An Agent-based Model of the Earth System & Climate Change

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***Abstract*—Simulation is a computer-based experimentation tool suitable to determine the efficacy of a previously untried decision. In this paper, we present a model of climate change. The goal behind this project is to provide a test-bed to evaluate theories related to the Earth system so as to test and evaluate metrics such as greenhouse gases and climate change in general. The proposed approach is based on a multi-agent model which has as input a representation of nature and as output the changes that will occur on Earth within a given instant of time. Most views about climate change do not take into account the real severity of the subject matter; however, the present perspective is given in a way so as to make non-experts aware of the risks that are threatening life on Earth. Just recently, the general population has developed considerable sensitivity to these issues. One important contribution of this work is to use agent-based modeling and simulation as an instructional tool that will allow people to easily understand all aspects involved in the preservation of the environment in a more aware and responsible way.**

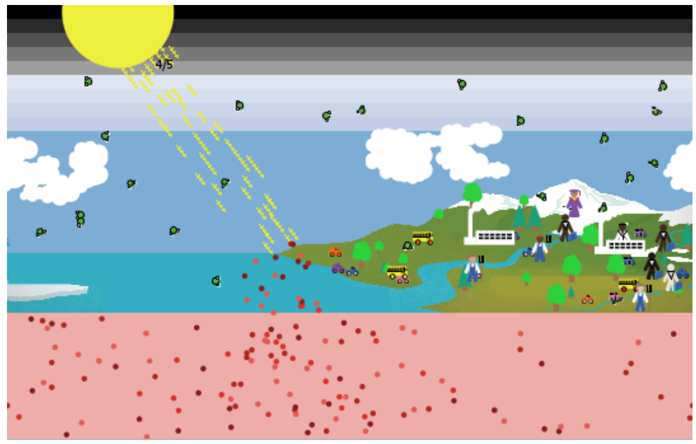

Figure 1. The new NetLogo model of climate change.

I. INTRODUCTION

The increasing number of vehicles and factories everywhere is the major cause of global warming [1]. In ecology, simulation is a tool that is used to study the complex relationships between all the elements of nature and simulate the natural phenomena before their actual occurrences. As for other specialists, ecologists as well study the risks and effects of irresponsible decisions made over the ecosystem. One of such decisions, for example, is the satisfaction of men's economic greediness, ignoring the serious damage inflicted on nature. The issue has had a global dimension and many international conferences have taken place to warn mankind and make them aware of both the existing risks and the expected ones in the future. To save nature from men's destruction, it is imperative that we all develop a social awareness of preservation.

This paper proposes an agent-based model of climate change using a social simulation platform, namely NetLogo [2], as a test-bed to experiment with different configurations. NetLogo allows for rapid prototyping of agent models and experimentation of different policies. As a result, the framework can be used as an instructional tool besides serving as a simulation asset. This paper is organized as follows. The materials and methods section describes the model and discusses its different inputs and outputs. In the data collection section, we will present the approaches used to collect data, whereas in the data analysis and discussion section, we analyze the data and explain each point so as to make it easily understood by non-experts. At the end, we will conclude the paper remarking main achievements and envisaging trends for future work.

As this model is intended for educational purposes, it follows the same path as the one followed by the United Nations for fighting climate change.

II. LITERATURE REVIEW

During their studies about the behavior of the Earth system, a number of researchers in nature and social sciences realized that this behavior is, most of the time, different from each individual agent behavior within the same system [3]. The behaviors of these systems acquire properties during these situations [4], whereas systems formed up by agents that are relatively independent do not. The systems where each agent behavior is influenced by the other agents are called complex systems. Even thought the prediction of changes that will occur on earth is difficult due to the complexity of the Earth system, it remains possible to gain essential insights into important Earth patterns. The NetLogo library contains a simple model of climate change [5] that demonstrates only a part the Earth system. That is why this model, depicted in Fig. 2, needs some improvements. The equation has now multiple variables and the updated version of the aforementioned model can cover a large part of the actual complexity of the Earth system.

III. MATERIALS AND METHODS

The model depicted in Fig. 1 was developed in a multi-agent programming language and modeling environment for simulating complex phenomena, namely NetLogo [2].

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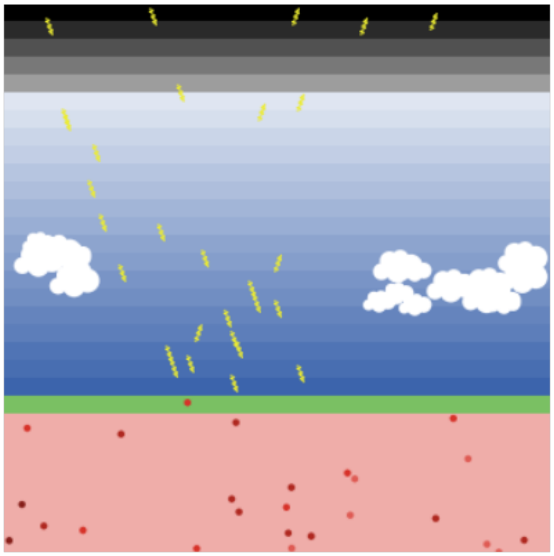

Figure 2. The original NetLogo model of climate change.

Table I
PARAMETERS

Parameter	Value
Sun brightness	From 1 to 5
Albedo	Auto
Landscape	Field / Desert
Population	Add / Delete
Trees	Add / Delete
Factories	Add / Delete
Cars / Buses	Add / Delete
Days simulated	Max 3 days
Co2 emission factories	Percentage
Co2 emission vehicles	0 to 12 hours / day
Rain intensity	Percentage

Such a computational environment is used across a wide range of educational levels as a tool for both teaching and research. As a programming language, NetLogo, is simple and highly recommended for any open source development and can be easily adopted by people without any previous programming abilities. An example of using NetLogo in other domains include the simulation of crowds and pedestrians [6].

The structure of the model is based on many climate theories which allow the user to run multiple scenarios. The scenarios are defined by multiple inputs set by the user after the environment modeling is concluded. While modeling an environment scenario, the user is able to set up the following parameters summarized in Table I :

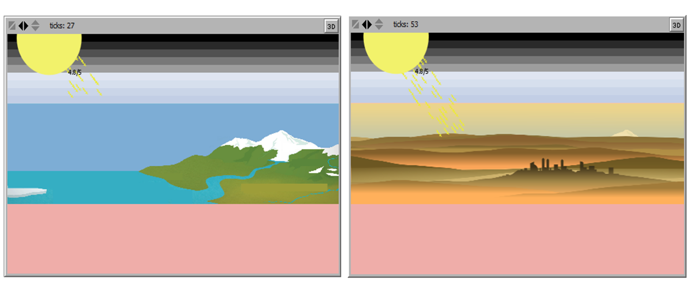

Figure 3. Field and Desert.

A. *Landscape*

Two types of landscapes are now available: field and desert. The field landscape depicted in Fig. 3-Left is set by default and contains three types of landscapes: sea, field and icy grounds. The second landscape is desert as depicted in Fig. 3-Right. Selected to illustrate the effect of climate change at a regional scale. The Earth behaves as a system in which oceans, atmosphere and land, and the living and non-living parts therein, are all connected [7].

B. *Sun Brightness*

A value of ”1” corresponds to the current position of the sun. Higher values would allow us to see what would happen if the Earth were closer to the sun in its orbit, or if the sun got brighter. Climate is influenced by natural changes that affect the amount of the solar energy that reaches the Earth.

- Changes occurring in the sun Fig. 5-a itself can affect the intensity of the sunlight that reaches the Earth’s surface. The intensity of the sunlight can cause either warming (during periods of stronger solar intensity) or cooling (during periods of weaker solar intensity).
- Changes in the shape of the Earth’s orbit as well as the tilt and position of the Earth’s axis can also affect the amount of sunlight reaching the Earth’s surface: aphelion and perihelion [8].

C. *Dynamic Albedo*

Each landscape absorbs the sun energy in a different and specific way. The sea absorbs 100% of incoming energy; the ground absorbs from 50% to 60%; however, ice reflects all the incoming energy. That is to say it avoids warming. The model is developed to automatically detect the type of the land (ground, icy, or sea) for the reflectiveness process as it appears in Fig. 4). The blue rays are the reflected incoming energy from the green land according to the rule of 50% to 60% of absorption.

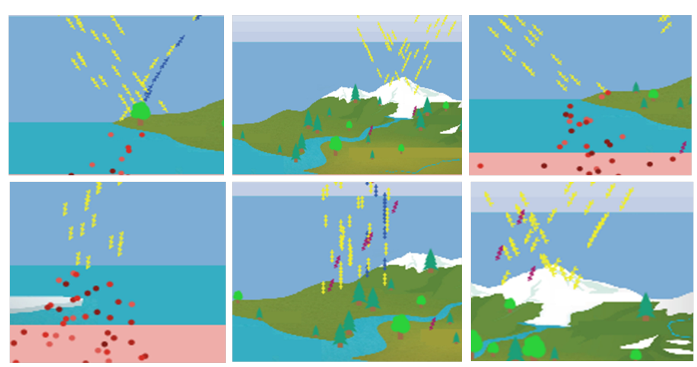

Figure 4. Reflection of sunlight

D. Earth System

The equilibrium between the entering energy (yellow rays in Fig. 5-k) and the leaving energy (purple rays in Fig. 5-i) from the planet system relies on the Earth's temperature. The Earth becomes warmer if its system absorbs the external incoming energy from sunlight [9]. However, when solar energy is reflected due to clouds Fig. 5-h, the planet is no warmer and the sunlight is reflected back to space (red rays in Fig. 5-j). In addition, the Earth becomes colder when the absorbed energy is released into space (purple rays in Fig. 5-i).

There are numerous causes of global warming, and they can be either natural or human.

- Variations in the sun's energy reaching the Earth.
- Changes in the reflectiveness of the Earth's atmosphere and surface.
- Changes due to effects of the greenhouse gases, which affects the amount of heat retained by the Earth's atmosphere

For decades now, scientists have analyzed a number of scientific measurements on ice cores, glacier length, boreholes, etc. and have studied the changes that have occurred in the Earth's orbit which happen around the sun in order to construct a picture of the Earth's climate.

Yet, natural factors alone are not the only cause of global warming; there are also man-driven activities and behavior, such as the factories and vehicles smokes. Prior to the seventeenth century, the Industrial Revolution was the period when human activities were the starting point of climate change, thus considered today as the dominant causes of global warming.

E. Trees Density

Photosynthesis is a process in which sunlight is used by and carbon dioxide (CO2) is absorbed from the atmosphere; consequently, carbon, water and nutrients are used to make up the wooden body of trees. For this reason, the convenient way to fight global warming is to plant more trees because they play a major role in reducing carbon dioxide from the air. However, to play their role effectively, trees Fig. 5-b should be planted in specific places. Forests are the great providers of oxygen for the world's ecosystem because they accumulate 20 to 50 times more CO2 than any other natural elements which is illustrated in [10]. From this standpoint, tropical forests are exceedingly essential as their biomass is substantial. In these areas, 50% more of carbon dioxide is absorbed than in any other wooded spots. In virtue of deforestation i.e. destruction of trees, the volume of carbon dioxide which is released as greenhouse gases in the atmosphere has increased a lot. As a result, these greenhouse gases significantly cause global warming. If carbon dioxide is not reduced, the temperature on Earth will continue to rise. Thus, a huge number of animals, plants and species will undoubtedly disappear. It is clear that global warming is a matter of life or death to humanity. In this vain, many scientists are raising the alarm about this phenomenon.

In the implemented simulation, the user is able to set a number of trees directly using the slider or simply by clicking a button to add trees. For a significant result, it would be better to set the right number of trees given in the user's region. The correlation between the presence of trees and global temperature is significant.

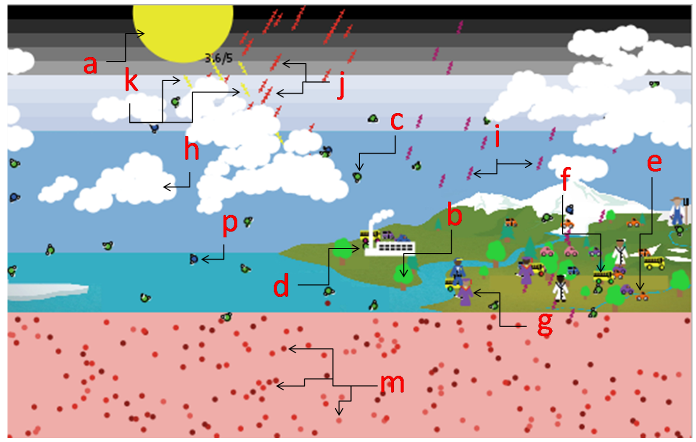

Figure 5. Model principal elements

F. Greenhouse Gases

A value of 0% in the slider for the CO2 emission from factories corresponds to non-functional factories; a higher value allows the variety between all type of factories and their respective degree of gas emission. While a small amount of greenhouse gases is produced naturally, the majority is emitted by human activities.

The massive use of fossil fuels (hydrocarbons: coal, gas, oil), deforestation, livestock and intensive agriculture produce large amounts of greenhouse gas that is poured in the atmosphere [11].

The CO2, is the most abundant gas emitted by human activities alone provides 1/3 of the greenhouse effect [11]. In our model, the amount of CO2 added is proportional to the factories CO2 emission as well as the number of vehicles. Carbon is emitted according to the following rules:

- At 75%, by factories Fig. 5-d. It is a source of energy to:
  - **Real representation** : The factories
  - **Model representation**: Factories have a big effect on the greenhouse gases on the atmosphere. The factories emit only the CO2 in the current model.

  The user is able to set a number of factories. For a significant result, it would be better to set the approximate number of factories given in the user's region.
- At 25%, by transportation, defined as follows:
  - **Real representation** : Road transport.
  - **Model representation**: When running, cars and buses produce an amount of CO2 every n moves where n is given 15 by default.

  Pollution boosts the climate change; it remains important to join the cars depicted as Fig. 5-e and buses depicted as Fig. 5-f to our model as well.

G. *Population*

People modeling is relevant to guarantee a good approximation to reality Fig. 5-g. It increases the degree of similarity to the real world.

- As well as for the CO2 (green molecule Fig. 5-c) and the Methane CH4 (blue molecule Fig. 5-p) which are emitted by cattle excrement and other ruminants in intensive farming [11], we related this gas to the presence of people in our model Fig. 6.

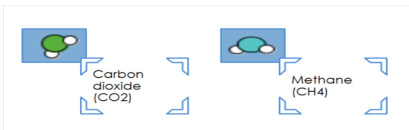

Figure 6. Molecules of CO2 and CH4.

The CH4 is emitted after 300 walking steps of each person.

Other important inputs can also be set on the model through the new user interface, such as:

- The time of the simulation (per day)
- The rain intensity
- Enabling natural rain fall
- The time of vehicles run

Multiple buttons are used for the configuration of the interface between the model and the user analyzing different scenarios:

- Add car / Remove car, Add bus / Remove bus
- Add tree / Remove tree
- Add people / Remove people
- Start vehicles / Stop vehicles
- Start sun / Stop sun
- Start factories pollution /Stop factories pollution
- Add factories / Remove factories
- Add clouds / Remove clouds
- Add CO2 / Remove CO2

IV. DATA COLLECTION

The model in hand provides data to be analyzed, depending on the scenario carried out. The model computes Earth temperature, the amount of greenhouse gases and people's concerns.

The scenarios (number of cars / trees / factories, etc.) are the key actors in our analysis; they are used to test the accuracy of the model. The results that are analyzed are the global temperature and levels of greenhouse gases. Assuming, sun brightness is equal to 1, we carry out the following scenarios:

- **Scenario 1** - We propose a scenario which represents the desired world, a world without any CO2 emitter, with no climate change effect. The model contains simply an amount of people and trees.

Albedo	Factories	Cars	Buses	Trees	People
Auto	0	0	0	60	20

- **Scenario 2** - The second scenario is a balance between carbon emitters and the number of trees. A moderate number of factories and cars/buses.

Albedo	Factories	Cars	Buses	Trees	People
Auto	3	22	4	60	20

- **Scenario 3** - Here, trees are removed (from the second scenario) and the factories, cars and buses are kept.

Albedo	Factories	Cars	Buses	Trees	People
Auto	3	22	4	0	20

- **Scenario 4** - Trees are added back to the model.

Albedo	Factories	Cars	Buses	Trees	People
Auto	3	22	4	34	20

The aim is to analyze the evolution of global warming effect after each scenario, analyze the results and report the flaws.

V. DATA ANALYSIS AND DISCUSSION

In this section, we will perform a detailed analysis about the available data after carrying out the model step by step, starting by the modeling of a typical spring day Fig. 7 and following it up with a typical winter day Fig. 10. It should be noted that the formulas of greenhouse gases emissions are not based on the right amounts emitted in the real world but the values are appropriate for demonstration purposes.

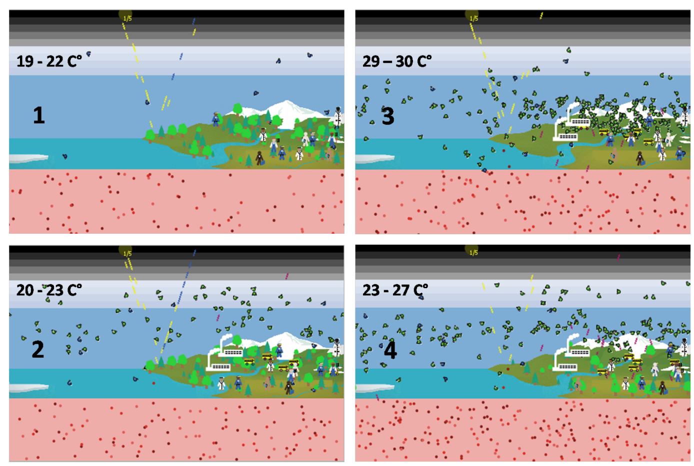

Figure 7. Four scenarios of a spring day

In the first scenario, we notice that there is no CO2 emission and no clouds but an occurrence of CH4 gas due to the presence of people. The temperature looks normal and static. At the beginning of the day the temperature goes from (12°) to (19°) and ends at (22°) in the mid-day as a maximum value as depicted in Fig. 8.

In the second scenario, the trees create a certain equilibrium in the global temperature, since the temperature evolution is not different from the first scenario; however, the temperature increases by one degree. As for the level of CO2, it is quite good since the amount does not exceed 28.

In the third scenario, the absence of the trees leads to a higher increase of the global temperature. It is observed between (24°) and (29°) and ends at (30°) in mid-day as a

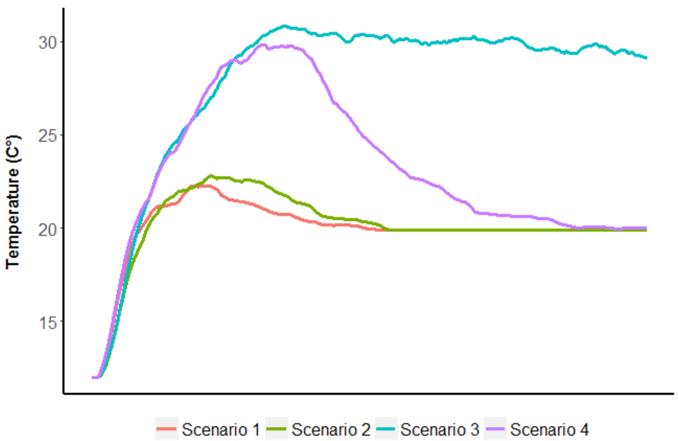

Figure 8. Temperature evolution in a spring day

maximum value. Besides, the CO2 level reaches the top by an amount of 1000 (see: Fig. 9).

Finally, at the fourth scenario, the temperature before and after plantation of new trees is totally different. The temperature before adding trees is between (24°) and (29°) and ends up to (30°). After adding trees, the temperature recovers its normal state: (19°) to (23°). The CO2 level follows the same trend.

As aforementioned, the user is able to set clouds on the model. The clouds appear both automatically and manually. Automatically, the Earth warms and the sea starts to evaporate. The rain system is implemented. First clouds appear and then it starts to rain; that is to say simulating a winter day . The clouds reflect the sun rays (yellow rays) back to space (red rays) i.e. the Earth avoids warming, as it appears in Fig. 5-m, the red points underground decrease.

During the first scenario of the winter day Fig. 10, the simulation gives us a temperature around (12°) during all the day. The global temperature in winter is low in reality as well

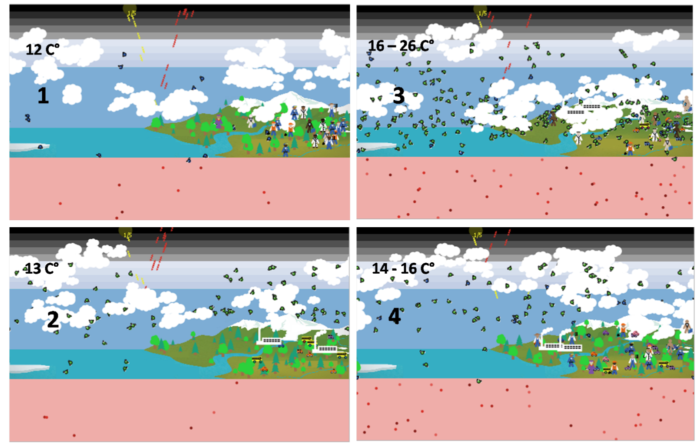

Figure 10. Four scenarios of a winter day

as in the model simulation. Clouds are the key actors of these results. To avoid warming, clouds reflect the sunlight back to space and the temperature remains static or decreases.

As for the second scenario, the correlation remains equal to a spring day simulation, following the same decrease of the global temperature in the first simulation. The global temperature does not exceed (13°) (see: Fig. 11).

In addition to the decrease of the global temperature, the lack of trees remains the key player for a climate change effect since the temperature is observed increasing throughout time. The maximum degree observed is (27°).

Just like the spring day, the trees are added back to the third simulation of a winter day. The temperature has stabilized but does not go less than (16°) that is to say; it does not decrease immediately like in the spring day.

VI. CONCLUSIONS AND FUTURE TRENDS

This model is developed for educational purposes. Although it is a virtual process, it helps us take part in the protection of our Mother Earth. The model also contributes in fostering

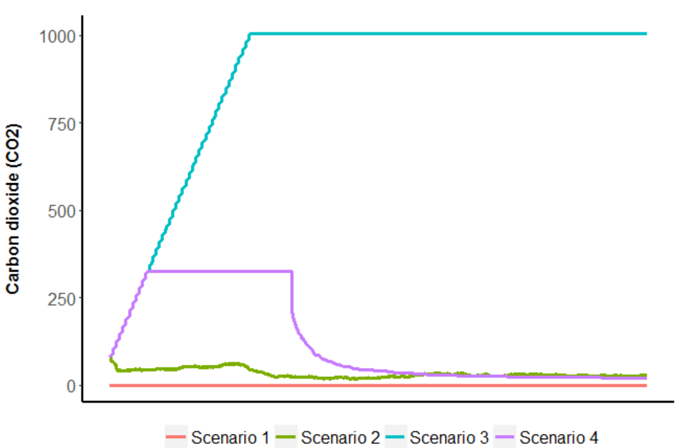

Figure 9. CO2 levels in a spring day

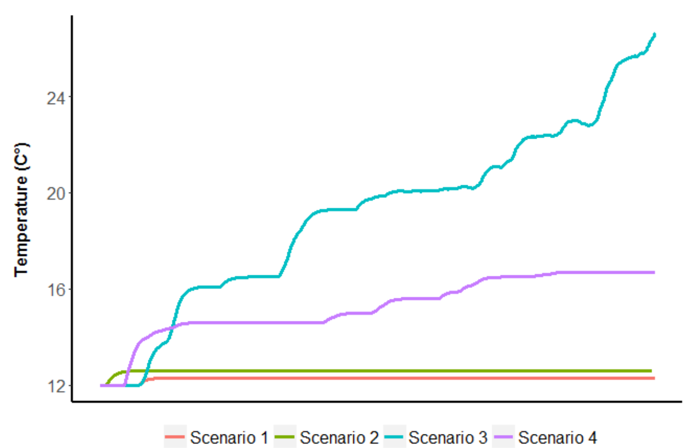

Figure 11. Temperature evolution in a winter day

understanding of the climate change effect and the Earth system. However, we believe that the current model still needs maturation time and further effort to be improved. One possible improvement will include a deeper exploration of concepts such as serious games and gamification as a behavioral modeling tool [12], and a mechanism to incentivize behavior change in a positive and constructive manner [13].

For the current stage, the model gathers only the high influencers on climate change effect but not all of them. It would be appropriate to this study to update the model by implementing all the actors on the climate change effects. This could be done through a more robust agent-based modeling methodology, such as the one proposed by Passos and colleagues [14].

Apart from education, the model needs also to be introduced to biologists as well as chemists to update the formulas applied in it for more accuracy and to carry out simulation per year(s). This will give us an idea of the future trend of the global temperature. We also believe that this model would help ecologists to predict the amount needed of green spaces on any region relatively to its amount of greenhouse gases emitters. Different simulation models, with different purposes and resolutions can also be considered for more complex analysis of multi-variate formulations, following the principle of simulation interoperability [15].

The model is an educational project to promote sustainable development on the purpose of climate change. This project gathers different fields (e.g. science, geography, mathematics and ICT), and highlights the contribution of all of us through an educative virtual world.

It helps also to understand the mechanisms of climate change, via human or natural causes and their consequences on the global temperature. These will raise awareness to protect the environment in our daily actions and empower ourselves by becoming aware of our role both as human beings and citizens.

VII. Acknowledgment

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