

3.1.3 SAI Simulator

(Irvin et al., 2024)

Apart from entertainment-focused video games, climate themes are also often depicted in serious games, simulators, or tools that do not belong in the category of games. One such example is *SAI Simulator*, a climate modelling tool with slight game elements, developed by Irving et al.¹ and the Reflective organisation. It focuses on deep simulation of scenarios relating to the deployment of stratospheric aerosol injection (SAI, detailed in section 2.5.4 above) and its consequences on the planet². The user interaction is very simple, consisting of a set of sliders and choice selectors such as target cooling and global geopolitical conditions where the user can input a SAI deployment strategy to be simulated. The tool

¹ IRVIN, *Stanfordmlgroup/planet-parasol-demo: Initial release: Initial release*, 2024.

² REFLECTIVE, *Simulating the impacts of SAI deployment – Reflective*, 2024.

then processes the data in real-time, displaying both a global temperature map and a predicted graph of yearly average temperatures and water statistics. The tool models individual regions and calculates grid-based results for the entire planet. Users can compare the simulated scenario with SAI deployment with a predicted baseline scenario where SAI is not deployed.

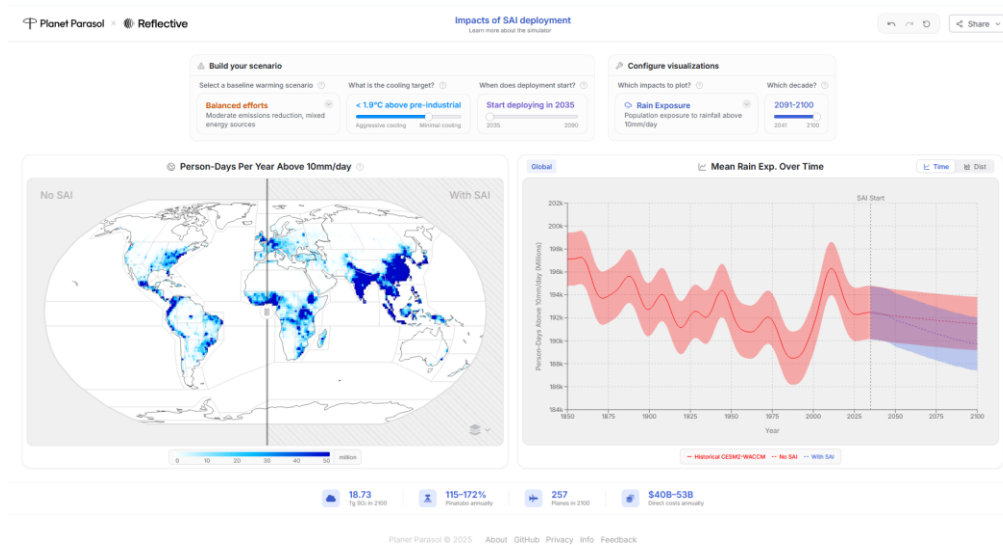


Figure 23: *SAI Simulator* (2024) interface

Tools such as this, while not games, can serve an educational or entertainment purpose for curious users who can use them to experiment with hypothetical scenarios or imagine the results of policies they would like to see implemented.

In the development of *Revenant Earth 2*, I attempted to incorporate detailed simulation inspired by tools like this, but in a real-time game setting where players do not input values using sliders but influence them using game mechanics.

3.2 Artistic inspiration

3.2.1 Replaced

(Sad Cat Studios, TBA – upcoming)



Figure 24: A promotional screenshot from *Replaced* (TBA).

Replaced (also stylised as REPLACED) is an unreleased cyberpunk sci-fi action platformer with an innovative approach to pixel art. The game features “2.5D” graphics where hand-drawn pixel art sprites are placed in a 3D environment with advanced lighting effects, reflections and camera animations. The game is still in development and has released gameplay trailers and screenshots to the public, showcasing the world and art style. The developers describe the game’s art direction as “cinematic” – scene composition, lighting, colour, movement and camera placement are all very controlled and designed to evoke the aesthetics of a film production rather than a conventional game.

The dynamic lighting and colour direction in particular stand out to me as inspiring elements: the developers seem to prioritise them over the clarity and readability of a scene, which appears to tie into gameplay design that doesn’t demand clear vision of a scene to move around and play the game efficiently – perhaps by reducing available movement directions to left and right and limiting player interactions during particular scenes intended more as a visual artwork than a playable challenge.

For *Revenant Earth 2*, I considered adopting similar rendering technology to allow 2.5D scenes and significantly more control over lights and camera motion. This was later reconsidered due to time and technical constraints and would be more appropriate for a work solely focused on experimenting with visual style in pixel art games. Nevertheless, *Replaced* remains a strong visual inspiration for *Revenant Earth 2*, and some of my game's natural backgrounds and lighting effects are inspired by the strong art direction of *Replaced*.



Figure 25: A screenshot from the trailer for *Replaced* (TBA).

3.2.2 The Last Night

(Odd Tales, TBA – upcoming)



Figure 26: A promotional screenshot from *The Last Night* (TBA)

The Last Night is an unreleased pixel art platformer game with a visual style similar to that of *Replaced*. It has also been described as “cinematic” and makes heavy use of 2.5D

rendering technology, dynamic lighting and camera work combined with hand-painted pixel art sprites in a cyberpunk setting. It takes direct inspiration from films like *Blade Runner* and has dark, atmospheric art direction. The game has been announced in 2014 and is still in development, having gone through significant visual style evolution during that time.

Similarly to *Replaced*, this game serves as an inspiration in how much pixel art can be combined with novel and cinematic rendering techniques.

3.2.3 Cast n Chill

(Wombat Brawler, 2025 – upcoming)



Figure 27: A lake scene in *Cast n Chill* (2025)

Cast n Chill is a relaxing fishing game where players can choose from a variety of fishing locations and catch fish through low-intensity gameplay, with an optional that automates the fishing process entirely – allowing the game to focus on well-developed aesthetics that casual players can enjoy. The game is notable for its atmospheric depiction of nature and water surfaces, and its emphasis of visuals over gameplay.

For my work, I took inspiration from this game especially in its detailed natural scenes and its approach to merging a visually deep “above water” view with a flattened, gameplay-oriented “underwater” view with a prominent water line as separation between the two perspectives. A similar approach is used in *Revenant Earth 2* for merging the game’s landscape views with the cutaway underground layer that displays soil properties.

3.2.4 Signalis

(rose-engine, 2022)



Figure 28: Gameplay of *Signalis* (2022)

Signalis (also stylised as SIGNALIS) is a sci-fi survival horror video game inspired by retro *PlayStation 1* visuals combined with high-fidelity pixel art. Players take the role of a “biosynthetic clone” called a *Replika* and explore 2.5D isometric levels themed around abandoned facilities divided into individual screens with static camera placement¹.

The game features cinematic cut-scenes, which utilise a combination of fully 3D graphics and 2D animation, often based on strong typography used as a main visual element. Themes of identity, culture and totalitarianism influenced stylistic choices, reflecting on the prominent red-black colour palette and on the typography, which often blends typeface characters from English, Chinese and German in a single composition.

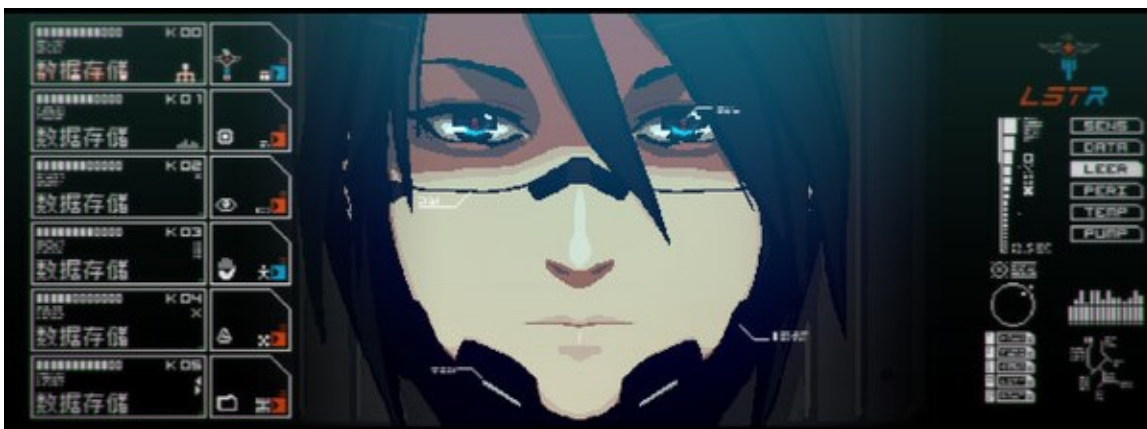


Figure 29: A cut-scene showcasing the graphical UI style of *Signalis* (2022)

¹ SIGNALIS on Steam, 2025.

During gameplay, characters are animated and rendered in low resolution 3D graphics stylised as pixel art, and composited into scenes consisting of 2D textures with static pixel art. The game has a technically interesting lighting system that interacts with both the 2D scenes and the 3D characters, including shadows cast from one onto the other. Apart from the standard top-down 2.5D horror gameplay, the game also features occasional first-person 3D interactive sequences, which serve as puzzles or tie into cut-scenes as a storytelling element.

The user interface and graphic design of *Signalis* is rendered in pixel art, utilising the aforementioned red colour and multilingual typography as some of its main elements. Within the user interface, there are commonly present decorative elements resembling graphs, charts and console readouts, adding detail to UI screens beyond the information necessary for gameplay.

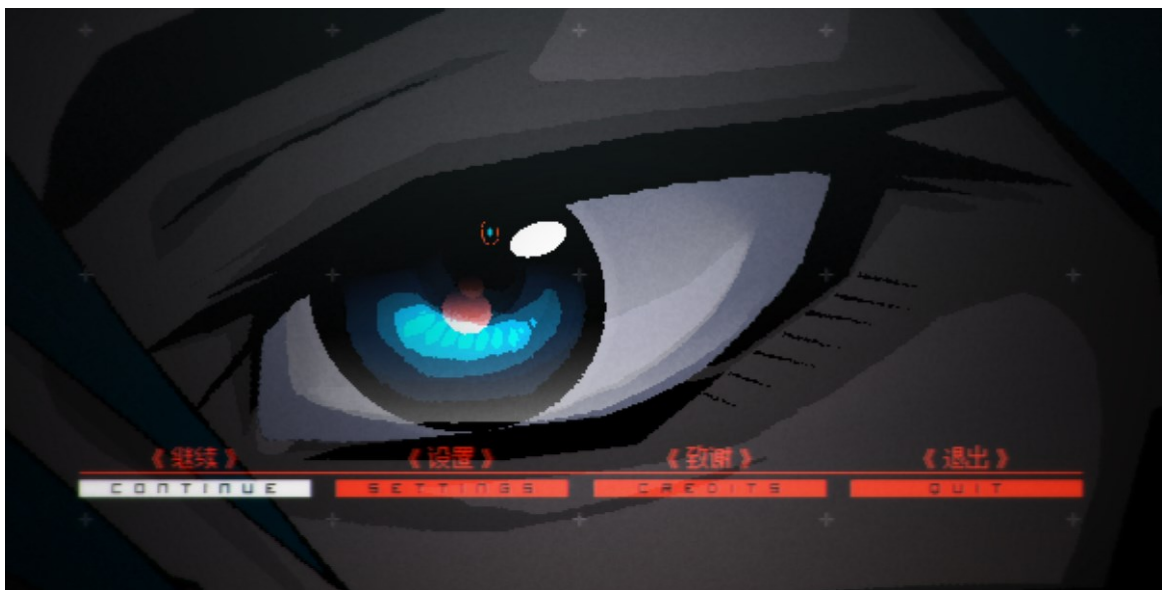


Figure 30: The main menu screen of *Signalis* (2022)

For my own work on *Revenant Earth 2*, this game is an inspiration especially for its seamless blending of 2D and 3D, transitioning between different camera modes during gameplay, and the graphic design of the user interface. Some elements of *Revenant Earth 2*'s in game HUD are inspired by the flat colour boxes and decorative graphical elements seen in *Signalis*.

4 DEVELOPMENT PROCESS

This chapter describes the design and development of the practical part of this thesis – the video game *Revenant Earth 2*. It is a side-scrolling pixel art adventure game following the climate restoration of Earth after an ecological catastrophe. Real-world research and relevancy to current climate challenges were key factors in designing the game, as well as aiming to improve on many aspects of the original demo version from 2023, based on player feedback and own elaboration.

4.1 Initial concepts

The first ideas and visions for the game were strongly formed by artistic inspiration listed in section 3.2 above, with the ideas then being based around a *graphical* overhaul of the demo, while game mechanics were not a major focus. Graphics would be remade closer to 2.5D or 3D rendering, and features like volumetrics and advanced lighting would be implemented. After initial testing and feedback analysis, I concluded that the planned graphical improvements would require more development time than appropriate, to the detriment of the rest of the project.

After this conclusion, the focus of *Revenant Earth 2*'s development became game mechanics, accuracy, a potential educational aspect, and simulation depth – all interesting parts of the original demo that could be significantly improved upon.



Figure 31: An early concept of *Revenant Earth 2*, rendered in the software Blender
(own elaboration)

4.2 Game design

With the new development goals, a core focus of *Revenant Earth 2* has been well-planned, systematic game design centred around climate research results, environmental simulation and interaction with the player. Game mechanics evolved from the demo version's linear progression system of a single metric (pollution) controlled by a single interaction (planting trees) into a non-linear *system*, where variables influence each other more complexly and the player has a wider array of tools to affect those variables.

4.2.1 Cause-effect model

According to this philosophy, the main loop was redesigned around the principle of cause and effect. This is a common methodology used in scientific research to describe, for instance, the behaviour and changes of complex ecosystems. Figure 32 below illustrates an example of a cause-effect diagram used as an ecosystem model for the Aral Sea.

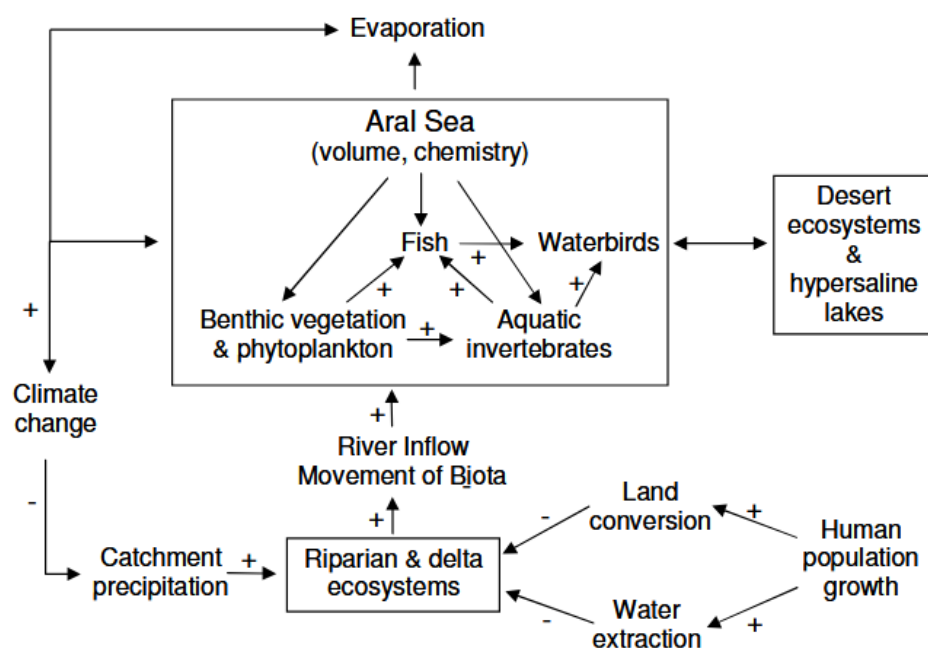


Figure 32: Cause-effect model of ecosystem dynamics for the Aral Sea by Keith et al.¹ A similar model was designed to document the the game flow of *Revenant Earth 2*.

In cause-effect diagram like this one, different factors are interlinked with arrows signifying positive or negative influences. Note that a “positive” influence means an increase or intensification in the affected factor, and not necessarily a positive or desirable outcome from an overall ecological perspective.

¹ KEITH et al., *Scientific foundations for an IUCN Red List of Ecosystems*, 2013.

In *Revenant Earth 2*, cause and effect simulation happens on the scope of several *layers*: Air (atmospheric properties), Soil (terrain and ground properties), Weather (temporary environmental events), Plants (generally any living part of the ecosystem), and Technology (non-natural effectors built by the player or present on the map). Properties or elements within the same layer often interact with other layers in similar ways: For example, air properties generally do not influence soil properties directly but affect them by causing weather events. According to this scheme, I developed a cause-effect model (Figure 33 below) to serve as the core of the game design of *Revenant Earth 2*.

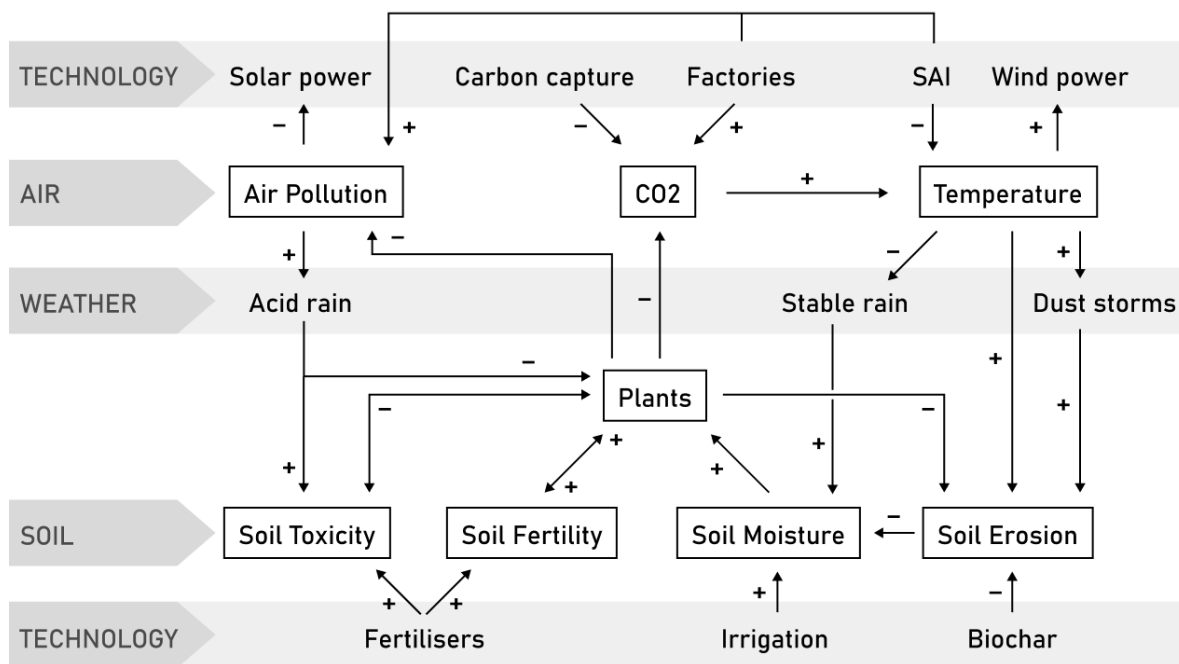


Figure 33: The cause-effect model documenting the different game elements in *Revenant Earth 2* and their interactions. (own elaboration)

Many of the technologies described in chapter 2.5 can be seen here as game elements that the player can directly control. Those in turn affect weather, air and soil properties that the player has no direct control of. Plants serve as the central element connecting the various layers and serve as a key indicator of game progression. They are directly managed by the player but grow and react to the environment on their own, eventually dying or reaching maturity and spreading seeds without the player's involvement.

There are smaller closed-off feedback loops within the game flow of *Revenant Earth 2*, such as the cycle of plants – CO₂ – temperature – dust storms – soil erosion – soil moisture – plants. This is an example of a *positive feedback loop* – where the outcome of an action (plant growth reducing CO₂) intensifies the original action (better conditions for more plant growth). There are also *negative feedback loops* – where the outcome slows down or reverses

the original cause. An example within the game is wind turbine power output decreasing as temperature drops and weather patterns stabilise, thus reducing the available power for carbon capture technologies and slowing down further temperature reduction. Positive feedback loops are appropriate for core game mechanics as they give feelings of progress, while negative feedback loops are appropriate for secondary mechanics and stimulate innovation and finding different approaches.

4.2.2 Environmental simulation

The relations between player actions and their effects on the ecosystem are governed by an environmental simulation system. This tracks all the various properties of soil and atmosphere and updates them over time to match the current state of the game. The simulation system also tracks and creates weather events such as rain and storms, making sure they reflect atmospheric properties.

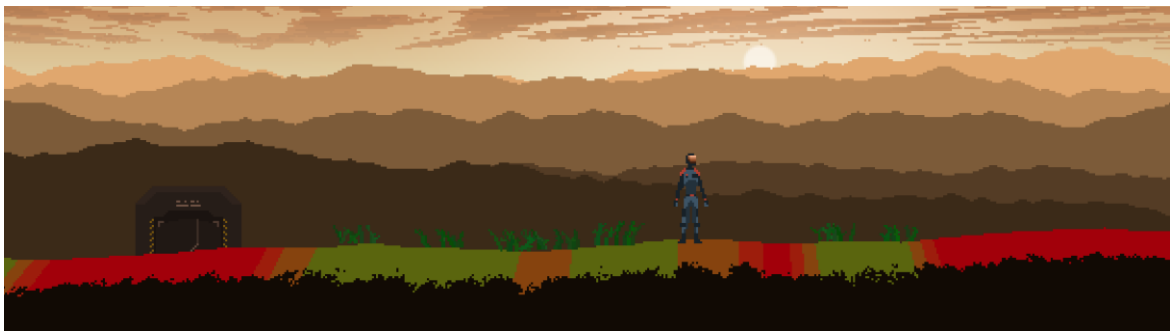


Figure 34: An in-game inspection view showcasing soil erosion values in the simulation.
(own elaboration)

The player is equipped with tools to analyse the changes in the simulation over time, such as charts and graphs. Certain variables within the simulation are also tracked as “progress variables”, which means improving them yields game score and advances progress tiers.

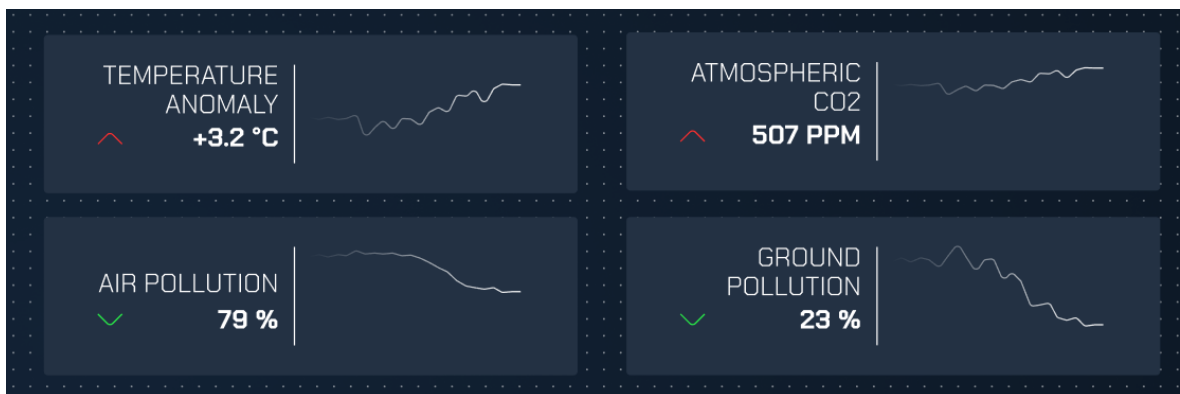


Figure 35: Environmental variables tracked in-game (own elaboration)

Below is an overview of the properties being tracked and their effect on the game:

- **Atmospheric CO₂** is a key value and the main cause of climate change. It has a profound effect on temperature. It is tracked globally for the whole region.
- **Atmospheric temperature** is calculated from CO₂ over time and is the most important value for weather simulation. High temperatures cause unstable weather, droughts, soil erosion and other undesirable effects. Reducing atmospheric temperature is one of the ultimate goals of the game. It is tracked globally for the whole region.
- **Atmospheric pollution** represents both toxic pollutants and large dust particles. It has the most effect on the visual appearance of the environment. High pollution causes acidic rains, directly harms the player, and obscures visibility, which lowers solar panel efficiency. It is caused by existing sources at the start of the game and removed using plants or filters. It is tracked locally for every coordinate in the game.
- **Soil erosion** represents how capable the soil is of holding water, nutrients and its own mass. It is caused by high temperatures that dry and crack the soil and intensified by weather conditions such as dust storms. Plant roots very efficiently reduce erosion in the soil they are growing in. It is tracked locally per terrain point.
- **Soil moisture** is the presence of water held in the soil, which fluctuates a lot over time. It is increased by rain or irrigation and decreased as plants use the water or as it evaporates. If a soil has high erosion, it cannot hold water and the water will quickly evaporate. Without moisture, plants will struggle to grow and eventually die. It is tracked locally per terrain point.
- **Soil fertility** is the presence of nutrients that plants need in the soil. It is necessary for the stable and quick growth of plants, but already grown plants require only minimal fertility to survive. It is consumed by plants, but some plants like nitrogen fixers can also increase it. High erosion causes nutrients to wash away. It is tracked locally per terrain point.
- **Soil toxicity** represents harmful pollutants in the soil. Plants regardless of growth stage get damaged by soil toxicity, but some plants known as phytoremediators can absorb soil pollutants and store them within cells, slowly clearing up toxicity. Toxicity can also increase due to acid rains and pollutant spills. It is tracked locally per terrain point.

4.2.3 Progression system

Revenant Earth 2 is divided into rough progression tiers and milestones, which help separate the game's complex and transformative process of climate restoration into smaller, more easily understandable goals – which helps both during the game's design process and during gameplay. Within each progression tier, the player has a given set of goals and tools to approach them, which get progressively more complex as the ecosystem builds up. Mechanics are thus slowly introduced, and old mechanics phased out to avoid repetition.

This section lists the progression tiers within *Revenant Earth 2*. Each has an accompanying illustration portraying the key environmental changes in that stage.

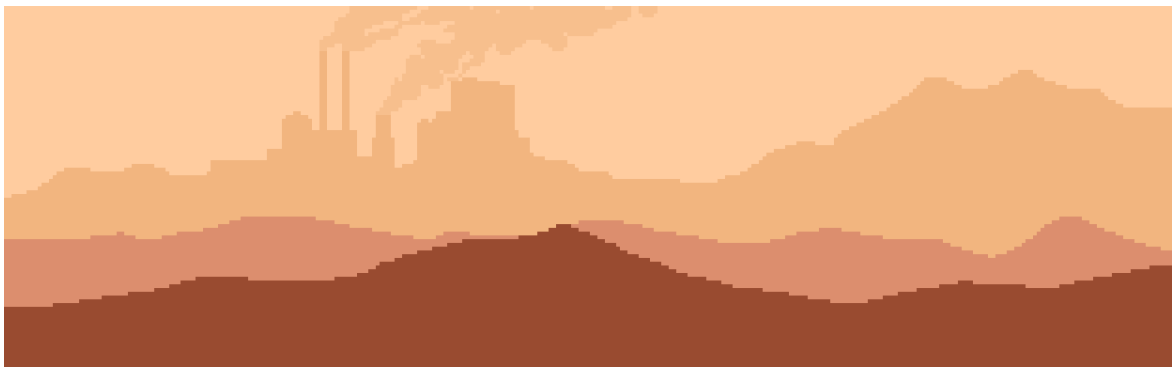


Figure 36: Tier 1 illustration (*own elaboration*)

Tier 1: introduction, exploration and survival

The player is dispatched from their base in orbit and lands on the deserted surface of planet Earth. There are minimal signs of life and the air is so polluted that the player character needs protective gear and periodic breathing air resupply. There is also dangerous harsh weather due to the high temperatures disrupting weather patterns. The player can scan the environment and see that while most properties remain static, there is a source of air pollution and CO₂ somewhere in the region and is given the task to find it. This one of the autonomous factories that represent obsolete industry that the player needs to disable in order to stabilise the environment and start improving it.

The other task of this tier is to find appropriate locations for pioneer species of plants – spots that have lower soil erosion or higher fertility than the rest. While the player receives basic plant seeds from their base in space, there are also salvageable containers that contain seeds of unique plant species.

Milestones in this tier: First day survived, Successfully disabled a pollution source

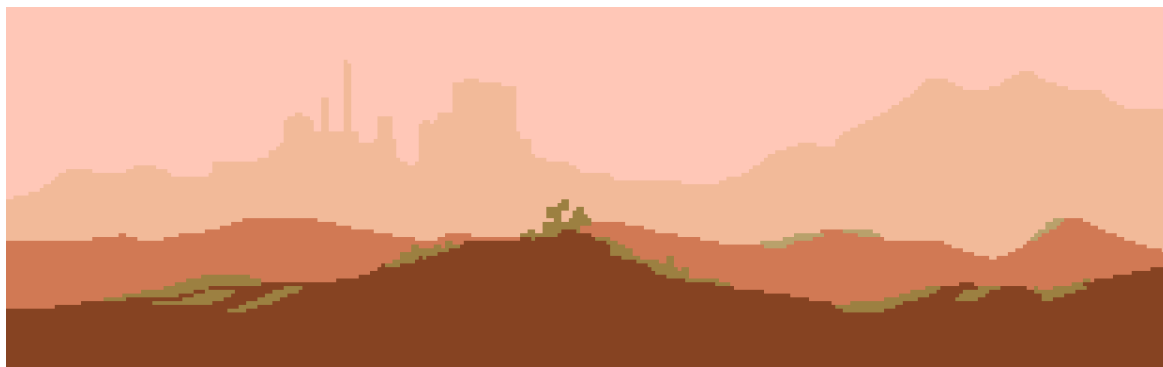


Figure 37: Tier 2 illustration (*own elaboration*)

Tier 2: pioneer species, soil stabilisation, temperature reduction

Once a suitable spot is found, the player can select from their available seeds the species that fits the location the most. Appropriate species for this phase include mosses, lichens and certain types of grass. These have minimal requirements to survive and their main purpose is to slowly reduce soil erosion for future planting cycles. To support these pioneer species, the player can start deploying fast-acting technologies such as SAI to temporarily reduce temperature or fertilisers that temporarily improve soil fertility, although inefficiently as the eroded soil cannot hold nutrients well. After soil has been sufficiently stabilised, the player can move on to the next tier.

Milestones in this tier: First seed planted, First plant reached maturity, Successfully improved soil quality

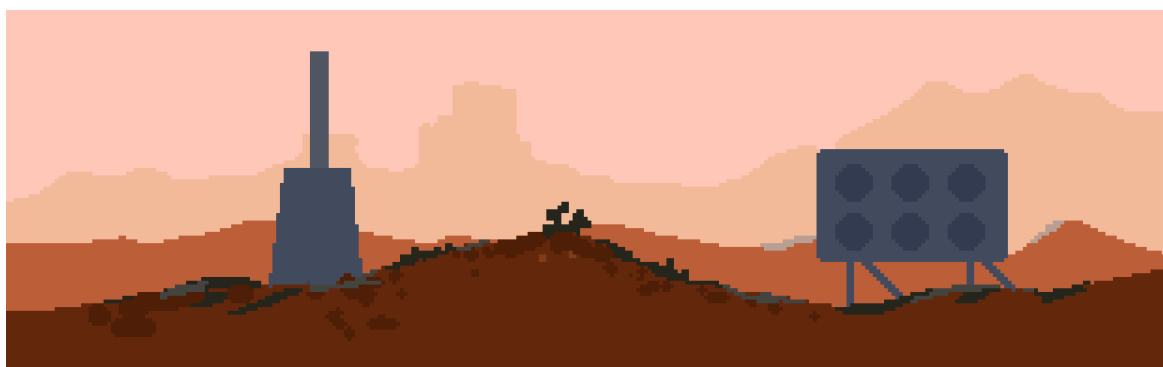


Figure 38: Tier 3 illustration (*own elaboration*)

Tier 3: biochar, fertilisation, carbon capture

After succeeding with the first cycle of plants and proving their viability, the player is rewarded with new technologies sent from the space base: a biochar kiln and a DAC unit. The first generation of plants can now be harvested and processed into biochar, ensuring that their captured carbon gets stored in the soil, further decreasing erosion and improving

fertility. Later on, the player can also choose not to use biochar and instead let the plants decompose, which increases soil fertility more but releases most of the plants' captured CO₂ back into the atmosphere. At the start, however, composting is not available because there is no established soil biota that would facilitate the decomposition process. The player can either find biota samples in the world or order them from space in exchange for score.

More complex plants like shrubs can now be planted in the higher-quality soil, capturing more CO₂ and stabilising soil even more. However, the player has to be careful not to over-extend the water supply or soil nutrients, as these are still scarcely available at this stage. Irrigation systems can be built to capture the irregular rain and distribute it to plants over longer drought periods.

The air pollution also slowly starts to decrease at this stage, as pollutants settle on the plants' leaves or drain into soil through acid rains, where they get absorbed by phytoremediator plants. The player can explore further thanks to this.

Milestones in this tier: First biochar cycle, First ton of CO₂ captured, First complex plant



Figure 39: Tier 4 illustration (*own elaboration*)

Tier 4: species diversification, weather stabilisation, greenery expansion

After a few cycles of growth, biochar and carbon capture, the atmospheric CO₂ starts to drop and temperatures lower slightly. The air is also significantly cleaner, improving the health of both plants and the player. Thanks to this success, new shipments can be ordered from the space base, containing new technologies, flowering species of plants, and pollinator insects that can be bred to support the new plants. With these advancements, the area suitable for greenery expands considerably and the player now manages a small self-sustaining ecosystem.

The main challenges in this stage are still-unstable weather patterns, hot temperatures, and making sure that the expanding ecosystem is stable and doesn't destabilise or lose species diversity.

The player is encouraged to introduce new species of plants and insects, utilise cloud seeding technology to stabilise weather and rainfall temporarily, and explore to find new resources and seeds.

Milestones in this tier: First insect colony, First clean rainfall, First pollination



Figure 40: Tier 5 illustration (*own elaboration*)

Tier 4: reforestation, animal reintroduction, technology recycling

Once conditions are sufficiently improved and weather is more stable, the player can introduce larger trees and begin reforestation at scale. Trees capture significant amounts of CO₂, speeding up climate restoration. They also provide habitats for various animal species, which can be reintroduced by cloning genetic data from planetary vaults or the space station. With the reintroduction of complex ecosystems and expansion of green areas over most of the playable region, atmospheric quality is improved and the climate gradually returns to a natural state. This is the final tier of the game, after which the region is marked as completed and the player is awarded a victory. The game implies that following this, sustainable human settlement can start in the region, and other regions can be accessed to expand the restored areas.

Milestones in this tier: First tree, First large animal, Stabilised weather, Restored the ecosystem

4.2.4 Resources, score and currency

Since the gameplay of *Revenant Earth 2* focuses on sustainability and ecology, resources and scarcity need to play an important role in limiting the player. However, as explored in the demo version, resource extraction or mining mechanics are counter-productive to the idea of the game. There are a few options for resources that are both sustainable to create in-game and fit the gameplay need of rewarding ecological progress. One option is that players still acquire physical resources, but the extraction is limited to recycling waste and gathering pollutants from the environment without disrupting the natural resources present. However, this leads to a sustainability problem – once players run out of accessible waste to recycle, they may start wanting to overexploit the other natural resources to advance quickly.

An alternative that avoids sustainability pitfalls is to completely replace the concept of “physical resources” with a virtual currency or score that is awarded to the player for completing desirable actions such as planting trees, cleaning pollution or exploring new areas. This ensures that players don’t need to harvest any resources to progress and can be immediately rewarded for every action up until the game’s end. This is similar to experience (XP) systems common in role playing games. In *Revenant Earth 2*, this currency is called RP or *reputation points*. Story-wise, it represents trust that the player has gained with project supervisors aboard the space station. It serves both as the game’s currency and overall score. As currency, it can be used for purchasing technology shipments from the space base, which deducts RP from the player’s balance. As overall score, the total number of gained RP is accumulated and isn’t deducted when the player purchases something. This accumulative score is also used for determining the player’s *rank*, which is both a cosmetic achievement and a tiered system of unlocking upgrades.

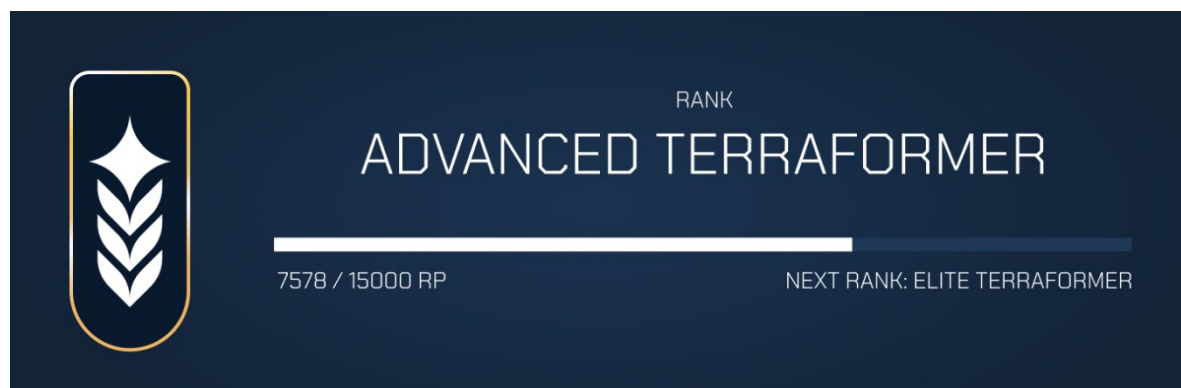


Figure 41: In-game reputation points (RP) tracker (*own elaboration*)

4.2.5 Inventory

Anything that the player purchases with RP or salvages while exploring the game world is stored in the inventory. This includes plant seeds categorised by species, deployable technology like DAC units, and player equipment like suit breathing tanks. Items can be selected in the inventory to learn additional information, or (in the case of seeds and deployable technology) directly summoned in the game world to activate placement.

Purchasing items for RP is done using a similar interface. After selecting items to buy, RP is deducted but the item is not immediately added to inventory. Instead, an orbital drop pod appears on the game map and the player needs to reach it to receive the contents. This helps tie the virtual “shop” back into the game world and avoid a feeling of “magically” creating items in the game.

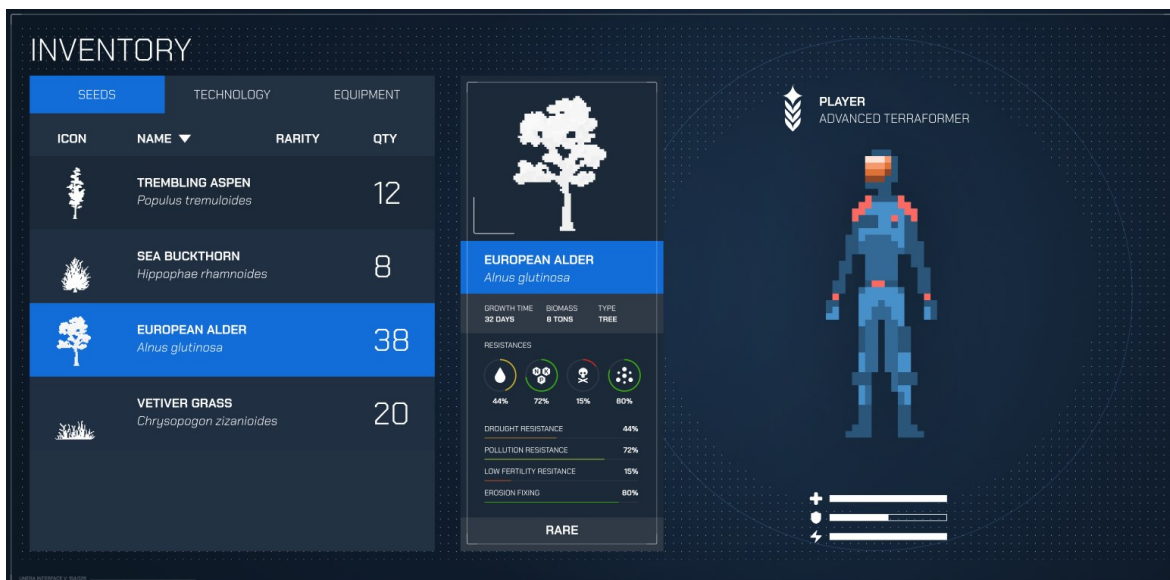


Figure 42: The in-game inventory screen overview (*own elaboration*)

Items have detail cards that show additional information when inspected either in the inventory screen, or in the game world. The amount of detail on these cards has been changed multiple times during development, as well as the way numerical values are presented. Figure 43 shows two iterations of detail cards with text-based and icon-based displays.

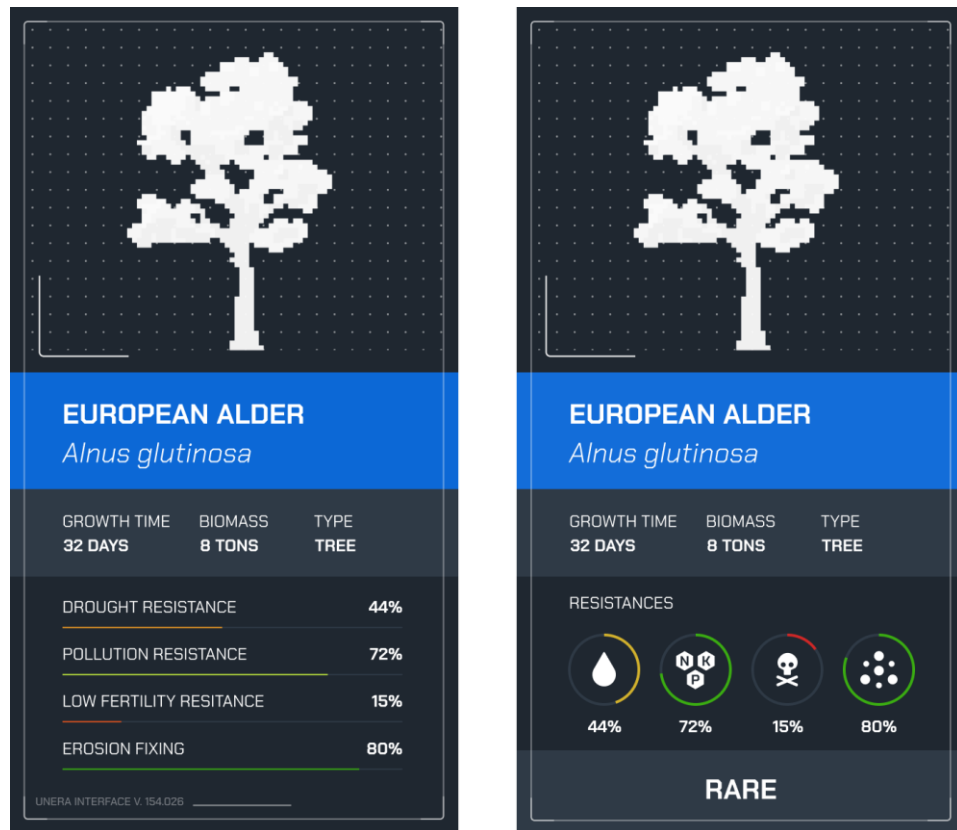


Figure 43: Two concepts of detail cards for in-game plant species. (own elaboration)

SEEDS		TECHNOLOGY	EQUIPMENT
ICON	NAME ▼	RARITY	QTY
	TREMBLING ASPEN <i>Populus tremuloides</i>		12
	SEA BUCKTHORN <i>Hippophae rhamnoides</i>		8
	EUROPEAN ALDER <i>Alnus glutinosa</i>		38
	VETIVER GRASS <i>Chrysopogon zizanioides</i>		20

Figure 44: The in-game inventory screen interface displaying a selection of plant species (own elaboration)

4.3 Art

While developing *Revenant Earth 2*, the focus was primarily on research and gameplay design as explained in section 4.1. However, advancing the art and visual aspect of the game remained a secondary focus and significant examination was conducted on updating the visual presentation. The main topics of focus in this area were:

- The environment, terrain and sky
- The player character and its animations
- The graphic design of the game including user interface

This section outlines the three topics, the associated creative processes and the final results applied to the game.

4.3.1 Environment

The main inspirations for experiments on improving environmental graphics were the game concepts of *Replaced* (TBA) and *The Last Night* (TBA), as described in section 3.2. Their 2.5D environments rendered using 3D technology and complex lighting combined with pixel art are possibly some of the most visually interesting developments in the pixel art style in recent years.

I experimented with implementing a similar 3D rendered approach for the natural scenes and uneven terrain of *Revenant Earth* – making the approach additionally complex. The main benefits of 3D terrain would be artistically expressive scenes, immersion in the game setting, and greater freedom in showcasing the significant environmental changes occurring during the gameplay. A drawback I had to consider was that a 3D terrain surface would extend downwards due to perspective, covering up the cut-away underground view that is relevant for gameplay information. A potential solution could be to make the 3D effect toggleable or hide it around the mouse cursor when inspecting terrain properties.

An additional technical constraint was that the demo of *Revenant Earth* is originally developed in Pixi.js, an exclusively 2D rendering framework with no support for 3D surfaces or perspective rendering. Therefore, some experiments were conducted in the software Blender, and in the real-time 3D rendering library Three.js.



Figure 45: An early test of 3D terrain using Three.js (*own elaboration*)

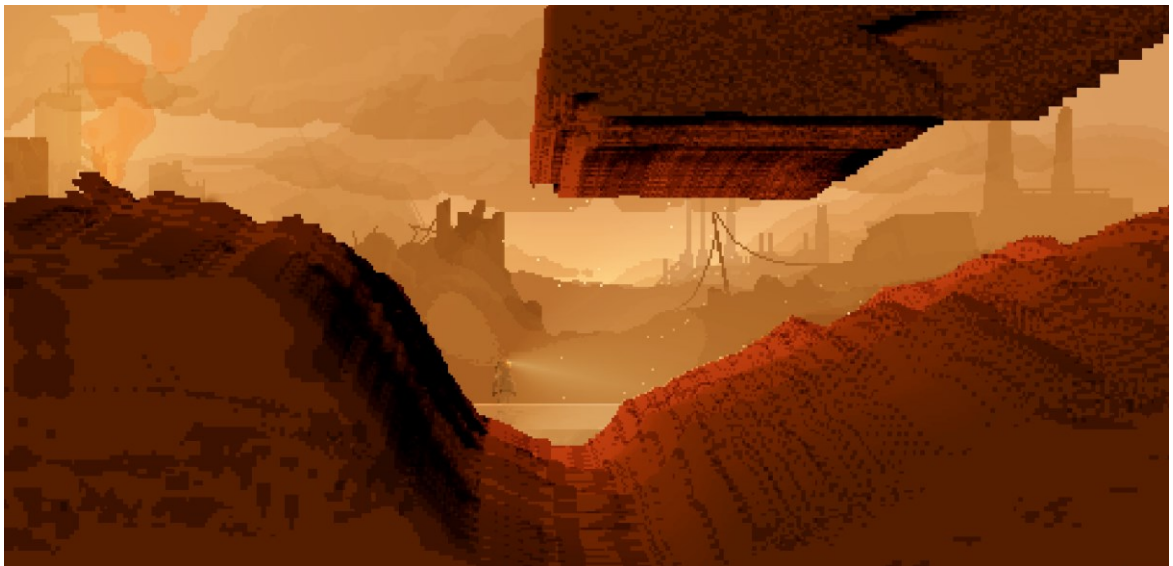


Figure 46: An experiment in implementing 3D terrain into *Revenant Earth* (*own elaboration*)



Figure 47: A concept of "brush stroke"-based 3D surfaces in *Revenant Earth*, hand-drawn over original game footage. (*own elaboration*)

As can be seen from Figure 45 and Figure 46, experiments with 3D terrain mainly consisted of *extruding* the 2D shape of the terrain towards the camera, creating an illusion of depth or a surface leading towards the 2D plane where gameplay happens. On Figure 47, an alternative approach was tried where the illusion of depth would be provided by individual objects or “brush strokes”, dynamically rendered in 3D space on points approximating the extruded terrain surface. This would have the benefit of keeping a similar hand-drawn pixel art aesthetic as is present in the rest of the game.

After significant experimentation, I decided to avoid 3D terrain altogether. The main reasons were increased artistic and development complexity, obscuring useful game information, and the 3D terrain not fitting well into the game’s art style. It is possible that an alternative 3D style could be developed to alleviate those issues, but the required resources do not fall into the scope of this thesis.

Instead, terrain was revised in a less dramatic way – in *Revenant Earth 2*, it is now internally represented by vertices instead of pixels, creating a continuous *surface* instead of a *volume* of pixels. This allows for displaying a smooth ground texture with a slight 3D illusion that does not depend on simply copying and extruding terrain pixels.

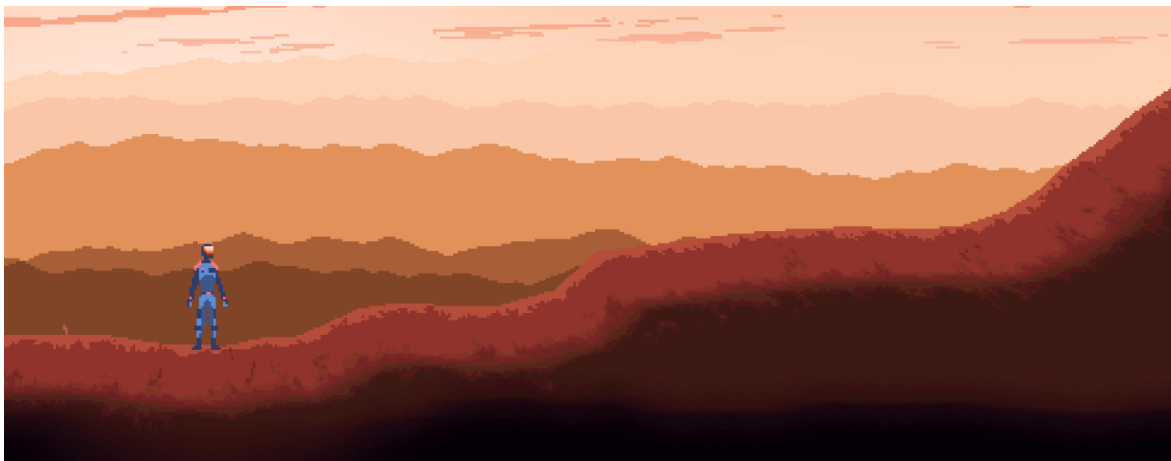


Figure 48: The final version of the terrain in *Revenant Earth 2* (own elaboration)

The switch to vertex-based terrain representation also allows for rendering artificial spaces and interiors much easier. A scene loading system allows the player to visit different environments and switch between interiors and exteriors easily.

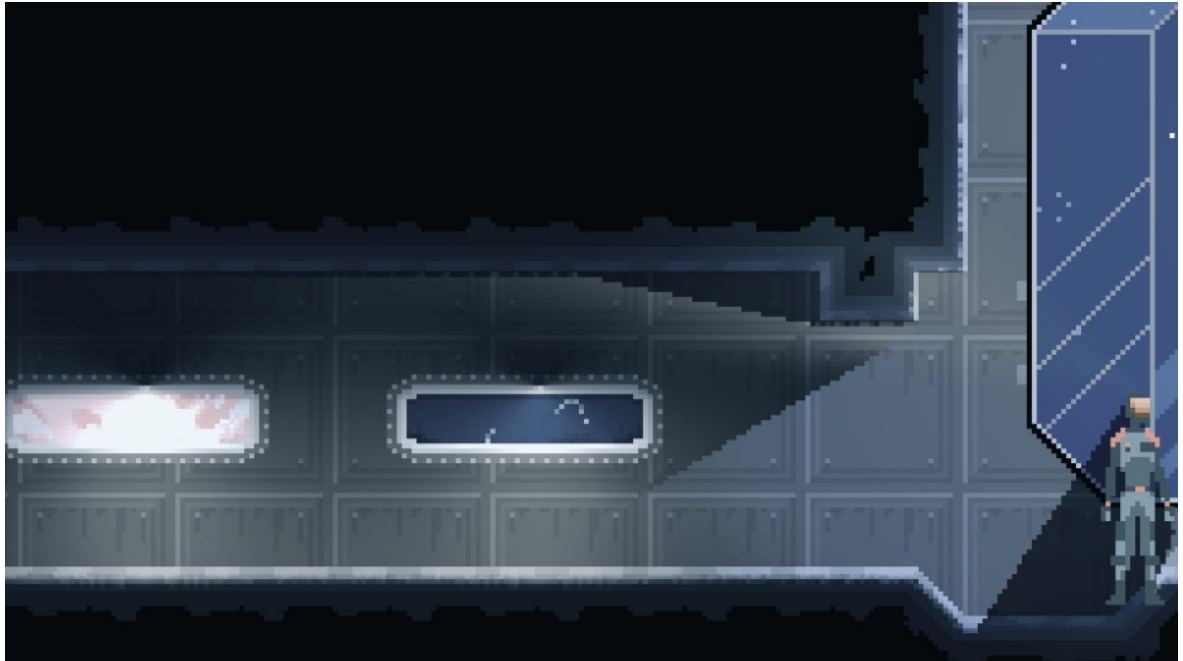


Figure 49: An interior environment made possible using the new vertex surfaces
(own elaboration)

Thanks to the new rendering method, terrain graphics can now more accurately represent properties like moisture, erosion, fertility and pollution. The portion of the terrain close to the surface has a procedurally generated texture that dynamically changes according to the properties. With increasing moisture, a pattern of darker soil expands from the surface downwards, eventually covering the whole visible area. With increasing fertility, the soil gets darker and more reddish. With increasing erosion, cracks appear in the soil and expand to cover the surface. With increasing pollution, discoloured puddles cover increasing portions of the surface.

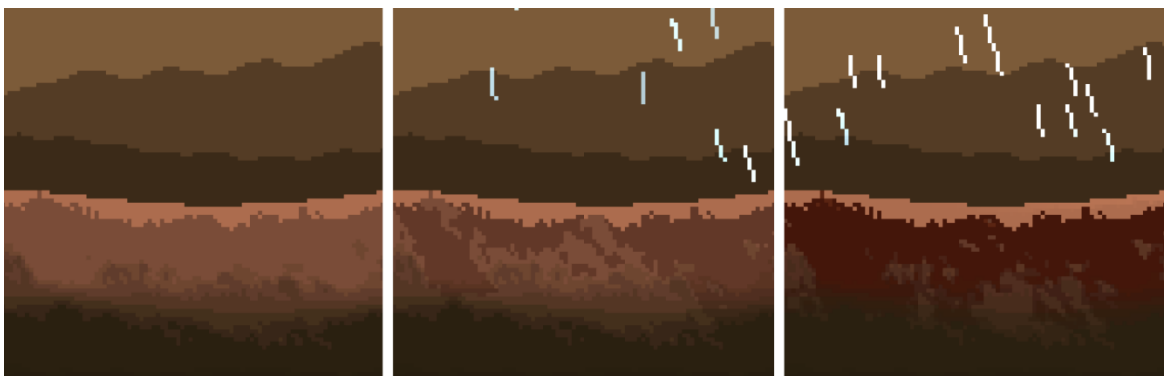


Figure 50: The terrain surface texture as it changes water content during rain
(own elaboration)

Another area that was significantly visually improved was the atmosphere and weather rendering. Similarly to the terrain surface, the sky is rendered by a procedural shader that processes parameters like cloudiness, sun position, air pollution and wind speed. Along with the terrain improvements, this also serves a gameplay purpose in showing the player the current state of the environment.



Figure 51: The sky shader during various stages of cloudiness (*own elaboration*)

4.3.2 Player character

The player character in *Revenant Earth 2* underwent a style update to reflect the slightly cleaner, more high-resolution aesthetic of the game. A significant point of improvement were the character animations, which went through several iterations and style experiments before the final version.

An initial idea for *Revenant Earth 2* was to replace parts of the hand-drawn character animation (most importantly the legs) with a custom procedural animation system based on inverse kinematics (IK)¹ and UV mapping. This would allow the character to have accurate animations on all angles and slopes of terrain, which can suffer visual disconnection when using traditional frame animation.

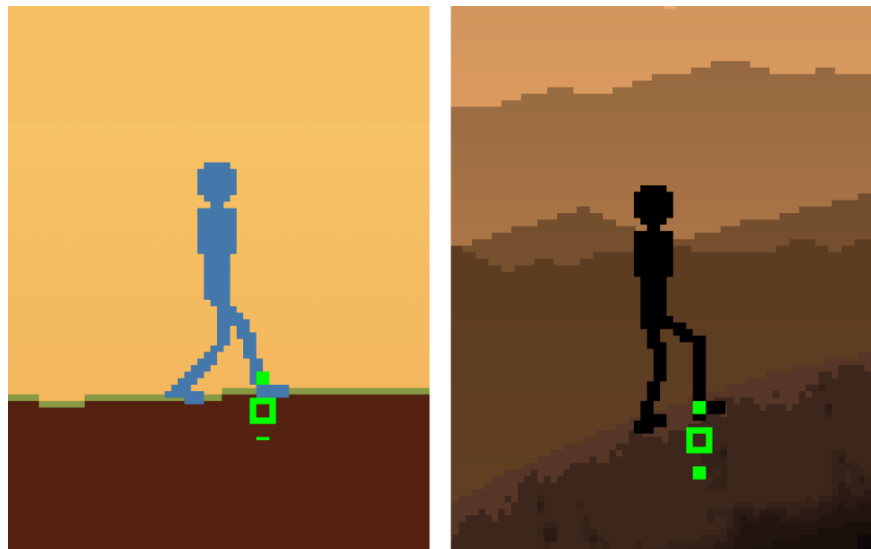


Figure 52: Early iterations of the procedural animation system (*own elaboration*)

However, during development, the inverse kinematics system proved to be unstable and did not produce natural looking results despite repeated adjustments. While the IK knee calculation worked correctly, the foot positioning looked unnatural, especially during animation. After these experiments, I decided to switch to traditional frame animation to produce reliable results with more artistic control. An initial concern that the hand-drawn animation would adjust badly to slopes and uneven terrain proved to have minimal impact thanks to the changes in terrain structure earlier. The character was designed to be simple enough to animate, but still clearly read as a stylised figure in a space suit.

¹ An algorithm to determine positions of upper limb joints (i.e. knee) from the end position of a limb (i.e. foot)



Figure 53: The final idle and run animations for the player character (*own elaboration*)

4.3.3 Logo and graphic design

The initial demo of *Revenant Earth* had no comprehensive graphic design or visual identity, and simple lettering was used in place of a logo. For *Revenant Earth 2*, I designed a logo and an associated visual language to improve the game's recognisability and the quality of its user interfaces.

The logo is based on themes of verticality, space symbolism, and nature elements. Its goal is to represent the sci-fi and ecological themes of the game, the story connecting space and Earth, and combine a simple geometric design with a logotype. First iterations quickly settled on the star symbol as a main visual element, and variations were explored on how to combine it with the logotype and the other elements.

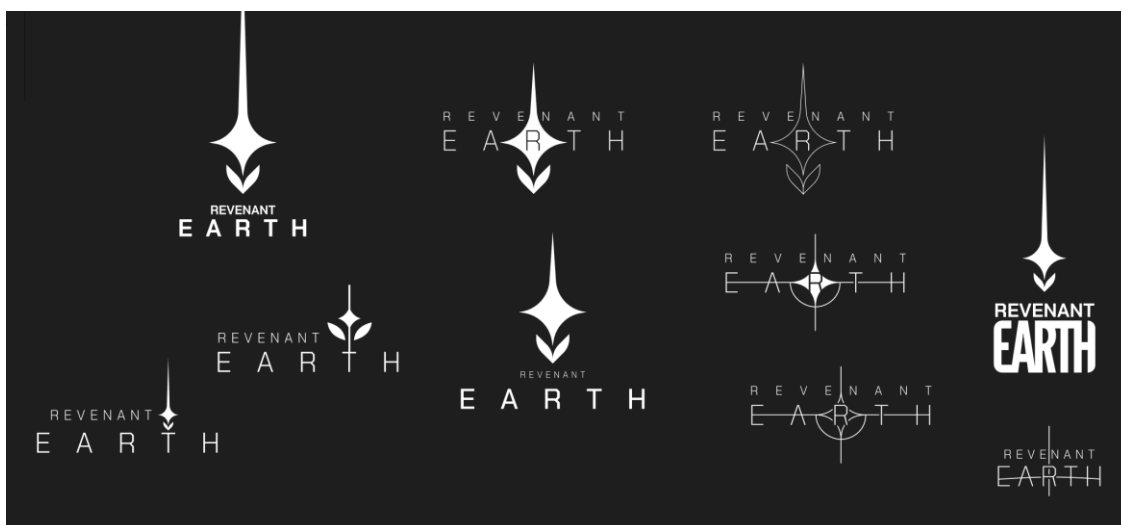


Figure 54: Sketching board during the finalisation of logo ideas (*own elaboration*)

Eventually, I created a design merging the text and graphics into one shape, adding complexity to the otherwise simple geometry. There are still avenues for further improvement of the logo, as the merge between typography and graphics is potentially problematic in terms of readability. The font used is Chakra Petch.



Figure 55: Dark and light versions of the logo (*own elaboration*)

The interface design is derived from the logo and among its sources of inspiration is the videogame *Starfield* (2023). It targets a clean, retro-futuristic space style, combined with small scale typography used as a decorative element. The main colours employed are an intense blue for highlights and a dark, desaturated blue for backgrounds. The entire interface stands in contrast to the in-game world and scenes, which use mainly warm, saturated tones of orange and brown, as well as the contrast between the interface's high-resolution vector design and the game world's pixel art. This contrast is intentional, highlighting the disconnect between humanity and Earth within the game's story.

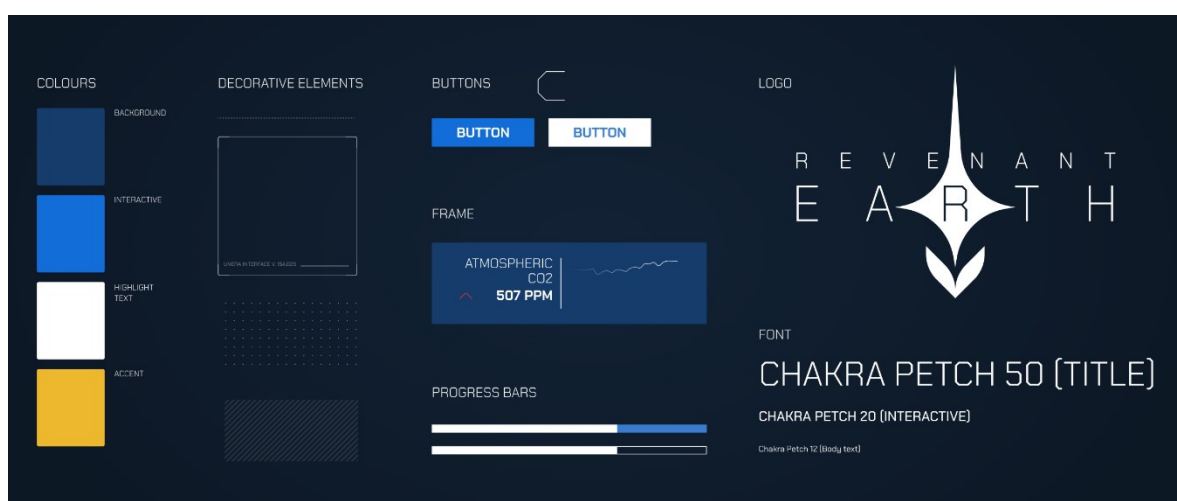


Figure 56: An overview of the game's UI elements. (*own elaboration*)

4.4 Technology

Apart from game design and visuals, *Revenant Earth 2* also underwent technical improvements from the demo version. The base technology the project runs on is still the same: Web browser, the TypeScript language, the Pixi.js rendering library, and WebGL / GLSL shaders. However, the structure of the project has changed considerably. To facilitate loading, saving and scene design, all game elements are structured in a scene-entity-component hierarchy. *Scenes* each contain a set *entities* and other objects, while entities contain individual *components*. Components hold the actual data and code that adds graphics and behaviour to the entity. During scene saving, this hierarchy is traversed from the bottom up in order to serialise all components and entities into the JSON data format which can be stored on disk and loaded at a later point.

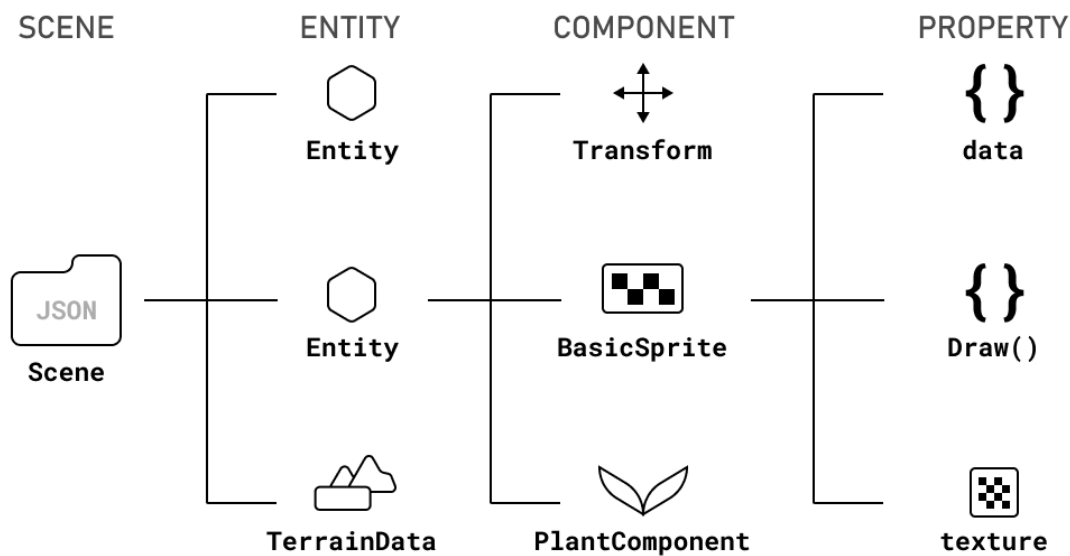


Figure 57: A schematic representation of the game's scene-entity-component structure
(own elaboration)

This type of scene hierarchy is common in game engines such as Unity thanks to its scalability and ease of loading/saving data. All pre-made scenes in the game, such as the tutorial area aboard the space station or the interiors of abandoned factories, are stored in JSON format in the same way the game is then saved to store the player's progress.

Rendering is done using the Pixi.js library and WebGL technology. Many effects in the game are rendered in real-time using shaders, such as terrain, clouds, lighting, atmosphere and plants.

```

vec2 perspectiveTimeUV(vec2 uv, float speed) {
    uv.y *= 2.f;
    uv.x = 0.5f + (uv.x - .5f) * (1.f / (1.f - uv.y)) * .2f;
    uv.y *= uv.y * 3.f;
    uv *= 2.f;
    uv.x += uTime * .1f * speed;
    return uv;
}

void main() {
    vec2 uv = vUV;
    float ratio = uResolution.y / uResolution.x;
    uv.x /= ratio;
    vec2 sunPosition = uSunPosition;
    sunPosition.x /= ratio;
    vec2 originalUV = uv;
    uv = perspectiveTimeUV(originalUV, .2f);
    float noise1 = fractalNoise(uv, 5, 2.f, .8*(1.-originalUV.y*.5));
    float noise = noise1;
    noise *= smoothstep(.5f, .45f, originalUV.y);
    float originalNoise = noise;
    noise = step(uClouds, noise);
    noise *= 1.f - originalUV.y * 1.5f;
    vec3 sky = vec3(.3f, .5f, .5f) * pow(originalUV.y * 2.f, 2.f) + vec3(.7f, .4f, .2f);
    float sun = 1.f - length(originalUV - sunPosition);
    float sunShine = pow(smoothstep(.2f, .95f, sun), 2.f);
    float sunDisk = pow(smoothstep(.97f, .98f, sun), 2.f);
    float totalSun = sunDisk * 2.f + sunShine * .5f;
    totalSun -= noise * 1.f;
    totalSun = clamp(totalSun, 0.f, 2.f);
    sky += totalSun;
    vec3 cloudColor = vec3(.5f, .2f, .1f) + vec3(.3f, .2f, .1f) * (floor(smoothstep(.9f, .2f, originalNoise) * 3.f) / 3.f);
    color = vec4(mix(sky, cloudColor, noise), 1.f);
    color.rgb = PBRNeutralToneMapping(color.rgb);
}

```

Figure 58: A section of code from the shader for generating procedural clouds
(own elaboration)

```

void main() {
    vec2 uv = vUV;
    color = texture(uSampler, uv);
    float noise = fractalNoise(uv * 1.f, 4, 2.f, .8f);
    float HFnoise = fractalNoise(uv * 1.f, 5, 2.f, .9f);
    float baseMask = (2.f - uv.y * 3.f) * (noise + .2f);
    baseMask = posterise(baseMask * 1.5f + .5f, 6);
    float surfaceLight = step(uv.y * 8.f - .2f, HFnoise);
    float wetness = posterise((1.f - uv.y) * noise * 1.f * vTerrainStats.x + vTerrainStats.x * .9f, 2);
    float fertility = step(uv.y, noise * vTerrainStats.y * 2.f);
    vec3 baseColor = vec3(0.24f, 0.15f, 0.11f);
    vec3 wetColor = vec3(0.61f, 0.44f, 0.41f);
    vec3 fertColor = vec3(0.22f, 0.1f, 0.05f);
    float inspect = posterise(vTerrainInspect, 5);
    vec3 inspectColor = normalize(vec3(1.f - inspect, inspect, 0.1f)) * .8f;
    vec3 mixedColor = baseColor;
    mixedColor = mix(mixedColor, fertColor, fertility);
    mixedColor *= mix(vec3(1.f), wetColor, wetness);
    mixedColor = mix(mixedColor, baseColor * 1.4f, surfaceLight);
    color = vec4(mixedColor, 1.f);
    color.rgb = mix(color.rgb, inspectColor, float(uInspectMode));
    baseMask = mix(baseMask, step(.5f, (1.f - uv.y) * .7f + HFnoise * .5f * clamp(.2f + inspect * .2f, 0.f, 1.f)), float(uInspectMode));
    color *= baseMask;
}

```

Figure 59: A section of code from the shader for generating the terrain surface texture
(own elaboration)

All code written for *Revenant Earth 2* is available on the project's GitHub repository,
<https://github.com/Mylapqn/revenant-earth-2>.

4.4.1 In-game editor

To help with development and with designing pre-made scenes, I developed a custom in-game editor that interacts with entity-component data and can perform actions such as controlling game speed, moving or duplicating entities, interactively editing collision shapes, exporting and importing JSON data at runtime and inspecting various properties of the scene.

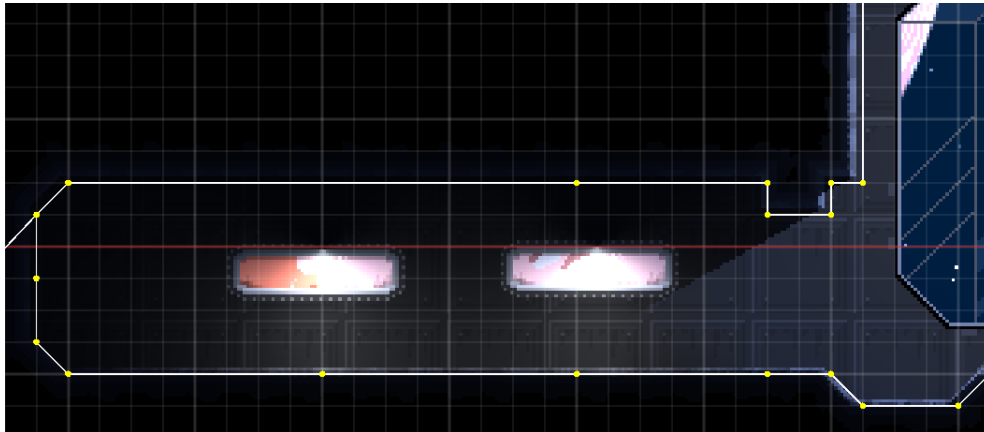


Figure 60: The in-game editor, showcasing collision shape points and the world grid
(own elaboration)



Figure 61: An interaction menu when selecting an entity in the in-game editor
(own elaboration)

The editor could be later improved and opened to the players, facilitating the creation of user-made levels or creative editing of worlds.

5 RESULTS, FUTURE DEVELOPMENT AND RELEASE

While the core part of the development work on *Revenant Earth 2* can be described as completed as of the conclusion of this thesis, the game is far from complete. Real game development intended for market release often takes multiple years of concentrated effort and there is indeed a long path ahead if I intend to truly complete this project.

In this chapter, I outline some key points on this future development path, as well as ideas and concepts that did not entirely make it into the initial development window but still deserve thorough consideration in future work on this project.

5.1 Completing game content and additional features

The area perhaps the most impacted by the relatively short development time has been game content. *Revenant Earth 2* at this point contains only one playable region, consisting of a single biome type (temperate forest).

There is space for significantly **expanding on the story**, introducing characters, dialogues, and cut scenes. With the addition of **multiple playable regions** and diverse biomes (such as tropical rainforest, marsh, tundra, etc.), the game would benefit from a **world map** and an inter-region progression system similar to that of *Terra Nil* (2023).

An ambitious idea that has been present throughout the entire development process has been the addition of **multiplayer**. There are multiple ways to effectively implement multiplayer mechanics in a game like this, ranging from full synchronous interaction between player characters in the same world, to very asynchronous mechanics – like a global score of total captured CO₂ or total regions terraformed – shared between players by uploading game statistics to a central server. Personally, I find the idea of **asynchronous multiplayer** very interesting, with potential mechanics of players helping each other across worlds – akin to some game mechanics in *Death Stranding* (2019).

5.2 Educational value

While developing *Revenant Earth 2*, I have conducted thorough research on environmental mechanics in order to simulate climate change accurately and portray it without misinformation or misconceptions.

This would naturally allow the project to work as an **educational game**. While there already is great potential for educational content, thanks to the game containing real species

of plants being used in plausible scenarios, as well as existing or experimental climate technology, it could be leveraged with more intent. **Partnering with an educational institution** or a science popularisation organisation could be the right steps to both ensuring the information in the game is verifiably correct, but also helping it reach interested children and students.

5.3 Promotion and release to market

One of the initial stated goals of the project was to conclude with developing a marketing approach and explore viable strategies to **prepare for releasing the game** on an online store like Steam or Itch.io. However, during work on the project, it became apparent that such a release would require years of additional development, discouraging me from pursuing this direction for now.

Despite that, an approach of low-intensity **promotion on online social media** or **devlogs** could still be viable even in these early stages, especially in communities focused on indie game development or ecologically themed games. I have mentioned the game in casual conversations on the social network **Reddit**, with slight success as the game's concept captures players' curiosity. A more deliberate promotional strategy could expand on this.

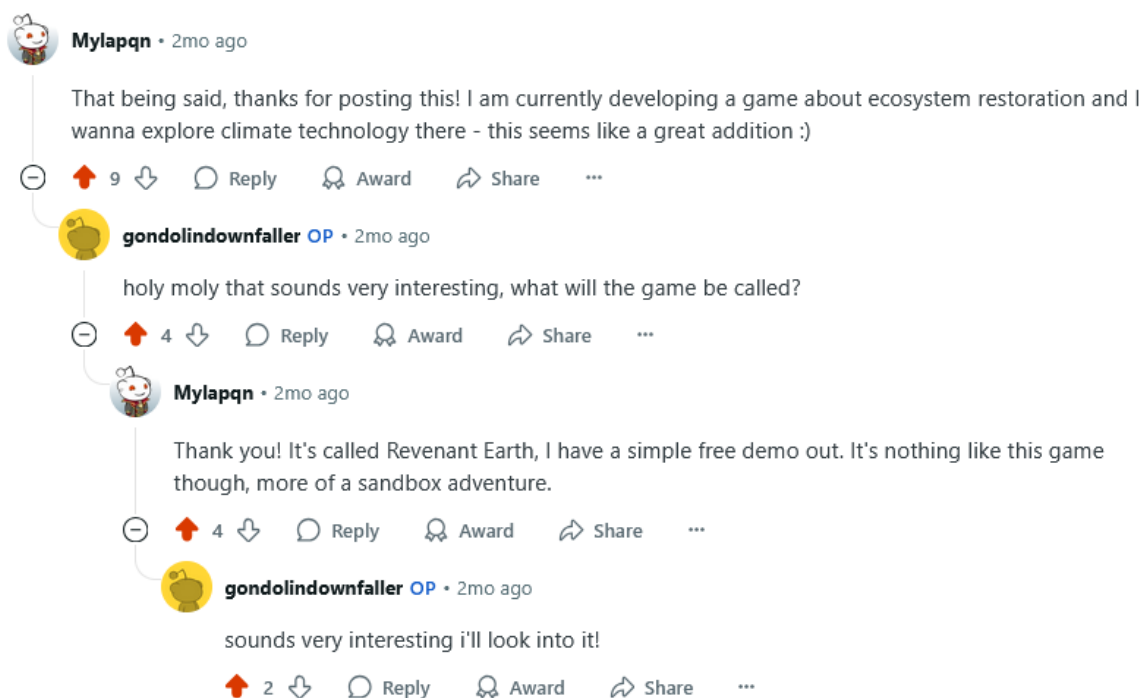


Figure 62: A conversation on the social network Reddit where the concept of *Revenant Earth* seemed to receive interest (*own elaboration*)

CONCLUSION

Attempting to develop *Revenant Earth 2* as an early version of a full game, rather than an intentionally limited demo as in the first iteration, has proven both extremely complex and enriching. The game in its current state is a scaled-down vertical slice and contains only slightly more content than the original 2023 demo – albeit with a much more solid technical foundation and mechanical depth, enabling future development.

I can safely say that I have grossly underestimated the task of developing a full game – resulting in delays, missing features and scaling back of plans.

Despite that, or perhaps thanks to it, the work has yielded invaluable experience; in working towards such a complex project, designing game mechanics, managing time, and decision making over the countless creative directions this project could have taken.

Of the key goals of this project, the most successfully achieved one has been the extensive environmental research and the modelling of game mechanics according to it. Thanks to this phase, the game design of *Revenant Earth 2* could truly begin to reflect the real processes driving climate change on our planet, helping both me and hopefully many future players of the game understand and appreciate the environment in new ways.

Revenant Earth 2 is not a complete game, but a stepping stone towards finishing one – both as a project, and as the experiences gained while developing it.

I would like to end with a quote from Jason Schreier, the author of the book *Blood, Sweat and Pixels*:

*“... Is it possible to develop a game without putting in endless hours?
Will there ever be a reliable formula for making games that allows for
more predictable schedules?”*

*For many industry observers, the answers to those questions are: no, no,
and probably not.”¹*

¹ SCHREIER, Blood, sweat, and pixels: the triumphant, turbulent stories behind how video games are made, [2017].

BIBLIOGRAPHY

ALADIN, N. V. a POTTS, W. T. W. Changes in the Aral Sea ecosystems during the period 1960–1990. *Hydrobiologia*. 1992, roč. 237, č. 2, s. 67-79. ISSN 1573-5117. Dostupné z: <https://doi.org/10.1007/BF00016032>.

ANWETING, IB; EBONG, GA; OKON, IE; UDOFIA, IM a OLADUNNI, N. Evaluating the Concentration of Pb, Hg, Co, V, As, Fe, Cu, Cd, Cr, Mn, Ni, and Zn and their Potential Sources in Soil from Two Abattoirs in Itu and Ikot Ekpene Local Government Areas of Akwa Ibom State, Nigeria. *Journal of Applied Sciences and Environmental Management*. 2024, roč. 28, č. 5, s. 1335-1343. ISSN 2659-1499.

AU - WILSON, Kelpie J.; AU - BEKKER, Wihan a AU - FEHER, Stephen I. Producing, Characterizing and Quantifying Biochar in the Woods Using Portable Flame Cap Kilns. *JoVE*. 2024, č. 203, s. e65543. ISSN 1940-087X. Dostupné z: <https://doi.org/doi:10.3791/65543>.

BEECH, Martin. *Terraforming: the creating of habitable worlds: the creating of habitable worlds*. 1. Springer, 2009.

BESTON PYROLYSIS PLANT. *Biomass Pyrolysis Plant - Sustainable Biochar Production*. Online. Beston Pyrolysis Plant. 2025. Dostupné z: <https://bestonpyrolysisplant.com/biomass-pyrolysis-plant>. [cit. 2025-05-17].

BIELCZYNSKI, Ludwik W.; ŁĄCKI, Mateusz K.; HOEFNAGELS, Iris; GAMBIN, Anna a CROCE, Roberta. Leaf and Plant Age Affects Photosynthetic Performance and Photoprotective Capacity. *Plant Physiology*. 2017, roč. 175, č. 4, s. 1634. Dostupné z: <https://doi.org/10.1104/pp.17.00904>.

BRAȘOVAN, Andreea a CODREA, Vlad A. *Data on Coal Dumps Retrieving in Petroșani Basin Using Sea Buckthorn (Hippöphae Rhamnoides)*. 2008. Dostupné také z: <https://api.semanticscholar.org/CorpusID:127780093>.

BYRNE, John. *File:SHB-Red-Dust.jpg - Wikimedia Commons: SHB-Red-Dust.jpg - Wikimedia Commons*. 2025. Dostupné také z: <https://commons.wikimedia.org/wiki/File:SHB-Red-Dust.jpg>.

CARBON ENGINEERING. *Carbon Engineering | Direct Air Capture of CO2 | Home*. Online. Carbon Engineering. 2023. Dostupné z: <https://carbonengineering.com>. [cit. 2025-05-17].

COUNCIL, National Research; EARTH, Division on; STUDIES, Life; SCIENCES, Board on Atmospheric; OF, Committee on the Status et al. *Critical issues in weather modification research*. National Academies Press, 2004. ISBN 0309090539.

COUNCIL, National Research. *Vetiver Grass: A Thin Green Line Against Erosion: A Thin Green Line Against Erosion*. Washington, DC: The National Academies Press, 1993. ISBN 978-0-309-04269-7. Dostupné z: <https://doi.org/10.17226/2077>.

DOTY, Sharon L.; FREEMAN, John L.; COHU, Christopher M.; BURKEN, Joel G.; FIRRINCIELI, Andrea et al. Enhanced Degradation of TCE on a Superfund Site Using Endophyte-Assisted Poplar Tree Phytoremediation. *Environmental Science & Technology*. 2017/09/05, roč. 51, č. 17, s. 10050-10058. ISSN 0013-936X. Dostupné z: <https://doi.org/10.1021/acs.est.7b01504>.

ENESCU, Cristian Mihai. Sea-buckthorn: a species with a variety of uses, especially in land reclamation. *Dendrobiology*. 2014, roč. 2014, č. 72, s. 41-46. Dostupné také z: <https://www.idpan.poznan.pl/pl/vol-72/72-41-46>.

ESPELAND, Erin K. a KETTENRING, Karin M. Strategic plant choices can alleviate climate change impacts: A review: A review. *Journal of Environmental Management*. 2018, roč. 222, s. 316-324. ISSN 0301-4797. Dostupné z: <https://doi.org/https://doi.org/10.1016/j.jenvman.2018.05.042>.

FADNAVIS, Anushree. *Delhi shrouded in toxic smog*. Online. Reuters. 2024, 18.11.2024. Dostupné z: <https://www.reuters.com/pictures/delhi-shrouded-toxic-smog-2024-11-18/>. [cit. 2025-05-14].

FENG, Zihan. How Game Ecology Drives Player Choices in Strategy Video Games: An Environmental Determinism Perspective: An Environmental Determinism Perspective. *Simulation & Gaming*. 2024, roč. 55, č. 2, s. 342-357. ISSN 1046-8781. Dostupné z: <https://doi.org/10.1177/10468781241231895>.

GOUGH, Clair a UPHAM, Paul. Biomass energy with carbon capture and storage (BECCS or Bio-CCS). *Greenhouse Gases: Science and Technology*. 2011, roč. 1, č. 4, s. 324-334. ISSN 2152-3878.

GUTIÉRREZ, Francisco L.; MEDINA-MEDINA, Nuria; GALLARDO, Jesús; PADEREWSKI, Patricia a CEREZO, Eva. Supporting Narrative Design in Video Games: Proposal and Case Study with an Educational Video Game: Proposal and Case Study with

an Educational Video Game. *International journal of human-computer interaction*. 2024, č. Journal Article, s. 1-25. ISSN 1044-7318. Dostupné z: <https://doi.org/10.1080/10447318.2024.2440143>.

HÄDER, Donat-P; HELBLING, E Walter a VILLAFANE, Virginia E. *Anthropogenic pollution of aquatic ecosystems*. Springer, 2021. ISBN 3030756017.

HALPIN, Claire. *Ceratodon purpureus* - *British Bryological Society*. Photo. 2023. Dostupné také z: <https://www.britishbryologicalsociety.org.uk/learning/species-finder/ceratodon-purpureus>.

HALSTEAD, John. Stratospheric aerosol injection research and existential risk. *Futures*. 2018, roč. 102, s. 63-77. ISSN 0016-3287.

HERZOG, Howard. Direct Air Capture. In: *Greenhouse Gas Removal Technologies*. The Royal Society of Chemistry, 2022. ISBN 978-1-83916-199-5. Dostupné z: <https://doi.org/10.1039/9781839165245-00115>.

HUGHHUNT. *SPICE SRM overview.jpg* - *Wikimedia Commons*. 2011. Dostupné také z: https://commons.wikimedia.org/wiki/File:SPICE_SRM_overview.jpg.

HULME, Mike. Climate change: Climate engineering through stratospheric aerosol injection: Climate engineering through stratospheric aerosol injection. *Progress in Physical Geography*. 2012, roč. 36, č. 5, s. 694-705. ISSN 0309-1333.

HUYNH, Han N a MCNEILL, V Faye. The potential environmental and climate impacts of stratospheric aerosol injection: a review: a review. *Environmental Science: Atmospheres*. 2024, roč. 4, č. 2, s. 114-143.

IBERDROLA. DESERTIFICATION. *Iberdrola*. 2021. Dostupné také z: <https://www.iberdrola.com/sustainability/desertification>.

ILLINOIS WILDFLOWERS. *Silver Moss (Bryum argenteum)*. 2017. Dostupné také z: https://www.illinoiswildflowers.info/mosses/plants/silver_moss.html.

IRVIN, Jeremy. *Stanfordmlgroup/planet-parasol-demo: Initial release: Initial release*. Zenodo, 2024. Dostupné z: <https://doi.org/10.5281/ZENODO.11467175>.

JACKSON, Stephen T a HOBBS, Richard J. Ecological restoration in the light of ecological history. *Science*. 2009, roč. 325, č. 5940, s. 567-569. ISSN 0036-8075.

JANET PELLE, Special to C&en. Firm footing for cloud seeding. *Chemical & Engineering News*. 2022, s. 18-21. Dostupné také z: <https://cen.acs.org/articles/94/i22/Does-cloud-seeding-really-work.html>.

KEELING, Ralph F.; POWELL, Frank L.; SHAFFER, Gary; ROBBINS, Peter A. a SIMONSON, Tatum S. Impacts of Changes in Atmospheric O₂ on Human Physiology. Is There a Basis for Concern? *Frontiers in Physiology*. 2021, roč. 12, s. 571137. Dostupné z: <https://doi.org/10.3389/fphys.2021.571137>.

KEITH, David A; RODRÍGUEZ, Jon Paul; RODRÍGUEZ-CLARK, Kathryn M; NICHOLSON, Emily; AAPALA, Kaisu et al. Scientific foundations for an IUCN Red List of Ecosystems. *PLOS one*. 2013, roč. 8, č. 5, s. e62111.

KENRAIZ. *Populus nigra kz1 - Wikimedia Commons*. 2025. Dostupné také z: https://commons.wikimedia.org/wiki/File:Populus_nigra_kz1.jpg.

LAKHANI, Nina. Nearly half of Americans breathing in unsafe levels of air pollutants – report. *The Guardian*. 2025. Dostupné také z: https://www.theguardian.com/us-news/2025/apr/23/americans-air-pollution?utm_source=chatgpt.com.

LINEMAN, Maurice; DO, Yuno; KIM, Ji Yoon a JOO, Gea-Jae. Talking about Climate Change and Global Warming. *PLoS ONE*. 2015, roč. 10, č. 9, s. e0138996. Dostupné z: <https://doi.org/10.1371/journal.pone.0138996>.

LYNAS, Mark; HOULTON, Benjamin Z a PERRY, Simon. Greater than 99% consensus on human caused climate change in the peer-reviewed scientific literature. *Environmental Research Letters*. 2021, roč. 16, č. 11, s. 114005. ISSN 1748-9326. Dostupné z: <https://doi.org/10.1088/1748-9326/ac2966>.

MAREK, Matouš. *Videohra Revenant Earth*. Bachelor thesis, vedoucí Novák, Pavel. Zlín: Univerzita Tomáše Bati ve Zlíně. Fakulta multimediálních komunikací, Ateliér Digitální design. Dostupné také z: <http://hdl.handle.net/10563/54481>.

MASSON-DELMOTTE, Valérie; ZHAI, Panmao; PIRANI, Anna; CONNORS, Sarah L; PÉAN, Clotilde et al. Climate change 2021: the physical science basis: the physical science basis. *Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change*. 2021, roč. 2, č. 1, s. 2391.

MAZZOTTI, Marco; BACIOCCHI, Renato; DESMOND, Michael J. a SOCOLOW, Robert H. Direct air capture of CO₂ with chemicals: optimization of a two-loop hydroxide carbonate

system using a countercurrent air-liquid contactor: optimization of a two-loop hydroxide carbonate system using a countercurrent air-liquid contactor. *Climatic Change*. 2013, roč. 118, č. 1, s. 119-135. ISSN 1573-1480. Dostupné z: <https://doi.org/10.1007/s10584-012-0679-y>.

MIRSAL, Ibrahim A. *Soil pollution*. Springer, 2008. ISBN 3540707751.

NASA GLOBAL CLIMATE CHANGE. *Carbon Dioxide Concentration | NASA Global Climate Change*. Online. Climate Change: Vital Signs of the Planet. 2025. Dostupné z: <https://climate.nasa.gov/vital-signs/carbon-dioxide/?intent=121>. [cit. 2025-05-15].

NASA. *NASA Satellites Help Quantify Forests' Impacts on Global Carbon Budget - NASA*. Online. NASA. 2023. Dostupné z: <https://www.nasa.gov/science-research/earth-science/nasa-satellites-help-quantify-forests-impacts-on-global-carbon-budget>. [cit. 2025-05-15].

NATIONAL ATMOSPHERIC DEPOSITION PROGRAM. *Air, Animals, and Plants*. Online. 2025. Dostupné z: <https://nadp.slh.wisc.edu/aqaw-2024/air-animals-and-plants>. [cit. 2025-05-23].

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. *Climate Change: Atmospheric Carbon Dioxide: Atmospheric Carbon Dioxide*. Online. NOAA Climate. 2024. Dostupné z: <https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide>. [cit. 2025-05-15].

NEUFELD, Dorothy. Visualizing Carbon Storage in Earth's Ecosystems. *Visual Capitalist*. 2023. Dostupné také z: <https://www.visualcapitalist.com/sp/visualizing-carbon-storage-in-earths-ecosystems>.

POMMERENING, Arne a MUSZTA, Anders. Methods of modelling relative growth rate. *Forest Ecosystems*. 2015, roč. 2, č. 1, s. 1-9. ISSN 2197-5620. Dostupné z: <https://doi.org/10.1186/s40663-015-0029-4>.

REFLECTIVE. Simulating the impacts of SAI deployment – Reflective. *Reflective*. 2024. Dostupné také z: <https://reflective.org/simulating-the-impacts-of-sai-deployment>.

Restoration Resource Center *What is Ecological Restoration?* 2025. Dostupné také z: <https://ser-rrc.org/what-is-ecological-restoration>.

RICHARDSON, D H. *The biology of mosses*. Oxford: Blackwell Scientific Publications, 1981.

RITCHIE, Hannah. Sector by sector: where do global greenhouse gas emissions come from?: where do global greenhouse gas emissions come from? *Our World in Data*. 2020.

RONGSEN, L. Seabuckthorn - A multipurpose Plan Species for Fragile Mountains. *International Centre for Integrated Mountain Development*. 1992. Dostupné z: <https://doi.org/10.53055/ICIMOD.129>.

ROSE-ENGINE. *SIGNALIS on Steam*. Online. Steam. 2025. Dostupné z: <https://store.steampowered.com/app/1262350/SIGNALIS>. [cit. 2025-05-20].

ROYAL SOCIETY a ROYAL ACADEMY OF ENGINEERING. *Greenhouse gas removal*. Royal Society and Royal Academy of Engineering, 2018. Dostupné také z: royalsociety.org/greenhouse-gas-removal.

SCHREIER, Jason. *Blood, sweat, and pixels: the triumphant, turbulent stories behind how video games are made*. New York: Harper, [2017]. ISBN 978-0-06-265123-5.

SETH BORENSTEIN, Brittany Peterson | The Associated Press. Did cloud seeding lead to unprecedented floods in Dubai? *NBC 6 South Florida*. 2024. Dostupné také z: <https://www.nbcmiami.com/news/national-international/what-is-cloud-seeding-dubai-floods/3288670>.

SMITH, P. Soils as carbon sinks: The global context: The global context. *Soil Use and Management*. 2006, roč. 20, č. 2, s. 212-218. ISSN 1475-2743. Dostupné z: <https://doi.org/10.1111/j.1475-2743.2004.tb00361.x>.

SUPERGIANT GAMES. *Hades*. Online. In: VOX MEDIA, LLC. Polygon. 2024. Dostupné z: https://platform.polygon.com/wp-content/uploads/sites/2/2024/09/hades_dad.jpg. [cit. 2025-01-10].

SVDMOLEN. *Hippophae rhamnoides-01 (xndr).JPG* - *Wikimedia Commons*. 2025. Dostupné také z: [https://commons.wikimedia.org/wiki/File:Hippophae_rhamnoides-01_\(xndr\).JPG](https://commons.wikimedia.org/wiki/File:Hippophae_rhamnoides-01_(xndr).JPG).

Terra Nil - 🎮 THE TERRA NIL VITA NOVA UPDATE IS HERE! 🎮 - *Steam News*. 2024. Dostupné také z: <https://store.steampowered.com/news/app/1593030/view/6595039229772983641>.

THE VETIVER NETWORK WEST INDIES. *The Vetiver System (VS) - The Vetiver Network West Indies*. Online. Vetiver Network West Indies. 2019. Dostupné z: <https://tvnwi.org/the-vetiver-system>. [cit. 2025-05-16].

TRUONG, P; VAN, T a TAN PINNERS, E. *Vetiver Systems Application, Technical Reference Manual. The Vetiver Network International*. 2008.

US GOVERNMENT ACCOUNTABILITY OFFICE. *Cloud Seeding Technology: Assessing Effectiveness and Other Challenges: Assessing Effectiveness and Other Challenges*. Online. 2025. Dostupné z: <https://www.gao.gov/products/gao-25-107328>. [cit. 2025-05-23].

VALLERO, Daniel A. *Fundamentals of air pollution*. Academic press, 2014. ISBN 0124046029.

WANG, Jianlong a WANG, Shizong. Preparation, modification and environmental application of biochar: A review. *Journal of Cleaner Production*. 2019, roč. 227, s. 1002-1022. ISSN 0959-6526.

WEIL, Raymond R. a BRADY, Nyle C. *The Nature and Properties of Soils. 15th edition*. 2017. ISBN 978-0-13325448-8. Dostupné také z: https://www.researchgate.net/publication/301200878_The_Nature_and_Properties_of_Soils_15th_edition.

What is Earth's Energy Budget? Five Questions with a Guy Who Knows - NASA. Online. 2023. Dostupné z: <https://www.nasa.gov/centers-and-facilities/langley/what-is-earths-energy-budget-five-questions-with-a-guy-who-knows>. [cit. 2025-05-23].

WRETBORN, Sara. *About Beccs Stockholm - Beccs Stockholm*. Online. BECCS STOCKHOLM. Beccs Stockholm. 2025. Dostupné z: <https://beccs.se/about-beccs-stockholm>. [cit. 2025-05-17].

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LIST OF ABBREVIATIONS

- CO₂ Carbon dioxide, a major greenhouse gas
- DAC Direct air capture of carbon dioxide or pollutants from the air
- SAI Stratospheric aerosol injection, a technology aimed at lowering global temperatures
- BECCS Bioenergy with Carbon Capture and Storage
- XP Experience points, a common game progression system
- RP Reputation points, the currency used in *Revenant Earth 2*
- 2D Two dimensions, a flat plane
- 3D Three dimensions, a space or object with depth
- 2.5D Two and a half dimensions, a graphic style that combines 2D and 3D elements, presents 2D elements that appear 3D, or 3D elements that appear 2D
- JSON JavaScript Object Notation, a format useful for storing data readable by code

LIST OF REFERENCED VIDEO GAMES

Hades. 2020. Supergiant Games

Terra Nil. 2023. Free Lives

Plan B: Terraform. 2023. Gaddy Games

SAI Simulator. 2024. Irvin et al.

Replaced. [unannounced release date]. Sad Cat Studios

The Last Night. [unannounced release date]. Odd Tales

Cast n Chill. 2025 [early access]. Wombat Brawler

Signalis. 2022. rose-engine

Starfield. 2023. Bethesda Game Studios

Death Stranding. 2019. Kojima Productions