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Analysis on the effect of human activities in the average global temperature

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Abstract— *In 2015, the challenge posed in Paris washow to regulate the consumption in the near future, to hold the increase of the temperature in this century below 2 degrees Celsius above pre-industrial levels. Considering the fact that the planet's temperature variation is the consequence of the increase of human activities over time, it is fundamental to build a mathematical model to diagnose the impact caused by human activity. In this context,with this research work, we developed a mathematical model which theoretically predicts the temperature variation, and with that, present possible scenarios considering human activity (Gross Domestic Product and demographic growth) over the last 100 years.With this model, it may be confirmed that the accumulation of economic wealth and nations' demographic growth generates an over exploitation of natural resources which leads to an increase of the average global temperature.*

Keywords— ***environment, temperature, human activity and models.***

I. INTRODUCTION

In December 2015, in Paris, France, 195 nations reached a historical agreement to address climate change and promote measures and investments for a low-carbon emission, resilient, and sustainable future.

To this end, it was proposed to reduce greenhouse gas (GHG) emissions which are identified as the main cause of global warming (increase in the average global temperature) according to the Kyoto Protocol ratified in 2009. This protocol stipulates that the increase of the atmospheric concentration of gases, such as carbon dioxide (CO2) and methane(CH4),is mainly associated with fossil fuels used by humans to produce energy for industrial processes.

It is important to clarify that not all changes in the weather system are exclusively due to emissions or other human actions. In fact, these anthropogenic emissions are combined with the natural weather variability, producing a long-term trend of a gradual temperature increment which is highly associated with global warming.

The challenge posed in Paris is how to regulate the consumption of natural resources, fuels and other goods and services, so that we may live in a dignified manner and with equity in the near future. Also, keep the temperature increase in this century well below 2 degrees Celsius, and promote efforts to limit the rise in temperature even further, below 1.5 degrees Celsius above pre-industrial levels.

This is a major challenge, not only for politicians, but also for the scientific community that needs to be involved and seek solutions through alternative energies or other procedures to reduce the use of fossil resources.In addition, they need to achieve more sustainable consumption patterns which allow us to reduce the emissions and the impact of human activities on a global scale.

According to the Intergovernmental Panel on Climate Change (IPCC,2000a) report on Emissions Scenarios, the "main determining forces of the future greenhouse gas trajectories will continue being demographic change, social and economic development, as well as the speed and direction of technological change".

One way to measure the economic activities of an entity is by calculating the Gross Domestic Product (GDP), which is defined as "the sum of the value of all goods and services produced in a country in a year" (Mochón, 2008).

Therefore, economic growth (accumulation of wealth through GDP) leads to an over-exploitation of resources or "unsustainable development" (López, 2012), activity that emerging economies continue to do in order to reach a status at the level of developed countries.

Additionally, it has been shown that population growth generates a major environmental impact on land and natural resources (Costeau, 1992), just as Thomas Robert Malthus presented in his book "Essay on the principle of population" in 1826.He raised the hypothesis: "the capacity of population growth followsa geometric progression, whereas the rate of the increase of the resources for the population's survival only follows an arithmetical progression".

Population growth leads to a greater demand for natural resources, putting pressure on natural reserves. In addition,

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most human activities generate a large amount of pollutants. Burning large amounts of fossil fuels produces greenhouse gases, which have caused immense variations in the temperature of the planet, further degrading ecosystems; (Semarnat, 2010).

Throughout history, a limit has been observed in the capacity to absorb the impact of human development, however, different societies have perceived and responded to those limits differently (Costnaza et al. 2006; Sörlin and Warde, 2009, p.). A regulatory approach was developed defining "safe limits" for human activities locally (Crowards, 1998), but now we also face planetary limitations. This as a consequence of the increased atmospheric concentrations of CO2 and global warming, caused by human activities and the use of resources, especially since the mid-twentieth century (Steffen Et al, 2007), where environmental conditions for development and growth began to deteriorate (Steffen et al, 2004; IPCC, 2012; IPCC, 2013). This implies that the economic system must be kept within the load capacity margins of the planet, understanding sustainability as development without growth or as qualitative improvement without quantitative increases.

It is clear that at some point, our modifications will cause unacceptable and irreversible changes in the resources on which we depend (CBD, 2014, IPCC, 2014, UNEP, 2013).

In this context, the objectives of this work are the following:

- Analyze by means of algebraic equations, the dynamics of temperature variation and its effects on natural reserves, based on changes experienced by human activity over time.
- Build an alternative scenario that allows us to control or minimize temperature variations, to optimize natural reserves.

By means of these objectives, we have the following assumptions:

- "Higher growth of the GDP and population leads to higher human activity"
- "Higher human activity leads to higher temperature variation"
- "Higher temperature variation leads to higher exploitation of natural reserves"

As a comparison with other mathematical models on the same matter, we can mention those made by the Intergovernmental Panel on climate Change (IPCC).They consider that to formulate projections on the impact of anthropogenic disturbances of the climate system, it is necessary to calculate the effects of all key processes involved in these components of the climate system and their corresponding interactions. These climatic processes can be represented in mathematical terms based on physical laws such as the mass conservation, the momentum conservation and the energy conservation.

All their climatic system models contain empirical parameterizations; and no model obtains its results solely with fundamental principles. The most important conceptual difference between the simple and complex models is the hierarchical level in which the empiricism is introduced. The choice of the most appropriate level of parameterization in the modeling of the climate system is a qualitative decision based on the best scientific knowledge and the conditionings of computing. (IPCC, 2000).

This work proposes mathematical model in a theoretical framework, based on the assumptions established above, which are based on complex systems such as demographic growth and socio-economic development. This is intended to minimize the impact of empirical parameterizations.

Just as the IPCC points out, a particular question may be raised: How do we know if the model predictions are credible? Today, science recognizes that there is no way to prove the absolute truth of any hypothesis or model, since it will always be possible to find a different explanation for the same observations. This paper aims to give another possibility to explain the impact of Climate Change in the sustainability of our resources.

II. METHODOLOGY

The building of a mathematical model of global warming is proposed in four phases (Ríos, 1995):

1- Mathematical formulation: this phase consists of transcribing through a mathematical language the functionality that the GDP and demographic growth have over human activity, and this, with the global temperature variation.
2- Resolution: in this phase, all appropriate mathematical operations are executed to obtain logical and adequate results of the dynamics of the global warming phenomenon.
3- Interpretation: in this phase, the theoretical results of the model are explained through graphs.
4- Prediction: in this last phase and through the interpretation of results, the possible scenarios of the global warming phenomenon are created.

The target population for this study is the global temperature variation, taking as reference human activity (GDP and demographic growth) overa time period: 1860 – 2014.

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III. BUILDING THE MATHEMATICAL MODEL

Mathematical formulation

In order to predict global warming, a mathematical model is established which reaffirms the relationship between the average temperature variation and human activity rate:

$$\mathrm{Tp} = \mathrm{f}(\theta)$$

where:

- Tpis the temperature variation rate over time.
- θ is the of human activity rate over time.

The human activity rate will be a function of GDP and DG:

$$\theta = \mathrm{f}(\mathrm{GDP}, \mathrm{DG})$$

where:

- GDPis the Gross Domestic Product over time.
- DG is Demographic Growth over time.

In addition, the temperature variation rate $V_t$has an effect on ecological reserves:

$$\mathrm{R} = \mathrm{f}(\mathrm{Tp})$$

where:

- Ris the total ecological reserves over time, which must be understood as the natural spaces where large quantity of species, animals and vegetables coexist together with abiotic factors such as water, soil, and sunlight. The increase in temperature generates climate change effects on the life of the planet, which result in the disappearance of some species, animals and vegetables, and with that, there is a risk of the food chain disappearing.

By means of what was previously analyzed by specialists in the environment, we have enough elements to build such equations[1], which are supported in the development of mathematical models[2]over time:

$$\theta = \mathrm{f}(\mathrm{GDP}, \mathrm{DG}); \quad \mathrm{Tp} = \mathrm{f}(\theta); \quad \mathrm{R} = \mathrm{f}(\mathrm{Tp})$$

Resolution of the mathematical model

In the Climate Change report presented by the EULA- Chile Center in 2015, global warming has increased exponentially, as the average temperature of the planet has increased by 0.74ºC from 1860 to 2014 (Gallardo, 1997).

[1]An equation is a ratio that expresses the equality of two algebraic expressions. It usually involves one or more variables and the symbol of equality (Arya, J. & Lardner, R., 2009).

[2]A mathematical model is a simplified representation of reality, with the purpose of understanding, changing, managing and controlling the behavior of a given phenomenon (García, 2015).

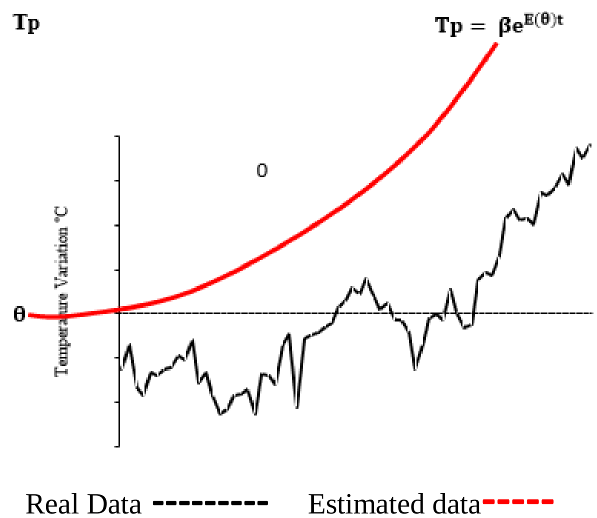

Fig.1: Behavior of temperature variation in the planet. Source. Global Climate Change

where:

- Tp is the temperature variation.
- $\mathrm{E}(\theta)$ is the expected value of the human activity rate.
- t is time.
- β is the expected value of temperature variation when human activity does not intervene over time.

From figure 1, it can be seen that the derivative of temperature variation with respect to time is called “marginal temperature variation”, which is interpreted as the change experienced by temperature variation before a change in human activity over time:

$$\frac{\Delta \mathrm{Tp}}{\Delta \mathrm{t}} = \frac{\mathrm{dTp}}{\mathrm{dt}} = \mathrm{E}(\theta)\mathrm{Tp}$$

Starting from the algebraic expression, the mathematical demonstration of the model of temperature variation is the following:

$$\frac{\mathrm{dTp}}{\mathrm{Tp}} = \mathrm{E}(\theta)\mathrm{dt} \rightarrow \text{clearing the time differential}$$

$$\int \frac{\mathrm{dTp}}{\mathrm{Tp}} = \int \mathrm{E}(\theta)\mathrm{dt} \rightarrow \text{through differential equations}$$

$$\ln|\mathrm{Tp}| = \mathrm{E}(\theta)\mathrm{t} + \mathrm{C}; \rightarrow \text{clearing } V_t$$

Therefore:

$$V_t = \exp\{\mathrm{E}(\theta)\mathrm{t} + \mathrm{C}\} = e^{\mathrm{E}(\theta)\mathrm{t}+\mathrm{C}} = \beta e^{\mathrm{E}(\theta)\mathrm{t}}; \ \beta = e^{\mathrm{C}}$$

Through this last equation, the dynamics of temperature variation can be described and with that, predict its effects on ecological reserves. The resolution of the model lies in determining the functionality of the human activity rate r, which is expressed in the following way:

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$$\theta = \mathrm{f(GDP, DG)} \rightarrow \text{symmetrising the information}$$
$$\theta = \ln(\mathrm{GDP} * \mathrm{DG}) = \ln(\mathrm{GDP}) + \ln(\mathrm{DG})$$

The human activity rate is equal to the sum of the natural logarithm of the Gross Domestic Product and the logarithm of the demographic growth. Its effects on temperature variation over time behave in the following way:

In the time t_0 exists a temperature Tp_0, for time t_1, Tp_1will coexist as a result of human activities θ, if the activity is constant over time, temperature variation would have the following dynamism:

$$\mathrm{Tp_1} = \mathrm{Tp_0} + \theta\,\mathrm{Tp_0} = \mathrm{Tp_0}(1 + \theta) \rightarrow \text{first momentum}$$
$$\mathrm{Tp_2} = \mathrm{Tp_1} + \theta\,\mathrm{Tp_1} = \mathrm{Tp_1}(1 + \theta)$$
$$= \mathrm{Tp_0}(1 + \theta)(1 + \theta)$$
$$= \mathrm{Tp_0}(1 + \theta)^2 \rightarrow \text{Second momentum}$$

Based on the above, the temperature variation converges to the finite:

$$\mathrm{Tp_n} = \mathrm{Tp_0}(1 + \theta)^{\mathrm{n}}; \quad \mathrm{n} = 1,2,3, \ldots\ldots \rightarrow \text{n momentums}$$

<u>Model Interpretation</u>

The interpretation of temperature variation (Tp)in the planet is as follows:

For every percentage point in which the demographic growth (DG) and the Gross Domestic Product (GDP) over time, human activity (θ) will increase, and with that, temperature variation (Vt) would increase, that is, as long as human activities continue, the average temperature of the planet will increase.

As noted, human activities stimulate global temperature increase, this was also documented in the study of Gitay, Suárezand Watson (2002), where they specify that "it is difficult to quantify in which proportion of Global Warming is attributable to natural causes, and which proportion is attributable to human causes.But the results of climate models, taking into account all possible causes, indicate that only considering the contribution of human activities it is possible to explain the significanttrend towards global warming that has been observed above all during the last decades".It was ratified as one of the main conclusions of the contribution of the Workgroup I to the Fifth Evaluation Report (GTI IE5), in 2014, which states that "it is highly likely that human influence was the dominant cause of the warming observed since the mid-twentieth century" (GTI IE5 RRP, sections D.3, 2.2, 6.3, 10.3-6, 10.9).

The impacts caused by Climate Change like heat waves, droughts, floods, cyclones and forest fires highlight the significant vulnerability and exposure of some ecosystems and many human systems to the current climate variability. Among the impacts of those extreme climate-related phenomena are the alteration of ecosystems, the disruption of food production and water supply, damages to the infrastructure and settlements, morbidity and mortality, and consequences for mental health and human wellbeing. For countries, regardless of their level of development, those impacts are in line with a significant lack of preparation for the current climate variability in some sectors (IPCC-GT II, 2014).

As it can be observed on Figure 2, the following conjecture is obtained: as long as human activity rate increases (GDP and DG), temperature variations will increase, and with that, ecological reserves will decrease. Stimulating the human activity rate translates into higher gas emissions resulting in the greenhouse effect whose mechanism heats the earth's atmosphere. The earth's atmosphere is composed by a thin layer of gases that surrounds the planet and that are fundamental for the development of most forms of life. Also, its chemical composition consists largely of two gases: 79% nitrogen and 20%oxygen, the remaining1% is formed by various gases such as argon and carbon dioxide (Caballero, Lozano & Ortega, 2007).

For environmental experts, global warming has run parallel with a $C0_2$(carbon dioxide) incrementtrend, this behavior may be associated with natural processes.However, there is a human mechanism (human activity) that explains it, like logging and burning of fossil fuels (coal and oil) that have caused an increase in the amount of atmospheric $C0_2$; and when this amount is above the required by the planet global warming is generated.

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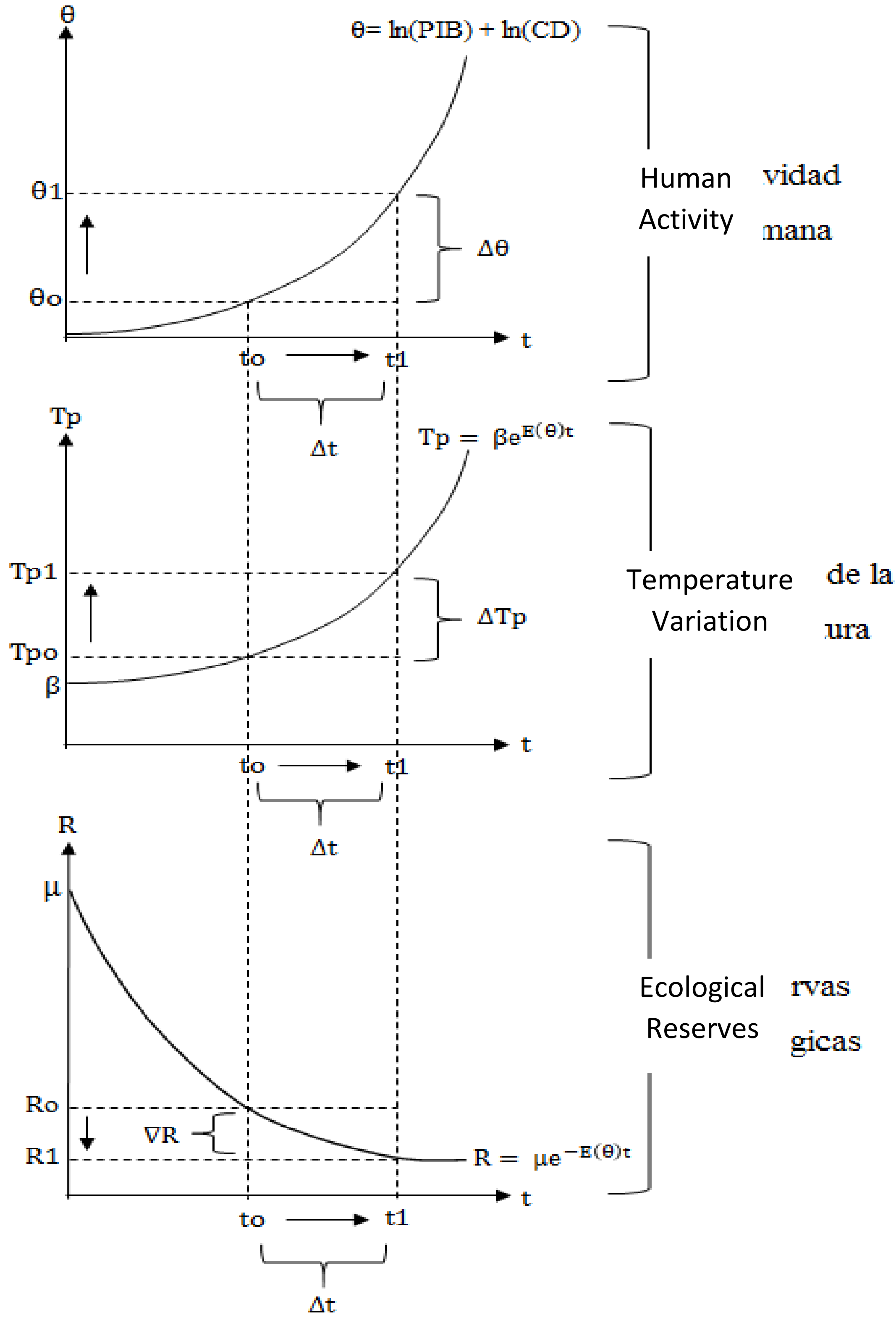

Fig.2: Effects of temperature increase on ecological reserves.

Source. Own authorship

Predicting Scenarios

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This mathematical model epitomizes two scenarios that include projections for *n* years. The first one refers to the current temperature behavior, human activity and the over exploitation of ecological reserves; and the second one represents an alternative scenario, where temperature is controlled through the minimization of human activities and with that, current reserves are optimized.

Current scenario

If this trend were to continue, ecological reserves would tend to be scarce, and with that, every living being would go into chaos (figure 3).

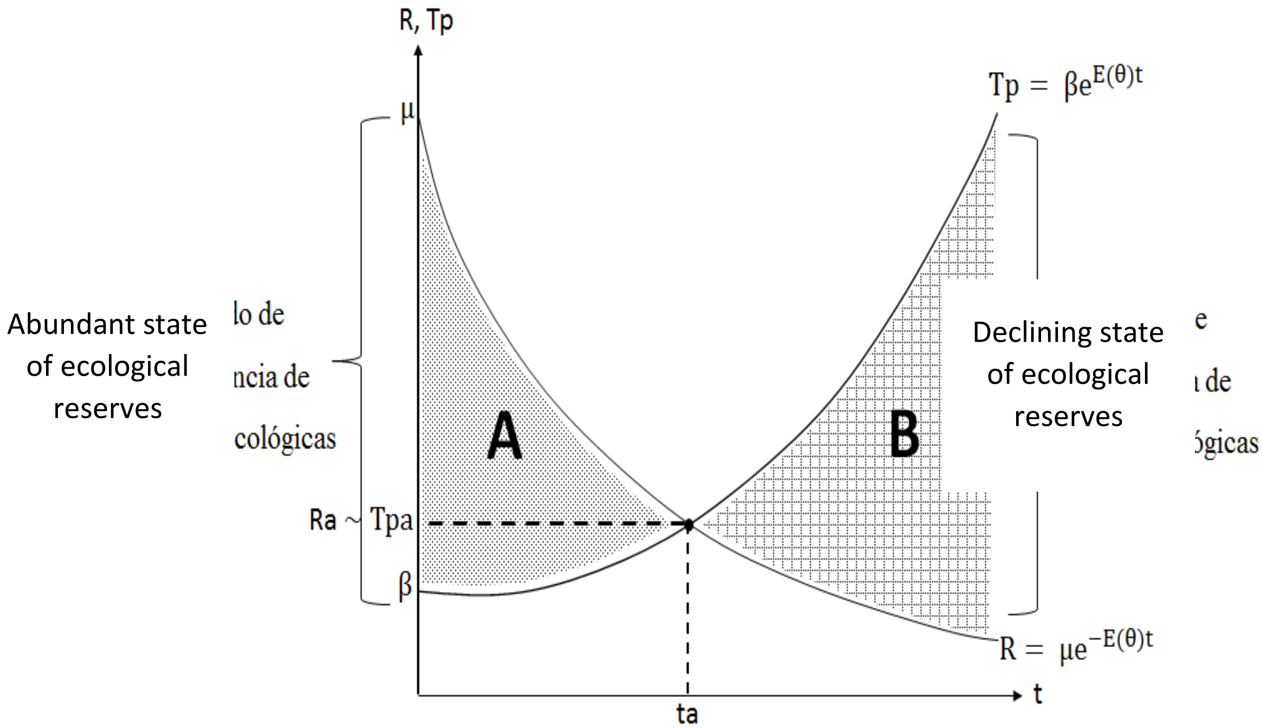

Fig.3: Dynamics of temperature over time on ecological reserves.

Source. Own authorship

Based on figure 6, t_a and $Tp_a \sim R_a$ is the equilibrium point where temperature variation is the same as ecological reserves, that is:

$V_t = R_e$ so that $Tp = \beta e^{E(\theta)t}$ and $R = \mu e^{-E(\theta)t}$

Equating and solving t,

$$\beta e^{E(\theta)t} = \mu e^{-E(\theta)t}$$

$$\frac{e^{E(\theta)t}}{e^{-E(\theta)t}} = \frac{\mu}{\beta} \rightarrow e^{2E(\theta)t} = \frac{\mu}{\beta}$$

$$2E(\theta)t = \ln\left(\frac{\mu}{\beta}\right) \rightarrow t = \frac{\ln(\mu) - \ln(\beta)}{2E(\theta)}$$

Substituting t in Tp and R, we have:

$$Tp = \beta e^{E(\theta)\left(\frac{\ln(\mu)-\ln(\beta)}{2E(\theta)}\right)} = \beta e^{\left(\frac{\ln\left(\frac{\mu}{\beta}\right)}{2}\right)}; \; R_e = \mu e^{-E(\theta)\left(\frac{\ln(\mu)-\ln(\beta)}{2E(\theta)}\right)} = \mu e^{\left(\frac{\ln\left(\frac{\beta}{\mu}\right)}{2}\right)}$$

The dynamics of the equilibrium point P is the reference to determine when ecological reserves are available or scarce (figure 3):

- The state of abundance of ecological reserves is determined by the area A, where R (ecological reserves) are greater than Tp (temperature variation), that is, the benefits produced by the environment are enjoyed irrationally:

$$A = \int_{t_0}^{t_a} R(t)dt - \int_{t_0}^{t_a} Tp(t)dt$$

- The state of scarcity of ecological reserves is determined by area B, in which R (ecological reserves) are lower than Tp (temperature variation), as a result of the irrational overexploitation of the available resources before the point of equilibrium P, giving rise to the survival problems for every living being:

$$B = \int_{t_a}^{\infty} Tp(t)dt - \int_{t_a}^{\infty} R(t)dt$$

The main goal would be that the state of scarcity of ecological reserves would not occur, since every living being would be in danger of existence. In order to avoid this scenario, it is essential to correct this trend by optimizing ecological reserves.

Scenario of optimization of ecological reserves

The optimization of ecological reserves would consist of the following, "to the extent that the population and economies approach the environmental load capacity, these would have to become more aware ofthe natural resourcesoverexploitation, that is, they have a limited capacity to support individuals (figure 4).

In this context, the growth rate of human activities is jointly proportional to the temperature variation itself as well as the missing amount to reach maximum sustainability.

The optimization of ecological reserves refers to the use of the logistic model, under this context and initially:

"Highergrowth of human activity (GDP and DG) leads to highertemperature variation and lower ecological reserves."

Initially, human activity grows rapidly, and becomes a source of constant pressure on ecological reserves, and loses its capacity for exponential growth as the result of the depletion of ecological reserves, that is:

- With a temperature variation rate in β, we have ecological reserves in μ.To the extent that the rate of human activities increases, ecological reserves will decline, until β^*point.
- In β^*, the point of inflection of temperature variation (t*, β^*) is presented, after it, temperature variation would be minimized, and with that ecological reserves would be optimized.

Looking for the equation of the logistic[3]environment model:

$$\frac{dTp}{dt} = E(\theta)Tp\left[1 - \left(\frac{Tpo}{Q}\right)\right]$$

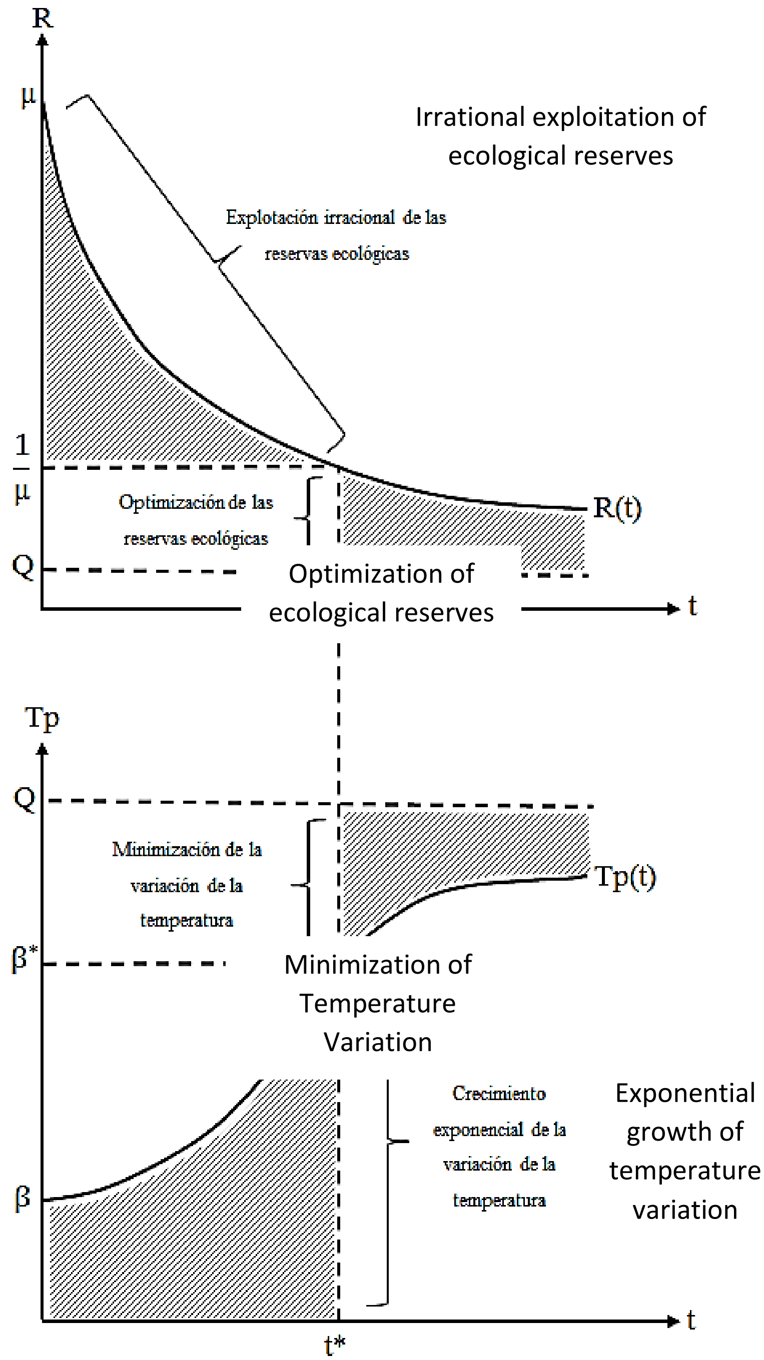

Fig.4: Optimization of ecological reserves
Source. Own authorship

where:

- $E(\theta)$is the expected value of the instantaneous change in the rate of human activity.
- Tp is the temperature variation rate.
- Q is the sustainability capacity of ecological reserves.

[3]The logistic growth model is the result of improving the continuous model of exponential growth, this model was presented by mathematician Verhulstin 1938 (Cortès, Romero, Rosellò& Villanueva, 2010)

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- Tpo is the maximum value that the temperature variation can have.

So that:

- If $Tp \sim 0 \rightarrow \left[1-\left(\frac{Tpo}{Q}\right)\right] \sim 1$, we reach the model of the irrational overexploitation of ecological reserves.
- If $Tpo \sim Q \rightarrow \left[1-\left(\frac{Tpo}{Q}\right)\right] \sim 0$, therefore $\frac{dTp}{dt} \sim 0$, this would make temperature variation constant.

Finding the equation from the logistic model:

$$\frac{dTp}{dt} = E(\theta)Tp\left[1-\left(\frac{Tpo}{Q}\right)\right] \rightarrow \frac{dTp}{Tp\left[1-\left(\frac{Tpo}{Q}\right)\right]} = E(\theta)dt$$

Through differential equations:

$$\int \frac{dTp}{Tp\left[1-\left(\frac{Tpo}{Q}\right)\right]} = \int E(\theta)dt$$

Solving both integrals:

$$\int E(\theta)dt = E(\theta)t + C$$

Solving through partial fractions:

$$\int \frac{dTp}{Tp\left[1-\left(\frac{Tpo}{Q}\right)\right]} = \frac{1}{Tp\left[1-\left(\frac{Tpo}{Q}\right)\right]} = \frac{K}{Tp} + \frac{W}{\left[1-\left(\frac{Tpo}{Q}\right)\right]}$$

If K = 1, therefore $W - \frac{K}{Q} = 0 \rightarrow W = \frac{1}{Q}$

Substituting:

$$\int \left(\frac{K}{Tp} + \frac{W}{\left[1-\left(\frac{Tpo}{Q}\right)\right]}\right) dTp = \int \frac{K}{Tp} dTp + \int \frac{\frac{1}{Q}}{\left[1-\left(\frac{Tpo}{Q}\right)\right]} dTp = \ln|Tp| - \ln|W - Tpo|$$

Equating:

$$E(\theta)t + C = \ln\left(\frac{Tp}{Q - Tpo}\right) \text{ where } Tp \sim Tpo;$$

Solving Tp:

$$\frac{Tp}{Q - Tpo} = e^{E(\theta)t + C}; \quad \theta = e^{C}$$

Therefore:

$$Tp(t) = \frac{Q\,\theta\, e^{E(\theta)t}}{\theta\, e^{E(\theta)t} + 1} = \frac{Q}{1 + \left(\frac{1}{\theta\, e^{E(\theta)t}}\right)}$$

With this algebraic expression, the relevant variables (GDP, Demographic Growth and time) are involved to obtain a result or behavior of the variables that generate the control of temperature variations, and with that, optimize ecological reserves. This model provides the necessary elements to create environmental policies, which would emphasize sustainable development.

Based on the above, this model as well as the IPAT equation aim toanalyze the global environmental impact of human activities since both models consider the global population, per capita income (the model we presentconsiders GDP as reference), and technological advancement. The differences between the two models lie in the following:

- In the IPAT equation, time is not taken into account, that is, they work through a crosscut, which limits the development of a historical analysis of the phenomenon (Castañeda, 2003).

IPAT Equation: I = (P)(A)(T)

Where:

- I is the general human impact
- P is the total population
- A is the per capita income
- T is the environmental impact per dollar of income

In addition to the above, it does not offer alternatives to minimize the impact of human activities on the environment.

Conclusions and recommendations

Through the theoretical development of the present models, the following could be identified:

- From 1850 to 2015, temperature variations have exhibited an exponential behavior. For environmental specialists, this dynamic has been the result of two factors; the first one, as a consequence of natural processes; and the second one, due to the accelerated increase of human activity, which is included in the Gross Domestic Product and in the countries'Demographic Growth.
- If this exponential behavior continues, it can present a scenario where temperature variation is higher than natural reserves.This would result in the disappearance of certain species in the ecosystem, and currently, this scenario already existsin some parts of the planet.
- It is of utmost importance that alternative scenarios are created where temperature variations are minimized. In this context, the second model developed in this paper gives the necessary elements in order to minimize temperature

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variations, based on the reduction of human activity over time, such reduction would mean the implementation of sustainable development policies, which should be based on the awareness of consumption and the use of alternative energies.

- The limitation in the present model isits theoretical development, that is, its dynamics depend on the assumptions raised at the beginning of the present paper.It would be advisable to obtain enough data to apply it; however, one of the issues related to the environmental impact phenomenon is the lack of data recording.

As a recommendation, it would be very useful to have a record of greenhouse gases (GHG) with projections over time, to ensure the certainty of this kind of model; as well as the determination of the gases that produce the majorimpact on climate change.Also by studying them in the time scenarios, it can provide another tool for decision makers of the countries'development of activities.

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