Applied Engineering on Biosystems – The reduction in global warming

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Abstract: - This work concerns the problem of decision making in the context of investment allocation in clean technology and in reforestation, aimed at reducing the global warming. In order to model the government actions, fuzzy rules are employed to represent the policies to be adopted for each scenario in terms of CO2 emission. The effectiveness of the adopted policy is evaluated by a cost function that reflects mathematically a compromise in terms of political, economical and social issues. The adopted dynamic model relates the environmental and economic variables such as the rate of CO_2 emission, forest area and gross domestic product.. A case study was carried out using published data for the European Union, in the period ranging from 2001 to 2016.

Key-Words: - Global warming, biosystems modeling**,** fuzzy control, optimization, simulation.

1 Introduction

Nowadays the global warming is a major political concern and the reduction in the emission of CO_2 and other greenhouse gases (GHG: carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, hydro-fluorocarbons, and perfluorocarbons) became a prime policy as pointed out in Kyotto Protocol. Several papers have been published showing the relationships between the global warming and its economic consequences around of world (see, for instance, Ackerman (2008), Azar (2002), Barker (2001), Bolin (2001), Dougherty (2009), Enkvist (2007), Hof (2008), Keohane (2008), Schaeffer(2008)).

The aim of this work is the use to concept of fuzzy logic to propose a set of rules for quantifying linguistically (control variables) the magnitude of investments in reforestation and in adopting clean technology in order to contribute to the reduce the effects of global warming. The required investments are determined according to each scenario in terms of the forest area, concentration of CO_2 and possibly other input data such as GDP (Gross Domestic Product), in order to reach an adequate performance as indicated by targets proposed in the Kyoto Protocol. For European Countries, the recommended reduction of the emission of greenhouse gases is 5.2%, averaged over the period of 2008-2012, taking as reference the year of 1990.

For the sake of simplicity, here it is considered only two decision variables, namely reforestation and investments in clean technology. Besides, only one type of Greenhouse Gases (GHG), more specifically, carbon dioxide (CO_2), is considered. However, the proposed methodology could very well be extended on include more variables. In order to obtain quantitative results, a mathematical model is used consisting of a system of coupled ordinary differential equations that relates the production of CO_2 with forest area and GDP.

Instead of following the optimal control approach as in Caetano *et al*. (2008, 2009), the performance index (cost function) is used here only to assess the adequacy of each decision rules provided in linguistic form in terms of a fuzzy inference system.

In the case study, the parameters of the model were adjusted using widely known published data, such as those available at UNEP (UNEP GRID ARENDAL, 2008).

2 A MATHEMATICAL MODEL FOR GLOBAL WARMING

The mathematical model adopted in this work consist of three differential equations relating the concentration of atmospheric carbon dioxide (CO_2): *x(t)*, forest area: *z(t)* and Gross Domestic Product (GDP): *y(t)*, as follows:

$$\begin{cases} \dot{x} = r\,x\left(1-\dfrac{x}{s}\right) - \alpha_1 z + (\alpha_2 - u_2)\,y & (1) \\ \dot{z} = u_1 y - h\,z & (2) \\ \dot{y} = \gamma\,y & (3) \end{cases}$$

where the dot above a variable ($\dot{x}, \dot{z}$ *and* $\dot{y}$) denotes, as usual, its time derivative (dx/dt). The input control variables u_1 and u_2 represent, respectively, the amount of investments in reforestation and in the adoption of clean technology. The model parameters (constants) are r, s, h, α_1, α_2 and γ and their relationships with respect to x, z, and y can be visualized by the graph in Figure 1 (Caetano *et al.*, 2008, 2009).

Equations (1), (2) and (3) represent a biosystem in which the CO_2 emissions (x) are dependent on r, the emission rate and s, the carrying capacity of the atmosphere in terms of CO_2. The right-hand side of (1) represents the net balance of emission and removal of CO_2 and the contribution of a certain region in terms of removal of CO_2 from the atmosphere is assumed to be proportional to the total forest area. The total area of forest at time t depends on the initial condition (z_0), such as an existing forest and the reforestation effort.

The reforestation effort is assumed to be a fraction of the GDP (in countries where there are laws and incentives to promote reforestation) with the coefficient u_1 representing the intensity of incentives directed to reforestation and u_2 representing the incentives to clean technology considering that the required clean technology is proportional to the GDP.

The parameter h is a constant representing the forest depletion rate and incorporates a variety of factors such as expansion of cattle ranching, fire, commercial logging, shifted cultivators and colonization, among others.

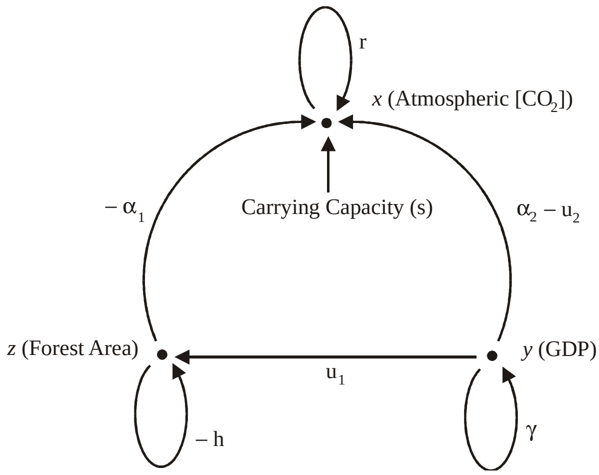

Figure 1 - Relations between the state variables

3 THE FUZZY INFERENCE

In environmental area, linguistic variables that are related to actual numerical data are quite useful in representing the political, economical and social perception of the environmental condition of a region. Therefore, fuzzy relations can be used in a control function to represent the chosen adequate policy to incorporate the emission by some incentive. In terms of this study, there are two types of investments to control the emissions.

The industries decrease its emission using some type of incentive to abandon the present policy of their profit, changing the actual relation with market to obtain better financial returns. The lower taxes in clean technologies development, for instance, will encourage industries to engage in production of durable goods with low CO_2 emission. Furthermore the incentive to reforestation in terms of lower taxes can be very interesting to promote carbon sequestration in all countries with growing of green area.

The proposed fuzzy control was conceived to indicate two level of investment: reforestation investment and clean technology investment as part of GDP on year. This transference is not so clear, so the fuzzy control developed here try to translate a qualitative form of investments to dynamic model.

Figure 2 shows the scheme used for computing the cost function and to apply feedback the control in dynamic system. The control of investments consists of choice of input controls u_1 *(reforestation)* and u_2 *(clean technology)* that are obtained by fuzzy logic rules.

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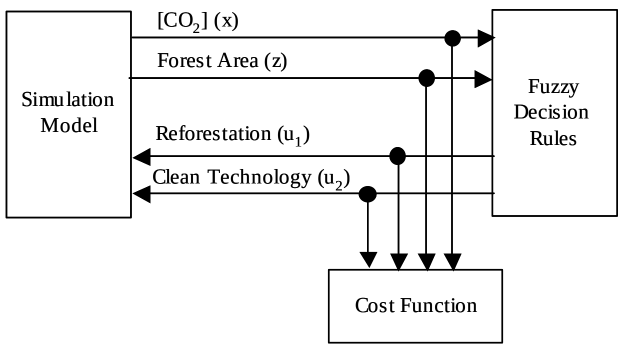

Figure 2 - Proposed setup to tune the fuzzy decision rules

The process is initialized with a sequence of random positive investments of u_1 and u_2. These investments are used to simulate the dynamic system of ordinary differential equations (1), (2) and (3).

The simulation results of CO_2 emission, forestry area and GDP are fed into the fuzzy logic block. The fuzzy block computes the value of the investments u_1 and u_2 that indicates conform rules that establishes a relationship between the input and the output. The output obtained for cost control is used by numerical integrator step-by-step until final time. The integrator used is obtained by Runge-Kutta 4/5 in Matlab © with the program *ode45.m*.

The logic rules for the fuzzy block were built as a exercise to test the method. A set of 9 rules were built to generate the output for each control u_1 and u_2. Each fuzzy rule has two conditions, namely the tons of CO_2, the forestry area. For instance a fuzzy logic rules may use the structure:

"IF <CO_2 is low> AND <forestry is low> THEN <control is high>". In this rule, it was considered that low emission with small forestry area tends to higher investments in reforestation incentives to reduce the excessive CO_2 emissions

Tables 1 and 2 present the complete set of fuzzy logic rules which were used in this work as designed based on the knowledge provided by others works. No supervised training was used so that the membership function was tuned by hand.

At each discrete instant t_i, let the corresponding output of the fuzzy control and define the overall cost function as

$$J(u_1,u_2)=\int_0^{t_f} e^{-\delta t}\left(ax^2+bu_1{}^2+cu_2{}^2\right)dt$$

subject to the state equations (1). The final time t_f is fixed and the state variables x, z and y are assumed free at the final time.

Following the ideas of Nordhaus (in Nordhaus, 1991), the proposed performance index adopts a discount factor (δ) for climate changes in the future. However, instead of maximizing a social welfare function as Nordhaus did, here the aim is to minimize the costs of reforestation and the atmospheric CO_2 emissions:

The weights a, b and c are adjusted to reflect the relative importance of the variables x, u_1 and u_2.

4 A CASE STUDY FOR EU, 2001-16

In order to illustrate the application of the proposed methodology, Europe Union actual data was selected. Firstly, the model parameters for the EU were identified yielding an adequate fitting, as can be seen in Figure 4. The parameters obtained by a least square adjustments of the curves with respect to the available data are in Table 3 and the initial conditions used in the simulation are shown in Table 4.

The length of the time series used in the model identification process covered 40 years, from 1960 to 2000. In this initial period it was assumed that the two investments (reforestation and clean technology are constants by Europe Union). The same figure show the results obtained by computer simulation using fuzzy control from 2001 to 2016.

The membership functions for the two inputs (CO_2, Forestry) and the two outputs (investments) are shown in Figures 3 and 4. The membership functions are of Gaussian type and they cover the universe of discourse partitioned into sets low, mean and high (linguistic variables) for both, input and output data. For the deffuzification the Center of Mass method was adopted.

The result in terms of the control variable can be seen in Figure 4. This figure is a simulation using Table 3 with the same initial condition from actual data.

Figure 5 is shown the results in terms of CO_2 emission comparing past data (actual data) and data obtained by numerical simulation using fuzzy control. One can observe that the fuzzy control variables are decreasing after the large initial investments in Figure 6 and Figure 7.

5 CONCLUSION

The present work shows the use of fuzzy logic in the control of a dynamic system to decrease global warming considering a fuzzy normalized evaluation of CO_2 emission and forestry. A set of 9 rules for each control variables were built. The actual data set of from *Europe Union* was used to compare the results since 1960 in terms of CO_2 emission and forestry area. The fuzzy logic was seen to describe, in a natural way, the assessment of the quality of incentives, as made by the Union Nation Organization (UN), by growing of reforestation and clean technology incentives. The membership functions were built as academic exercise and the results reflects the action for the reforestation investments and clean technology investments by computer simulation from 2001 to 2016.

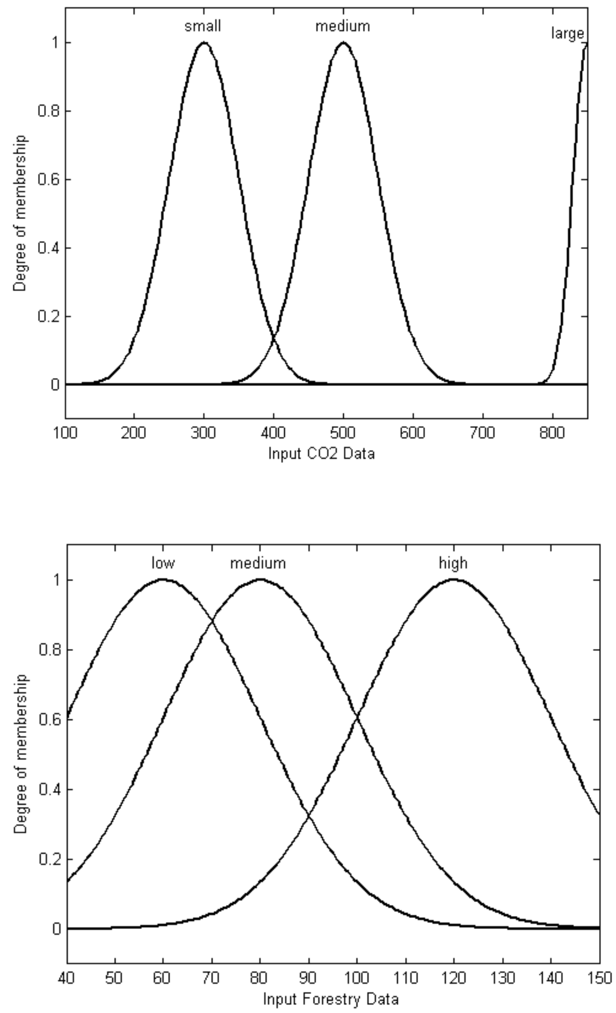

Figure 3 - Membership functions used in the antecedent part (inputs) of the fuzzy rules.

Obviously, a larger sample of actual data is needed to refine the results and carry out statistical tests.

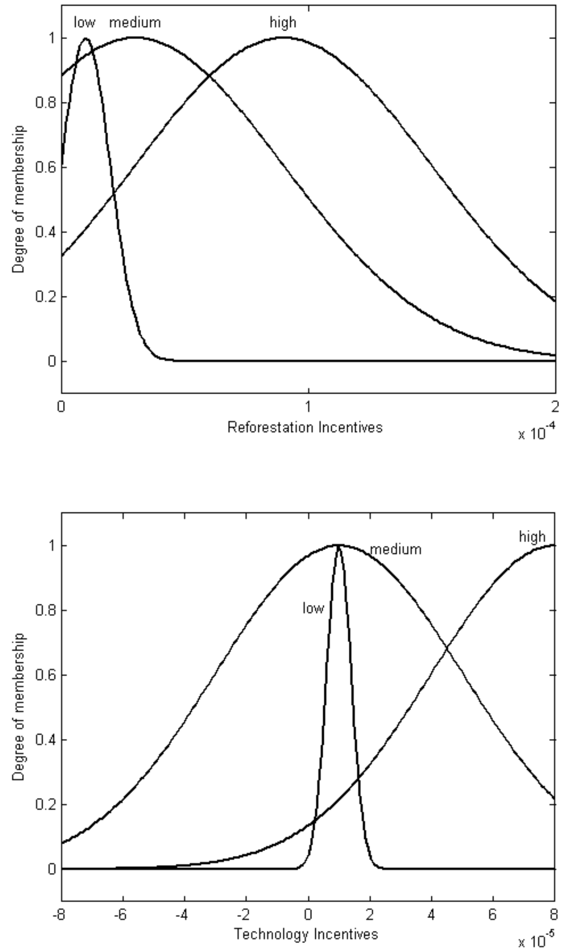

Figure 4 - Membership functions used for the consequent part (output) of the fuzzy decision rules

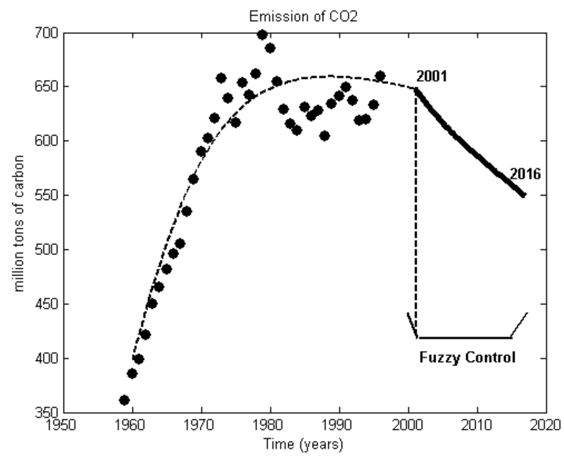

Figure 5 - Actual data and the the fitted model (1960-2000) and the results using the fuzzy decision rules (2000-2016)

Table 1 – Rules for determination of u_1

CO_2	Forest area	u_1
low	low	high
low	med	high
low	high	high
med	low	med
high	low	low
med	med	med
med	high	med
high	med	low
high	high	low

Table 2 – Rules for determination of u_2

CO_2	Forest area	u_2
low	low	low
low	med	med
low	high	high
med	low	med
high	low	med
med	med	med
med	high	med
high	med	med
high	high	high

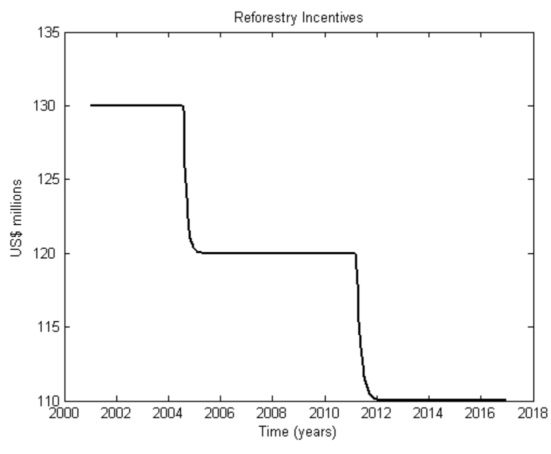

Figure 6 - Investments in Reforestation (2001-2016)

Table 3 – Model Parameters

Parameters	Values
r	0.15
s	700
h	0.0001
u_1	0.00012
u_2	0.0008
γ	0.035
α_1	0.15
α_2	0.00005
a	0.1
b	3.5e+9
c	1e+9
δ	0.01

Table 4 – Initial Conditions used in the simulation

Variables	Values
x(0)	649 million ton CO_2
z(0)	73 million m^3
y(0)	11,704 billion US$
Final time	16 year

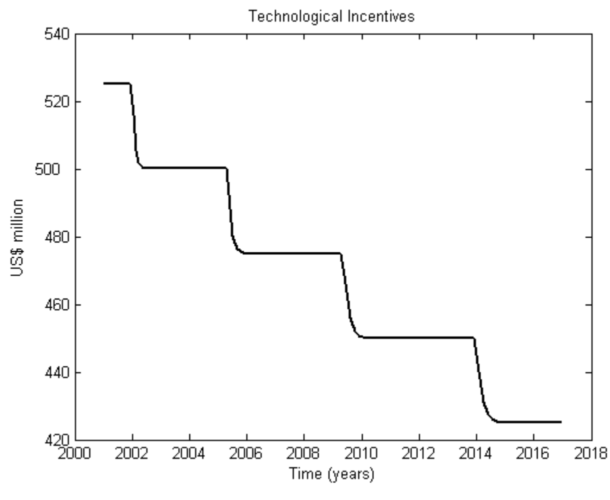

Figure 7 - Investments in the promotion of Clean Technology to (2001-2016)

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