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Gamification and climate changes: a challenge in Minecraft Education Edition

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Abstract

Gamification and game-based learning are innovative approaches used to address climate change by engaging players in meaningful and educational experiences. We make use of Minecraft Education Edition as a tool for teaching concepts related to climate change and clean energy by playing and preventing a critical rise of the global temperature . The game world, a simplified representation of Earth, includes several types of energy-producing plants that are used to sustain the current consumption expected for the start of the game. Initially, non-renewable energy sources dominate, risking planetary collapse if unchanged. The goal is to achieve climate neutrality within a time limit by altering energy sources passing to clean energies and minimizing the impact on the system's functionality. Using Minecraft Education Edition, players can explore climate changes and

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the role of non- and renewable energy plants, while learning physics concepts like energy types and temperature increase, making science education interactive and engaging.

Keywords: game based learning, climate change, Minecraft Education Edition, physics education, STEM

1. Introduction

Climate change represents one of the most urgent, important and complex challenges of our time. Including phenomena such as the rising of global temperatures and the increase in extreme weather events, these changes have significant impacts on the environment, economy, and society. The World Meteorological Organization reported the actual state of climate updating the situation for the 29th Conference of the Parties [1]. It has been shown that greenhouse gases reached record levels in 2023, and real-time data shows they continued to rise in 2024. Furthermore, from January to September 2024, the global mean surface air temperature was $(1.54 \pm 0.13)\,^{\circ}\mathrm{C}$ above the pre-industrial average.

Teaching about climate change is crucial for preparing new generations to face these challenges [2–4]. Educating young people on the importance of sustainability, responsible consumption, and renewable energy can promote more conscious and responsible behaviours. Additionally, a solid understanding of climate change can stimulate innovation and the search for effective solutions to mitigate negative effects and adapt to an evolving world.

Science, Technology, Engineering Mathematics and Physics, in particular, are fundamental to understand and harness some of the most important topics related to climate change. As a matter of fact, energy plays a pivotal role, as it provides the principles that enable the development and optimization of renewable energy technologies, such as solar panels and wind turbines, which are crucial for a sustainable future. Understanding the principles of energy conversion and the behaviour of different energy sources—e.g. the distinction between renewable and non-renewable energies—is essential to make possible a 'green transition' that is crucial for reducing greenhouse gas emissions and counteracting global temperature rise [5, 6].

Greenhouse gases are crucial in regulating the Earth's temperature, but their increased concentration is driving climate change. The primary greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. Among these, CO_2 is the most significant due to its large volume and long atmospheric lifetime, instead methane is a much more potent greenhouse gas than CO_2 [7]. CO_2 is released primarily through the burning of fossil fuels, deforestation, and various industrial processes. Reducing CO_2 emissions is essential for mitigating global warming and its associated impacts. In fact, the increase in global temperatures is a key topic in physics, particularly in the study of thermodynamics and climate science. It involves understanding how greenhouse gases trap heat in the Earth's atmosphere, leading to changes in weather patterns, melting ice caps, and rising sea levels.

One of the most promising approaches to educating the next generation about climate change is through innovative teaching methods like gamification. Gamification, the application of game-design elements in non-game contexts, has the potential to transform how we learn about and engage with complex issues such as climate change. In particular, game-based learning (GBL) is an innovative educational approach that uses the principles of game design to create engaging and effective learning experiences [8, 9]. By incorporating elements such as interactive gameplay and immediate rewards, GBL can significantly enhance student motivation and participation. Minecraft and, in particular, Minecraft Education Edition (MEE) are prime examples of

how GBL can be applied to teach complex subjects in an engaging way [10–15]. MEE is specifically designed for educational purposes, offering a platform where students can explore, create, and learn in a virtual environment.

By means of Minecraft Education Edition, students can see first-hand how it is possible to reduce greenhouse gas emissions and help mitigate climate change. This practical understanding is crucial for inspiring the next generation of scientists, engineers, and informed citizens who will drive the transition to a sustainable future.

Based on what has just been said, we have created an educational activity on MEE in which the game world, designed as a simplified representation of Earth, features various types of energy-producing plants that are essential for sustaining the initial energy consumption levels expected at the start of the game. These plants include both renewable and non-renewable energy sources. However, at the beginning of the game, non-renewable energy sources, such as coal and oil, dominate the energy landscape. This heavy reliance on non-renewable sources poses a significant risk of planetary collapse if not addressed. The primary objective of the game is to halt climate change within a specified time limit creating a challenge for players that must achieve this goal by transitioning from non-renewable to renewable energy sources, such as solar, wind, and hydroelectric power. This transition is crucial for reducing greenhouse gas emissions and preventing further global temperature rise. Throughout the game, players must strategically alter their energy sources to clean energies while ensuring that the overall functionality and stability of the system are maintained. This involves careful planning and management to balance energy production with consumption, all while minimizing the environmental impact and promoting sustainable practices.

After discussing the data, statistics, and the types of non-renewable and renewable energy used in our work, we will detail the game developed in Minecraft Education Edition. We will highlight its dynamics and features that encourage players to delve deeper into topics related to climate change and hard sciences, such as physics.

2. Climate change and statistical data

The power plants we have considered within our game-based teaching model are those that have the greatest environmental impact, and seek to represent the largest slice of the energy-producing industries to date in the world. In particular, there are nine power plants reported in the game, of which five are categorized as producing renewable energy and four as producing non-renewable energy.

The data used during the game correspond to actual data, so that the final score obtained by the player can be compared with one of the possible future scenarios predicted by the IPCC's Synthesis Report of 2023 [16].

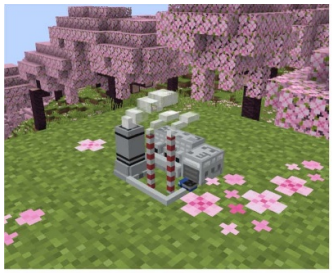
In the following subsections, we will detail the various types of renewable and non-renewable energy, also providing the game parameters used to reproduce them in the simplest and most intuitive way for the players.

2.1. Power plants and energy types

The power plants used in the game are shown in figure 1 and can be divided into two main categories: those that produce energy from renewable sources and those that use non-renewable sources. The main difference between this two categories is that renewable power plants make use of natural resources that regenerate naturally and are not likely to be depleted in the short term, such as Sun, wind, water, terrestrial heat, and biomass. In contrast, non-renewable power plants rely on limited materials that cannot be regenerated on human time scales, such as coal, oil, natural gas, and nuclear fuels [17].

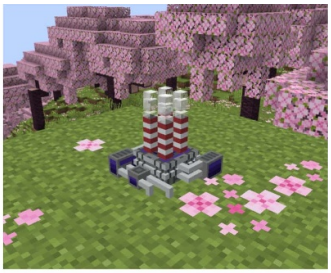
2.1.1. Non-renewable energies. In our game, four power plants can be classified as non-renewables:

- **Coal.** Although coal is the fossil fuel that produces the most carbon emission, it is still used to produce about one-third of global electricity. In the combustion process, coal heats water, converting it into steam, which in turn is used to turn a turbine connected to an electric alternator. It is crucial to

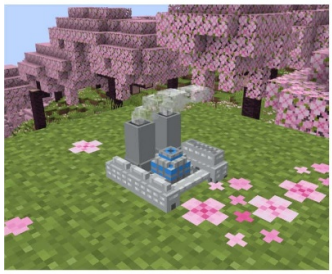


(a) Coal power plant

(b) Oil power plant



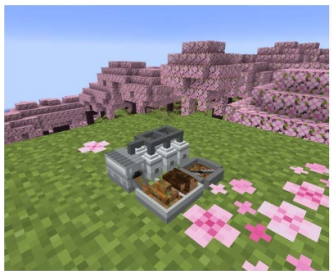
(c) Gas power plant



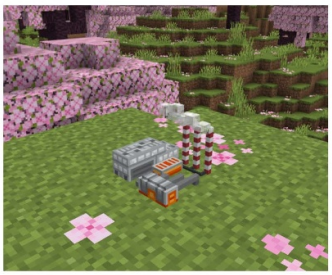
(d) Nuclear fission power plant

(e) Solar power plant

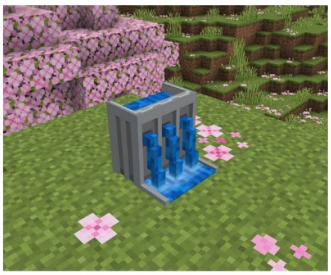
(f) Wind power plant



(g) Biomass power plant



(h) Geothermal power plant



(i) Hydroelectric power plant

Figure 1. Representation of the nine power plants used in the game, illustrating both renewable and non-renewable energy sources. The images depict various types of power plants, including solar, wind, hydroelectric, nuclear, coal, and natural gas, designed to accurately reflect their real-world counterparts.

remember that coal combustion also generates substantial carbon dioxide emissions, with the total exceeding 10 Gt in 2021, contributing about one-fifth of global greenhouse gas emissions.

The IEA's Net Zero Emissions by 2050 Scenario envisions that all unabated coal generation ends by 2040 [17], even if there is enough coal for the order of 150 yr left, so there is a lot of potential for CO_2 emissions.

In the game, the coal power plant is represented by the block in figure 1(a).

Advantages:

– Coal is cheaper than many alternative energy sources.

– It is widely available globally.
– Coal power plants can operate continuously.

Disadvantages:
– Coal power plants release significant amounts of CO_2 (and other greenhouse gases) being the highest carbon footprint among other energy sources.
– Coal reserves will deplete in future.
– Coal extraction has a great impact on the environment, destroying large portions of land and employing large amounts of water for cooling.

- **Oil.** The production of electricity by burning petroleum-derived oils (like diesel or heavy fuel oil) classifies this power plant as a thermal power plant. The combustion process generates various greenhouse gases that have significant environmental impacts, including sulphur and nitrogen oxides, methane, and, most importantly, carbon dioxide. In addition, oil combustion also produces toxic residues that require specific storage procedures. Despite these negative effects, oil is expected to continue to be a crucial component in global energy demand in the coming decades as backup power sources for peak demand periods, especially in the transportation sector and plastics production.

  Under the Zero Emissions by 2050 scenario, the use of low-emission liquid fuels is expected to increase, with the goal of reducing oil demand by 2030 [17].

  In the game, the oil power plant is represented by the block in figure 1(b).

  Advantages:
  – Oil has a high energy content per unit.
  – Oil plants can operate continuously and can be used in base load or peak load power generation depending on demand.
  – The facilities are generally small, compared to others, making them feasible in urban or constrained areas.

  Disadvantages:
  – Oil plants produce significant amounts of CO_2, SO_2 and other particulates, but have a less efficient energy conversion.
  – Oil can not burn directly, it have to be refined into other fuels, like diesel.
  – Oil is a finite resource and is typically more expensive than natural gas or other fossil fuels and leaks during the extraction can damage the environment.

- **Natural gas.** Natural gases are a mixture of fossil fuels, with methane as the main component; energy production by this fuel is through combustion processes. Among fossil fuels, natural gas has the least environmental impact, emitting less carbon dioxide, sulphur dioxide and nitrogen oxides for the same amount of energy produced. Natural gas is mixed with air and burned in a combustion chamber, producing high-temperature, high-pressure exhaust gases, and then directed into a turbine to generate electric energy. In some gas power plants, remaining high-pressure exhaust gases are used to generate steam from in another turbine, to increase significantly the efficiency.

  In the energy transition from fossil fuels to renewable energy, natural gas plays a limited role; however, power generation from natural gas may still be needed as a support system for power generation from wind and solar sources [17].

  In the game, the gas power plant is represented by the block in figure 1(c).

  Advantages:
  – Compared to other non-renewable sources, natural gas produces less CO_2 and particulates, and have higher thermal efficiency.
  – Gas plants cost less compared to others energy sources and can be used for both base load and peak load power generation, offering operational flexibility.

  Disadvantages:
  – Natural gas plants are cleaner than coal, but still emits CO_2.
  – Methane can contribute to greenhouse gas if it escape during the extraction process and transportation.
  – They are not renewable resources and will deplete.
  – Extractions destroy the environment and could contaminate aquifers.

- **Nuclear energy.** Currently, nuclear energy contributes marginally to global energy needs, producing only a small fraction of the energy required worldwide. This is mainly due to

political factors and public concerns, which have slowed the research and adoption of this energy source, despite its potential as one of the main tools for the transition to carbon-free energy production. Nuclear power is generated by atomic fission occurring in the reactor, a process that heats a heat transfer fluid (which varies depending on the type of power plant) whose vapours drive a turbine to produce electricity. Although it does not result in greenhouse gas emissions, nuclear power development nevertheless presents significant challenges, including managing the radioactive waste produced during the process, including spent fuel and radiation-contaminated materials, not to mention the economic and political challenges associated with building new plants [18, 19].

In 2022, new plants were developed that resulted in the production of 8 GW of new nuclear power, not in track with the Net Zero scenario that predicts four times annual growth by 2030 [17].

In the game, the nuclear power plant is represented by the block in figure 1(d).

Advantages:
- Nuclear fission produces almost no CO_2 during operation, generating immense energy with a small amount of fuel.
- These plants operate continuously providing consistent output.
- Nuclear energy is a low-carbon emission source, which makes it a significant component in the fight against climate change.

Disadvantages:
- Nuclear waste disposal represents a major challenge for this type of power plants, with the risk of radioactive pollution of the ground and water.
- Construction and safety measures are expensive.
- Uranium, used for fission, is a finite resource.

2.1.2. Renewable energies. In the game, five of the power plants employed can be classified as renewables:

- **Solar photovoltaics (PV).** The technology behind solar power generation is based on the photovoltaic effect, which allows sunlight to be converted into electricity. This form of energy production employs photovoltaic cells, compact and versatile modules that can be used both for domestic applications, such as powering homes, and for large-scale power generation facilities. Photovoltaic energy has a negligible environmental impact, although it still accounts for a small portion of global electricity generation (in 2022, 4.5% of the total). It is classified as a non-programmable energy source, as its production depends on weather conditions; however, solutions have been introduced to maximize energy efficiency (e.g. the use of trackers that enable the rotation of photovoltaic modules).

  In 2022, energy production through photovoltaic panels increased by 26 percent, and if these growth rates continue, Net Zero scenario forecasts for 2030 could be reached [17].

  In the game, the solar power plant is represented by the block in figure 1(e).

  Advantages:
  - Solar energy is inexhaustible and available worldwide and after installation, maintenance costs are minimal.
  - It produces no greenhouse gases or pollutants during operation and can be implemented at various scales, from small rooftops to large solar farms.

  Disadvantages:
  - Solar energy is dependent on weather conditions and daylight availability, so batteries are required to store energy during night and cloudy days.
  - The installation and infrastructure can be expensive and large solar farms require significant land area.
- **Wind turbines.** Wind power plants are considered non-programmable energy sources because electricity generation depends on wind's strength and the capacity of the turbines, which convert kinetic energy into electrical energy using the wind turbines. Onshore wind energy is a mature and well-established technology, but it continues to evolve, with a supply chain expanding globally. Offshore wind energy, on the other hand, is still in development, but holds significant potential due to the stronger and more consistent winds found

offshore, although it still requires investments and innovations to reduce costs.

To meet the Net Zero Emissions by 2050 scenario, it is expected that onshore energy production will double by 2030, while offshore energy production should increase significantly, potentially quadrupling, in order to fully harness the potential of offshore wind resources [17].

In the game, the wind power plant is represented by the block in figure 1(f).

Advantages:
– Low operational costs after the installation.
– Small or large installations providing high energy output in suitable locations.

Disadvantages:
– Wind turbines depend on wind availability and strength, which varies the energy output of the facilities.
– They can make noise and pose risks to birds.
– Turbines, and the relative infrastructures, are expensive and can alter the landscape.

- **Biomass.** Bioenergy is produced from biomass, organic material that absorbs carbon through photosynthesis. When used to generate energy, carbon is released during combustion, but an equivalent amount of carbon is absorbed again, making bioenergy a low-carbon fuel. Modern bioenergy is mainly used for heating, and although space heating is becoming increasingly electrified, it remains crucial in sectors that are difficult to electrify, such as aviation and shipping. Modern bioenergy does not include the traditional use of biomass in emerging economies, which causes environmental and health damage.

  The Net Zero Emissions by 2050 (NZE) scenario calls for a rapid increase in the use of bioenergy to replace fossil fuels by 2030, more efforts are needed to accelerate the implementation of modern bioenergy to align with the Net Zero scenario, which calls for an 8% annual increase between 2023 and 2030 [17].

  In the game, the biomass power plant is represented by the block in figure 1(g).

  Advantages:
  – Organic waste materials that can be replenished, converting agricultural, industrial, and municipal waste into energy.
  – Plants absorb CO_2 while growing, offsetting emissions during the combustion of waste.
  – Unlike others renewable power plants, biomass can provide base load power.

  Disadvantages:
  – This type of power plants are less efficient than fossil fuel combustion.
  – Transporting and processing biomass can be costly and resource-intensive, and can lead to deforestation if unsustainable in that region.
- **Geothermal energy.** Geothermal energy is a form of renewable energy that harnesses heat from the earth's subsurface, generated by the decay processes of radioactive elements such as uranium, thorium and potassium. The heat is extracted by drilling into the ground and used to produce electricity, heating or cooling. Geothermal power plants use working fluids, such as water, to transfer heat from the depths to the surface, where it is converted into electricity by turbines. This energy source has the advantage of being continuous and not dependent on weather conditions, as is the case with solar and wind.

  To meet the projections of the Net Zero 2050 scenario, geothermal energy has enormous room for growth. Today, it meets less than 1% of global energy demand, but with technological advances and cost reductions, it is projected to meet up to 15% of global electricity demand by 2050. New drilling technologies and geothermal resources at greater depths could make it possible to install plants in almost any country [17].

In the game, the geothermal power plant is represented by the block in figure 1(h).

Advantages:
– Geothermal power plants provide a consistent and predictable energy output, emitting very minimal greenhouse gases.
– They require less land compared to solar or wind farms, working at low cost after the initial investment.

Disadvantages:
– These power plants are limited to areas with significant geothermal activity.
– Drilling and setting up infrastructure are expensive, with the potential to trigger seismic activity or ground contamination during drilling.

- **Hydroelectricity:** At present, electricity generated by hydro-power plants is the leading renewable technology by converting the potential and kinetic energy of water into electricity by harnessing the movement of water masses of various sizes. The expansion of hydro-power globally is expected to slow down in the coming decades, mainly due to the increasing irregularity of rainfall caused by climate change, which makes hydro-power projects less and less cost-effective.
Therefore, in the Net Zero Emissions by 2050 scenario, hydro-power generation will not be the main renewable source, but will continue to contribute with an annual growth rate close to 4% between 2023 and 2030, however, over the past five years the average growth rate has been less than one-third of what would be needed, indicating the need for much stronger efforts to meet the targets [17].

In the game, the hydroelectric power plant is represented by the block in figure 1(i).

Advantages:
– The hydroelectric power plants rely on the water cycle, which is constantly replenished, providing base and peak load power.
– They produce no greenhouse gasses and operate for decades if proper maintained.
– Hydroelectric power plants can also be used as natural energy storage.

Disadvantages:
– Dams infrastructures are expensive and they disrupt ecosystems like rivers flow and fish migration.
– Droughts and climate change can reduce efficiency.

2.2. Game statistics

For the gameplay, three primary parameters were introduced for each power plant:

- Energy production, measured in TeraWatt-hours (TWh);
- Carbon dioxide (CO_2) emissions, expressed in tons (1 ton $= 10^6$ kg);
- Operating costs, presented in US dollars.

The values of these parameters were sourced from various publicly available datasets and subsequently analysed and organized into a structured analysis file. This allowed for the consistent and realistic integration of the data within the game environment. Additionally, an estimate of the total number of active power plants worldwide was incorporated into the initial conditions of the game, ensuring that the gameplay accurately reflects the current state of the global energy sector.

These values are written in table 1. The data used refers to the year 2022, as the corresponding dataset was the most complete compared to more recent ones. Furthermore, statistical fluctuations were considered negligible for comparable data.

For educational purposes, the game also introduced a symbolic parameter representing global energy demand, calibrated to match the average annual energy consumption on a global scale.

Each game session spans a fixed period of time, equivalent to approximately 100 yr in the real world, creating an in-game challenge that encourages the player to work hard to achieve goals while simultaneously allowing him to learn current concepts and issues. This temporal framework facilitates a direct connection between the player's decisions and the scenarios outlined in

Table 1. Values used in the game related to each power plant.

	PV [a]	Wind	Hyd [b]	Biomass	Geo [c]	Coal	Oil	Natural gas	NP [d]
Energy (TWh)	1	8	4	64	13	347	250	137	1000
CO_2 (tons)	1	0	0.2	4	5	1000	6	116	0.2
Price ($)	186	241	433	635	432	572	642	249	1000
Number	20	6	6	4	2	2	4	8	2

These values were obtained by making a proportion from actual values obtained from *U.S. Energy Information Administration (EIA)* datasets [17] referred to 2022. The first column refers, in order, to the values reported for energy production, CO_2 emissions, the price associated with each power plant, and the number of initial power plants in the game.
[a] Solar photovoltaic
[b] Hydroelectricity
[c] Geothermal
[d] Nuclear Power

the IPCC *Climate Change 2023: Synthesis Report*. In this way, the game establishes a meaningful link between the in-game actions and the real-world projections, perfectly fulfilling the educational purpose of the project.

3. Our challenge in 'Minecraft: Education Edition'

3.1. Software

The software used is Minecraft: Education Edition (MEE) [20], a specialized version of Minecraft designed for educational use in schools. It provides tools and features specifically developed to support teachers and students in learning through gameplay. We make use of 'Blockbench' [21], a free 3D modelling software designed to create low-poly models, to create the in-game blocks (e.g. see figure 1). This software allows users to easily create simple, or more complex, block models directly in a format compatible with Minecraft Java Edition, Bedrock Edition, and MEE.

3.2. Game

The game is designed to raise awareness about climate change, with a focus on educating the players about the importance of different energy sources. It introduces players to both non-renewable energy sources (coal, gas, and oil) and renewable ones (solar, wind, hydroelectric, biomass, geothermal, and nuclear).

Particularly aimed at school-aged players to raise awareness of climate change among young people, this game realized in MEE remains accessible and enjoyable for all audiences. Players begin their journey in a small stylized island, representing the planet Earth, (figure 2), starting on a small platform that serves as a central hub, shown in figure 3. From here, the players can learn the available power plants in the game, already reported in section 2. From this hub, the players have the option to start or stop the match, and to reset the game world, allowing them to experiment with different energy strategies and outcomes.

The game starts pressing the button 'start match'. In the HUD, shown in figure 4, several information needed to play the game are illustrated. The Hot-bar (figure 4 (a) allows the player to rapidly access nine inventory slots, each of which has a different power plant that the player can place. The number of placed power plants is given by a table, indicated in figure 4(b). At the beginning the map presents a certain quantity of power plants, reflecting the current real world energy situation, and the table updates itself every time a power plant is placed. Some power plants have different criteria for which blocks they can be 'placed on' or 'placed next to'. In general, power plants can not be placed on 'sand' blocks, as sand is not suitable for building on. Hydroelectric plants can be placed over 'lapis lazuli' blocks present along rivers, since the dams have to block the flow of the rivers. Geothermal plants can be placed only on volcanic regions of the map. Solar and Wind turbine plants can be placed in all regions. Biomass can be placed

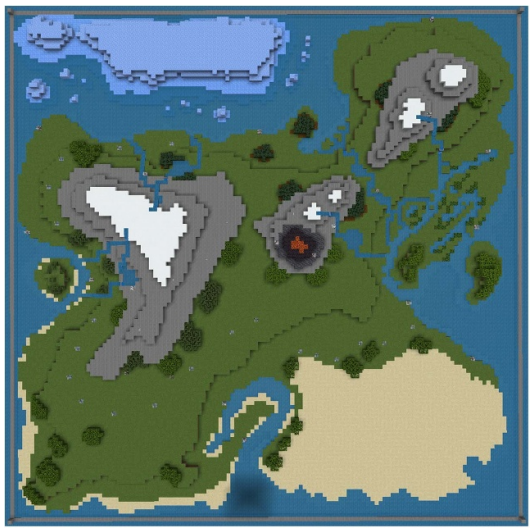


Figure 2. Game World. The island represents a small version of different biomes of the Earth. Starting from the top, we have cold biomes, then a big, jagged mountain region on the left, and a mountain range on the right. in the centre we present a small volcanic region and a more temperate regions with plains, forests and a swamp region on the right. At the bottom, is present a more flat plain region on the left, and a big desert biome.

Figure 3. Game Hub. The Hub presents three main buttons to *start* (green button), *finish* (red button) and *reset* (blue button) the game world. All around are shown the power plants blocks which can be placed during the game experience, presenting the block and the relative name on a sign placed in correspondence of each one.

on blocks next to a wooded area, represented by 'leaves blocks' on the map. The other power plants can be placed over all blocks which are adjacent to a 'water' block, due to the necessity of water for the operation of the power plant. Each power plants has different placing cost, CO_2 and energy production. Other important information are given by a small overlay over the Hotbar. Here, the energy produced and requested are indicated by two numbers (figures 4(c) and (d)). The global increasing temperature (figure 4(e)), in Celsius degree) is an important information, which gives an idea over the global warming. In the overlay are also indicated the remaining time (figure 4(f)) and the 'money' (indicated in figure 4(g)), which are given to the players every second to build the different power plants.

The players have ten minutes to play. The objective is to save the planet by removing (or decrease) the number of non-renewable power plants with renewable ones by slowing down the rising of temperature due to the increase of CO_2 and other greenhouse gases. When time is up, each player is given a score based on their energy production and the resulting temperature increase. The lower the temperature reached, the higher the

Figure 4. In Game HUD. In the picture is presented the player 'Head-Up Display' (HUD), which indicate the information that are constantly visible during the game in overlay (The game in the picture is played in the Italian language). (a) The 'hotbar', nine inventory slots which can be rapidly selected and used. (b) A tab representing the number of power plants present in the map. (c) the amount of produced energy by all the power plants. (d) The energy required to have at the end of the game. (e) The global temperature increase, expressed in degrees Celsius (°C). (f) The remaining time. (g) The quantity of money available to place the power plants.

score multiplier. At this point, the player can can press the 'reset game world' button and start a new game or allow another player to take their place (if playing one at a time).

Through interactive gameplay, the game encourages critical thinking and helps players understand the role of energy choices in combating climate change. It fosters curiosity and sparks meaningful discussions about the balance between renewable and non-renewable energy sources, making it both educational and fun for players of all ages.

4. Conclusions

The integration of gamification within educational platforms like Minecraft Education Edition presents a unique and promising approach to addressing climate change awareness. By leveraging the engaging and interactive nature of gaming, educators can foster a deeper understanding of environmental issues among students. This method not only enhances learning outcomes but also empowers the younger generation to become proactive in combating climate change. As showed in this work, the challenge lies in effectively designing and implementing these gamified experiences to ensure they are both educational and impactful. By structuring the game referring to real data on climate changes and creating a time'challenge' for players, we have successfully developed a game model that, accompanied by a theoretical approach to sciences (such as physics) related to renewable and non-renewable energy plants, allows the player to acquire knowledge and awareness about climate change. In fact, our work has already received several positive feedbacks, having partially presented the activity at schools and scientific dissemination events. Future research should focus on refining these strategies by improving our game model, updating the data used to the current situation, and exploring their long-term effects on students' attitudes and behaviours towards climate change. Ultimately, gamification in education holds the

potential to transform how we educate and inspire future environmental stewards.

Data availability statement

The data cannot be made publicly available upon publication because they are not available in a format that is sufficiently accessible or reusable by other researchers. The data that support the findings of this study are available upon reasonable request from the authors.

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