Development of mathematical models to elaborate strategies, to select alternatives and the development of plans for the adaptation of communities to climate change in different geographical areas including costs to implement it

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Abstract—**Climate change is on the policy agenda at the global level, with the aim of understanding and reducing its causes and to mitigate its consequences. In most of the countries and international organisms UNO, OECD, EC, etc … the efforts and debates have been directed to know the possible causes, to predict the future evolution of some variable conditioners, and trying to make studies to fight against the effects or to delay the negative evolution of such. Nevertheless, the elaboration of a global model was not boarded that can help to choose the best alternative between the feasible ones, to elaborate the strategies and to evaluate the costs. As in all natural, technological and social changes, the best-prepared countries will have the best bear and the more rapid recover. In all the geographic areas the alternative will not be the same one, but the model should help us to make the appropriated decision. It is essential to know those areas that are more sensitive to the negative effects of climate change, the parameters to take into account for its evaluation, and comprehensive plans to deal with it. The objective of this paper is to elaborate a mathematical model support of decisions, that will allow to develop and to evaluate alternatives of adaptation to the climatic change of different communities in Europe and Latin-America, mainly, in vulnerable areas to the climatic change, considering in them all the intervening factors. The models will take into consideration criteria of physical type (meteorological, edaphic, water resources), of use of the ground (agriculturist, forest, mining, industrial, urban, tourist, cattle dealer), economic (income, costs, benefits, infrastructures), social (population), politician (implementation, legislation), educative (Educational programs, diffusion), sanitary and environmental, at the present moment and the future.**

Keywords: Multi-criteria Decision Models, Climate Change, Optimization.

I. INTRODUCTION

Climate change is on the policy agenda at the global level, with the aim of understanding and reducing its causes and to mitigate its consequences [1][2]. As in all natural, technological and social changes, the best-prepared countries will support better their specific effects of climatic change and will recover more rapidly. Therefore, it is essential to know those areas that are more sensitive to the negative effects of climate change, the parameters to be taken into account for its evaluation, and comprehensive plans to deal with it. [3]

We understand like adaptation to the climate change the strategies that must be adopted to make the changes in the processes, practices and structures to moderate the potential damages or to benefit from the opportunities associated to the change. These strategies must contemplate all the factors intervening into the environment including the collectivities that dwell in. The costs must be evaluated and also the negative repercussions for the sustainable development that are going to appear. [4]

Adaptation to climate change is a natural process, but the man must anticipate, analyze and quantify it. The development of strategies and the choice of alternatives are need it, as well as to assess the costs of expressed adaptation plans. These plans may not be the same across the globe and each plan would depend on the geographical areas; however this study is trying to develop a common methodology and models which can be adaptive and flexible. [5]

II. OBJECTIVE

The objective of this project is to elaborate a mathematical model that will allow to develop and to evaluate integral plans of adaptation of the communities to the climate change, in vulnerable areas of Europe and Latin-America, and will help to select the most suitable alternative, evaluate the costs and design strategies of application, formation and diffusion for the knowledge and the education of the society. [6]

The results of this project will allow to lay the bases of economic and social sustainable development, by means of a suitable planning and territorial arrangement, including not

only the rational and sustainable use of the Earth but the others of the natural resources, in special, the one of the water resources by means of an arrangement of the hydrographic river basins and an integral management of these resources, as much in superficial as underground waters. All this will help, without a doubt, to promote a change in the social behavior of the involved area and the interrelated ones, by means of the opportune programs of information and education. [7][8]

III. THE STATE-OF-THE-ART

Currently, in most countries, international forums and institutions, universities and research groups are studying methods and plans to fight against climate change and, more recently, for the adaptation to climate change. This has been possible thanks to the fact that a group of researchers have been trying to convince public opinion and the institutions that they must not waist the efforts in the fight against the climate change and that they have to divert them to the study of the adaptation to climate change. However, still the majority of studies and models that are emerging target item to resolve specific problems, to predict the behavior of natural or human factors such as the elevation of the sea, the increase in CO2, etc., but without obtaining a global model that could give guidelines to make the appropriated decisions in every moment and in every place. [9][10][11][12][13][14]

The Framework convention of the UNO on Climate Change (CMNUCC), has created in most of the countries an Observatory or Commission on climatic change that is elaborating national plans of adaptation to the climate change, but always, on evaluation impact on certain factors like the water resources, the biodiversity, the level of the sea, ozone layer, etc., without including any model like the one that is set out in this proposal. [15]

There are organizations such as Oxfam doing basic reports directed to the controversy on that due to pay to the cost and on that the causes are the rich countries like the UE and those that suffer it are the poor countries. With the results of this project it will be possible to put in evidence interested affirmations or erroneous, as well as, a greater social support on the propose solutions. [16]

The Forums of the Earth, also called UN conference on Environment and Development, were held in Stockholm (Sweden) in 1972, Rio de Janeiro (Brazil) in 1992 and Johannesburg (South Africa) in 2002.

In the Rio Conference [17] the participating countries agreed to adopt a development approach to protect the environment while ensuring economic and social development. At this summit, various documents were approved by 178 governments, which are:

- Program 21: This is an action plan which aims to environmental and development goals in the XXI century.
- Rio Declaration on Environment and Development: defining the rights and duties of States.
- Statement of principles on forests.
- Convention on Climate Change, Biodiversity and Desertification

The summit Earth Summit +5 took place in a Special Session of the General Assembly in 1997. The main objective was to analyze the implementation of Agenda 21, adopted at the Summit of 1992. After an intense debate due to the differences among States on how to finance sustainable development at the global level, various agreements were obtained which were reflected in the final document of the session. These agreements are:

- To adopt legally binding targets for reducing emissions of greenhouse gases which are causing climate change
- Move more vigorously towards sustainable patterns of production, distribution and use of energy
- Focus on poverty eradication as a prerequisite for sustainable development

The World Summit on Sustainable Development, also known as the Johannesburg Summit (2002), is a follow up to Agenda 21 and therefore the main objective was the adoption of specific commitments in relation to Agenda 21 and achieving sustainable development.

During 2001, a series of national consultations and preparatory meetings and regional and sub-regional organizations were conducted to assess the opportunities and challenges posed by sustainable development and to establish priorities, initiatives and commitments needed to achieve this development.

The intergovernmental program was the central part of the summit, but also attention was paid to all sectors of the population who are committed to sustainable development, including those defined in Agenda 21 (enterprise and industry, children and youth, farmers, people indigenous, local authorities, NGOs, scientific and technological communities, women, workers, unions).

IV. METHODOLOGY

A. First step

The first step is the construction of a DATA BASE with significant information related to causes and consequences of Climate Change at regional and local scale that will be used as Initial decision Matrix.

B. Second step

The second step is the elaboration of the proposed model that is based on the discrete multi-criteria methods of aid to decision making, some of them developed by some of the members, in the Spanish Research Group GASC-UPM. It is based on the classic ELECTRE, PROMETHEE and A.H.P. and it has been complemented with bayesian methods, continuous multi-criteria methods and statistical methods of analysis of variance, temporary series and prediction. [18][19][20][21] [22][23][24][25]

At their disciplinary studies in collaborations with colleagues of several countries the authors have identified a

few number of alternatives in each region. The feasible alternative set is discrete. The variable set is also discrete, but some of the elements are continuous. For this reason continuous multi-criteria decision methods have been used. Besides, the Bayesian methods have been used in the case of random environments. In summarizes, a great number of variables have been taken into consideration classified in groups. For example, meteorological (temperature, CO_2 content, air pollution, ozone cover, pluviometry, winds, …), environmental (erosion, water management, forestry, hydro-basins, …), social (population, migration, rural or urban habitat, …), educational (cultural level, learning level, …), sanitary (epidemics, insalubrity, hospitals, rural assistance, professional level, technical level, …), productive (industrial, extractive, agriculture, tourism, sport, services, …), economic (markets, investment, benefits, finance, …).

Three MCDM methods were adopted as adequate for classifying alternatives when the criteria are of rather different nature, and requiring some subjective assignation of values and weights W_j for comparison. Two of them, the ELECTRE-I, used in environmental impact analysis, due to B. Roy (1971) and Benayoun (1966), and the PROMETHEE due to J. P. Brans et al. and the PROMETHEE modified by the authors useing systems of weights as in ELECTRE, are over-ranking methods. The third is the A.H.P. or "Analytic Hierarchy Process" due to Saaty using the commercial software Expert Choice, to range alternatives by direct weight assessment comparison made by experts.

1. In ELECTRE method, the experts elaborate an initial matrix **Im**. In it, each $\mathbf{Im}_{ij}$ indicates a measure adopted for valuation of the *i*-alternative respectively to the *j*-criterion, and an index I_j is 1 if that measure is of "more is better" kind and -1 if of "more is worse" kind.

   From that initial matrix **Im** to obtain preferences the Concordance Indexes Matrix **C** is

   $\mathbf{C}_{ik}$ = Sum of the W_j for which ($I_j \bullet (\mathbf{Im}_{ij} - \mathbf{Im}_{kj}) > 0$),

   adding only (W_j / 2) if ($\mathbf{Im}_{ij} = \mathbf{Im}_{kj}$); that indicates how much alternative *i* is better than alternative *k* adding the weights of the criteria for which that occurs.

   To consider the obstacles for these preferences it calculates the ranges $R_j = \underset{i,k}{\mathrm{Sup}} \left| \mathbf{Im}_{ij} - \mathbf{Im}_{kj} \right|$, and from them a Normalized Decisional Matrix $\mathbf{Dm}_{ij} = \mathbf{Im}_{ij} \cdot W_j / R_j$, and a Discordance Indexes Matrix:

   $$\mathbf{D}_{ik} = \underset{j}{\mathrm{Sup}} \left[\mathrm{Sup} \left(I_j \cdot (\mathbf{Dm}_{kj} - \mathbf{Dm}_{ij}), 0 \right) \right] \Big/ \underset{j}{\mathrm{Sup}} \left| \mathbf{Dm}_{kj} - \mathbf{Dm}_{ij} \right|$$

   Now it takes for concordance and discordance thresholds *ct* and *dt* the averages of the non diagonal elements of the square Matrixes $\mathbf{C}_{ik}$ and $\mathbf{D}_{ik}$ respectively, these values could have been changed if convenient, to obtain:

   - the Matrix of concordant dominance

   $\mathbf{Mcd}_{ik}$ = (1 if ($\mathbf{C}_{ik} \geq ct$), otherwise 0) and

   - the Matrix of discordant dominance

   $\mathbf{Mdd}_{ik}$ = (1 if ($\mathbf{D}_{ik} \leq dt$) , otherwise 0), getting with them the

   - Matrix of aggregated dominance for each (*i,k*)

   $$\mathbf{Mad}_{ik} = \mathbf{Mcd}_{ik} * \mathbf{Mdd}_{ik}$$

   If for a given (i,k) the $\mathbf{Mcd}_{ik}$ is 1 that is an indication of dominance of alternative *i* over alternative *k* , and if the $\mathbf{Mdd}_{ik}$ is 1 there is no discordance for that, and if both are 1, i.e. if $\mathbf{Mad}_{ik} = 1$, the alternative *i* is considered preferable to the *k* one.

   An alternative that is better than some of the others and worse to none is considered in the kernel.

2. PROMETHEE methods used similar Initial Matrixes $\mathbf{Im}_{ij}$, normalized weights W_j and indexes I_j .

   - PROMETHEE obtains the non negative "preference function" $P(i,j,k)$, positive if criteria *j* indicates preference of alternative *i* over alternative *k* and 0 if not, with

   $$P(i,k,j) = \text{if} \left[I_j \cdot (\mathbf{Im}_{ij} - \mathbf{Im}_{kj}) \leq 0 \right] \text{ then } 0 \text{ else } p\left(j, \left| \mathbf{Im}_{ij} - \mathbf{Im}_{kj} \right| \right)$$

   For that it uses for each *j*-criteria a *j*-Type of criteria preference function $p(j, x)$, going from o to 1, elected following one of six types. From them the Type V "Criterion with Linear Preference, threshold $a(j)$" gets

   $p(j,x)$ = if{$|x| \leq a(j)$ then 0 otherwise [if ($|x| \leq a(j)+b(j)$ then (($|x| - a(j)$)/$b(j)$), otherwise 1] }

   - Then PROMETHEE defines Preference indexes
     - for Initial PROMETHEE method as
       $q(i,k) = \sum_{j=1}^{n} P(i,k,j) \Big/ n$
     - and for modified or Weighted PROMETHEE method as
       $q(i,k) = \sum_{j=0}^{n} P(i,k,j) \cdot w_j$,
   - With that the PROMETHEE calculates
     - incoming flows
       $\mathrm{If}(i) = \sum_{k=1}^{5} q(k,i)$
     - outgoing flows
       $\mathrm{Of}(i) = \sum_{k=1}^{5} q(i,k)$
     - and from them, net flows
       $P_i = \mathrm{Tpf}(i) = \mathrm{Of}(i) - \mathrm{If}(i)$
   - For PROMETHEE II technique "Ranking the Actions by a Total Pre-order", the net flows, or total pre-order flows, Tpf(*i*) are taken as valuations, they are higher if the *i*-alternative is better.
   - For PROMETHEE I technique "Ranking the Actions by a Partial Pre-order", a combination of incoming and outgoing flows is considered obtaining a Partial pre-order matrix **Cpp** of elements **Cpp**(*i,k*) defined as:

   1 if {[Of(*i*) > Of(*k*) and If(*i*) < If(*k*)] or [Of(*i*) > Of(*k*) and If(*i*) = If(*k*)] or [Of(*i*) = Of(*k*) and If(*i*) < If(*k*)]}, indicating that "the alternative *i* outranks the alternative *k* "

   0 if [Of(*i*) = Of(*k*) and If(*i*) = If(*k*)] indicating that "the alternative i is indifferent to the alternative *k* ",

   -1 otherwise, indicating that "they are incomparable".

3. The AHP (Analytic Hierarchy Process) method relies of successive assessments of experts, inspired partly by the ELECTRE data structure, starting with the same list of criteria, called here objectives. The first level in hierarchy is "goal of the project", the second "criteria level" and the third "the alternatives". In AHP the evaluating team makes at various hierarchical growing levels comparisons resulting in successive ranking value indexes, getting global weights valuating the alternatives that were put in a hierarchical form. Values such as costs are externally considered but not included, only a relative comparison measure is data for AHP, that is somehow more subjective at start that the precedent methods

C. *Third step*

The third step is concerning with the use of the method to elaborate a General Plan of Adaptation to Climate Change (PGACA), to serve as framework for the development as Regional Plans of Adaptation to Climate Change (PRACA), management of water resources and control of desertification. [26] [27]

V. DISCUSSION

The models that currently exist, analyzed individually the variables that are altered by climate change (water, CO2, temperature, greenhouse gases, etc.) without considering it in an integrated way to understand how they can affect life on earth.

The model developed by the authors allows to see how the life on earth, including human people, can be affected by changes in all the variables analyzed, and to select the best alternative to develop and to evaluate integral plans of adaptation of the communities to the climate change in vulnerable areas.

The model will quantify the costs of actions derived from the implementation of the proposed alternatives.

VI. CONCLUSIONS

- It is a global solution applicable in every geographical area.
- It takes full advantage of existing information and it makes the maximum use of efforts carried out by Research groups, Universities and different Institutions.
- The proposed model generates results that can be more easily borne by society in accepting the mitigation and adaptation plans to climate change.
- It generates a scientific base that can be analyzed, adapted and presented at international decision forums
- Many of the current models to foresee certain changes can serve as a basis and support to the proposed integrated model

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