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Climate Change-Human Behavior: Towards Integrated Modeling

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Abstract *-* The aim of this paper is to contribute to understand the problematic of climate change by given an integrated model of ecological system. This modeling, in which we use several techniques that we seemed able to deal the problem, combines between the classical variants of climate change (temperature, water, …) and the human behavior towards the respect of the environment. To give the model, we use systematically two essential mathematical techniques: (1) Dynamic systems that allow studying complex systems with a systemic vision by describing the different variables of the system and analyzing the causal interactions between these variables. It is part of an approach of decision support. (2) Fuzzy logic theory used to estimate the qualitative variable, for us human behavior, influencing causes and impacts of climate change.

Keywords *- Climate Change Dynamic System, Mathematic Modeling, Fuzzy Logic Theory, Social-Ecological-System*

I. INTRODUCTION

Currently, climate change remains a universal phenomenon that threatens all living species. Indeed, no one, today, can ignore this problematic since many of us can perceive its harmful effects on the globe and its populations. Several definitions present climate change as a durable modification (measured over a minimum of 10 years) of the global climate of the earth or all regional climates known by the "Climate System" [11][12]. This climate system is considered as a complex system involving not only a multitude of variables and aggregates but also embedded interactions of its variables.

Contemporary scientists have all agreed that the earth has been undergoing climate change since the dawn of time. These climate changes were always due to natural causes. However, they wonder why the current climate change is important. Really, the latter is characterized by particular aspects in time and space: (1) It is very fast, which reduces the possibility of adaptation for many animal and plant species that may disappear; (2) It is very contextualized since it is manifested by inappropriate imbalances in each given territory; and especially (3) it is unique because it is the first time that human plays an important role [15].

Indeed, natural parameters- alone- are not enough to explain the modifications observed. This argument, as well as others (of a technical nature) explaining that the vast majority of scientists recognize a human responsibility for the current climate change. Nevertheless, accepting this reality forces to question our mode of life, our production and also our consumption [15][17].

A first observation requires remembering that if the human is at the origin of these perturbations, he also has the power to understand, analyze and improve the situation today. The consortium of scientific efforts in this area of analysis and synthesis [12](scientific, technical and socio-economic information on climate change) enables leaders and stakeholders to make decisions.

The purpose of this paper is to present a mathematical modeling of the phenomenon of climate change by introducing the responsibility of the human being in this change. This model uses traditional variables, generally recognized and exploited, and introduces human behavior as an important new variable.

This paper is organized as follows: First of all, we define the Social –Ecological-System. Then, we describe the principle of the proposed generic model using both system dynamics and fuzzy logic theory. This step led to a thorough investigation on mathematic modeling, followed by introducing the dynamic system and fuzzy logic to modelize the social ecological system.

II. THE THE MAIN INGREDIENTS FOR THE CLIMATE CHANGE INTEGRATED MODEL

A. Social-Ecological-System: a new multidisciplinary approach

Studying the climate system by integrating human responsibility has been the subject of several previous studies in different disciplines [16][17]. The aim was to provide a complete description of ecosystem models by introducing natural, social and political factors: Social-Ecological Systems. Some author studies proposed a new approach to SES by attaching them o the notion of territory: Regional Analysis of Social-ecological-Systems [16][17]. In fact, SESs are designed as integrated systems coupling societies and nature [13]. This coupling makes it possible to redefine ecosystems (traditional variables), by integrating humans as an active variable of the system.

This new multidisciplinary vision did not require the creation of a new discipline, but it was sufficient to build a mature interaction of disciplines to share common assumptions.

On the basis of schema given by Long Term Ecological Research in 2007[16], we developed the following diagram, named The tree of SES, which visualizes the interactions between the different disciplines, sciences and variables to empower a pluridisciplinary conception of the natural and social causes of climate change:

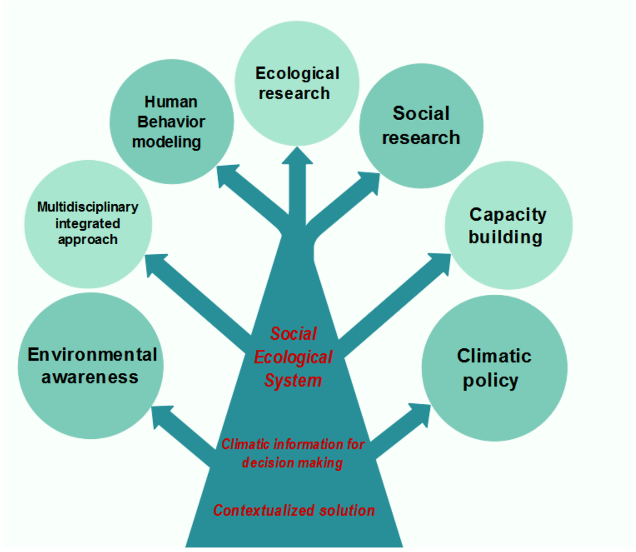

Figure 1. The tree of Social-Ecological-System

From this diagram, we model the SES as a dynamic system involving several heterogeneous variables [5] [9] [10]. In fact, system dynamics is the theory of system structures, a theory that deals with the study of the causal interactions between the components which constitute the structure of a complex system. We note that it is a modeling methodology for understanding and representing complex systems and ana lyzing their dynamic behavior [2].

B. Mathematics to understand climate change

Applied mathematics finds its legitimacy as a service discipline, through the transfer of their concepts and methods to solve external problems posed by the development of knowledge in other areas of human activity [4] [5]. It is a vision of use that privileges the tool aspect of Mathematics for other sciences in an interdisciplinary perspective.

For the present work, and because of the complexity of the processes involved in climate change studies, the stakes for current and future research are numerous, both for modeling (looking for the most appropriate model) and also for the integration of new decisive data of heterogeneous natures.

In this way, we are convinced that mathematics presents a variety of methods for analyzing, modeling and even helping to make decisions for future scenarios in terms of sustainable development and climate change.

As already mentioned in the previous section, climate change brings together several variables as well as their interactions. Through appropriate mathematical modeling, these interactions can be described to derive dynamics, equilibrium configurations and instabilities.

C. Fuzzy logic to quantify human behavior in CC

Human behavior is an important key in climate change challenge. In fact, to add the human behavior on the classic natural variables in climate change appears to be a key element to modeling the social ecological system. Indeed, analysis of this SES allows to more understanding the complexity and the diversity of the problem of climate change. In addition, the difficulty of this problem is that the human behavior cannot be assessed in a qualitative manner with precision and certainty. This paper presents one mathematic solution for quantify the human behavior in social-ecological-system. [4] [9]

In logic reasoning, we have a series of declaration which are either binary true of false. In this way, statement “Don’t respect environment” is a determinist one, true or false. However, for many live situations the answer like “not sure”, “maybe”, “that depends”. When the statement is a qualitative one, it's represents an opinion rather than objective fact, several mathematical studies use fuzzy logic to describe the situation.

The theory of fuzzy sets offers a formal framework to model the imprecise and uncertain aspects of natural language. This approach allows understanding emotional phenomena which are imprecise and difficult to model based on the definition of rules and membership functions in sets called “fuzzy sets” [3] [4].

III. INTEGRATED MODELING FOR SOCIAL-ECOLOGICAL SYSTEM

A. Climatic and non-climatic variable in CC.

According to our knowledge, existing work on the climate problematic is often handled in a mono-directional or bidirectional way (one or two variables) [11] [12] [14] .Indeed, one finds in the literature several scientific studies elaborated according to only one or two axes of research (meteorological, oceanographic, biodiversity, water ...) without considering the other factors impacting the climate and the ecological system. These visions risk neglecting not only other variables from other domains but also the role of intra- variable interactions, duality variables-territory and finally the trio variables-territory-human behavior. Following this perspective, we present in this paper an integrated mathematical modeling of the social ecological system in a given territory, which takes into account in addition to the classical (already known) ecological variables a new qualitative variable namely behavior eco-responsible human. The importance of this modeling is based on the fact that current climate change, on the one hand, is hardly the result of a single ecological variable, but rather the accumulation of several factors as well as their immeasurable interactions. On the other hand, the man plays an important and determining role by his behavior and his controversial attitudes towards this climatic problematic. Therefore, proposing an integrated systemic model of the situation remains a necessity imposed by the complexity of the multidisciplinary approach to climate change. It covers a multitude of climatic and non-climatic variables as well as interdependencies between them.

B. Territory under GNEH constraints and causal loop diagram

Let's Ω a given territory, and let's variables $(X_i)_{i \in \{1,2,3..n\}}$ all the components of Ω including climate and non-climate data.

In the following, without restricting the generality, a territory Ω is defined from the following components:

X_1 : Geography: emplacement, ocean, arid zone…

X_2 : Natural: temperature, biodiversity, water, meteorology…

X_3 : Economy: agriculture, industry, tourism

X_4 : Human behavior; attitude.

In this case, we talk about a territory under GNEH constraints model.

It is clear that the 4 components considered, as well as their constituents, cannot be taken separately. To explain this interdependence, the following causal loop diagram shows that strong dependencies exist and they are far from being linear.

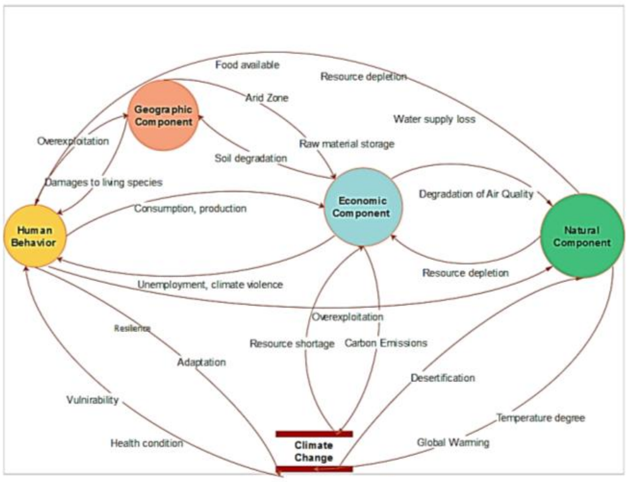

Figure 2. Causl loop diagram of Climate Change Variables in a territory

This diagram shows that climate change is affected by several variables as well as their interactions, taken as inputs, and it also shows that the same climate change affects the same variables which in this case remain inputs.

This description allows us to use dynamic systems to model the SES in a complete and integrated way.

C. Social-Ecological System model

As already mentioned in the previous section, we will present the SES as a dynamic system with its Inputs / Outputs and feedback.

Thus, an SES in a territory Ω is a dynamic system whose inputs are each of the four GNEC variables noted in the period t, and which, after entering into interactions with the other variables and its own components, becomes an output to the moment $t + \Delta t$. Δt is a minimum of 6 months.

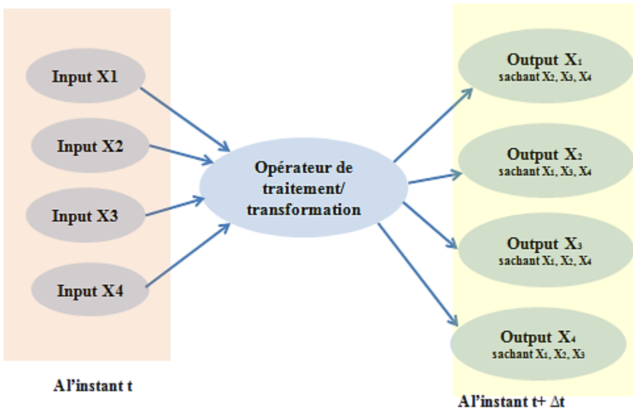

Figure 3. SES: Social-Ecological Systam model

According to this modeling, climate change remains a result of the change of state / phase transition of the SES system between period's t and t + τ.

On the basis of these inputs, the stakeholders will have a integrated climatic information. This information will assist in making decisions for possible adaptation or mitigation measures to Climate Change.

IV. Colclusion

In this work, we have presented a modeling of the phenomenon of climate change by introducing the responsibility of the human being in this change. This model uses traditional variables and introduces human behavior as an important new variable. Our methodology is based on the gathering of several scientific approaches from different backgrounds: dynamic system, fuzzy logic theory, human behavior... This diversity is due essentially to the complex and multidisciplinary nature of the climatic problematic. The proposed model can be used as a support to assist stockholders to make decision in CC. The methodology presented in this work is already being implemented. It will be developed with mathematical equations. Indeed, we will test the robustness of the model by a numeric simulation with really data for the four components of a given territory.

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