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A MULTILEVEL CYBERNETIC SYSTEM TO CONTROL THE RISK OF ENVIRONMENTAL POLLUTION

Abstract. *The authors present a cybernetic system to control the risk of environmental pollution at several levels, namely: at the level of each polluting economic unit, at the level of the region where these economic units act, and at the level of the whole country. A systemic approach is used in order to analyze all the systems implicated in environmental pollution, and to control all of these processes and prevent them. A data warehouse is used to obtain information about the environment pollution in a timely fashion, with the identification of place, of time, and of the factors which are responsible for these phenomena, using OLAP technology. The authors propose to assign a degree of pollution risk to each polluting economic unit, such that each of them can control its own optimal production, taking account also the degree of risk assigned to it. The decision-makers implicated at various hierarchical levels can better control their policies and the punishment measures applied to polluting economic units by also taking into account the degree of risk assigned to each polluting economic unit.*

Keywords: *Data warehouse, multidimensional model, cybernetic multilevel control system, measure of risk, benefit function:*

JEL Classification: D23

1. INTRODUCTION

In view of the fast growth of industrial production, of the great number of cars, of the big quantity of waste dumped in the environment, of global warming, and their negative effects on the environment, it is necessary to take some adequate measures at both local and global levels to stop these phenomena. Monitoring and controlling the process of environmental pollution implies that qualified organizations collect information about these phenomena, process this data and information in order to establish the causes leading to these effects, determine the risk of pollution represented by different economic units, and take the appropriate actions to control the pollution.

Monitoring the pollution process is done mainly by the Environment Ministry, and this process implies gathering samples from air, water, and earth, for different polluting factors, at different moments in time and in different locations, in order to establish the degree of risk pollution. To fulfill these objectives, one must take into account the number of units whose pollution surpasses the admissible (or alert) level, and also the distance between their level of pollution and the limit imposed by the Environment Ministry, with the purpose of evaluating the degree of pollution and taking the correct decisions regarding the standards for noxa and taxes, as applied to each polluting agent.

2. A SYSTEMIC APPROACH TO CONTROL THE POLLUTION RISK

The globalization process of production, of commerce, of information exchange impose the realization of a control and feedback system concerning the pollution of the environment, that must be implemented at both the local and the global level.

Taking in view all these considerations, the environmental pollution problem must be treated using a systemic approach, because it has consequences not only for a region, or country, but also for the whole earth. Global warming, as a consequence of the continuing growth of environmental pollution, requires taking adequate measures to control this process.

Decreasing the volume of noxa emanated by different polluting economic units, by setting the corresponding taxes for the volume of pollution, the internalization of theses negative external effects, and also the building of markets for pollution rights, are some adequate measures that will lead to the decrease the degree of risk for the pollution in air, water, and earth.

The control system for pollution is realized by entities lying at different hierarchical levels, depending on the sphere influence of the decision-makers who manage this process.

We can highlight three feedback loops:

- The first, placed at the upper hierarchical level – the European Community is represented by European Agency for the Environment.
- The second feedback loop lies at the intermediary level and is realized by the Environment Ministries of every country, who establish the admitted standards for pollution, the taxes, subsidies and penalties, and supervise and control this process.
- The third loop acts at the level of polluting economic units and their environment, and these economic units consider pollution as an externality that influences their functionality and profitability.

Taking into account this hierarchical decomposition and the interactions between these three levels, we can state ***that the control of environmental pollution can be viewed as a cybernetic multilevel system. This cybernetic multilevel system is also adaptable through structure and by the inputs.***

This structural adaptability implies the creation of new modes of organization (Commissions for Purveyance, at European, state or region level, or other types of structure components), which bring their own contributions to control this process.

The control can be made in *feedback and/or forward mode*, which means that corrective actions can be carried out after the output effects are seen, but there can also be preventive measures applied in order to avoid a high level of pollution, and thus improve the quality of the environment.

Adaptability through inputs means, for example, the change of standards concerning the admissible (or alert) threshold, but also changes in the level of taxes or penalties applied to different polluting factors.

Analyzing in more detail the first feedback loop, we can point to the activity of the European Agency for the Environment, which establishes strategies to limit the consequences of pollution, taking into account the state of the environment in the European Community but also the effects induced by it, or received, at the international level. The European Agency for the Environment, in order to fulfill its objectives, carries out a supervision of the state of the environment in every country, and on this basis prognoses the evolution of trends of pollution at a European or global level.

The policies for the environment at the European level are based on two principles:

- The principle of responsibility for environmental pollution, that has as its main objective the application of financial penalties to economic agents or private persons who damage the environment.
- The principle of prevention, which implies the application of prevention measures for environmental pollution.

In order to be able to successfully carry out the process of monitoring and controlling pollution, the European Agency for the Environment must use an integrated system, able to supply aggregated and detailed information concerning environmental pollution in a timely fashion. Using this integrated system, each member of the European Community receives information from the European Environment Agency concerning the pollution standards that must be respected, the price of pollution rights, and in its turn transmits the information to the economic agents. These exchanges of information allow to the Environment Ministry of every country to adjust its environmental policies. Figure 1 presents a cybernetic multilevel system to control the pollution environment.

At the intermediate control level acts the Environment Ministry of every country, which sets its own policies and tactics for the environment, in agreement with the directives of the European Union and with the proper economic needs of development, taking into account also the objectives of the economic agents lying in different developing regions. The Environment Ministry of each country realizes a coordination of the pollution effects for each development region, each economic polluting agent, and each polluting factor (in air, water or earth). In order to successfully fulfill all these processes, it must have at its disposal adequate mechanisms to collect, process and control information about the quality of the environment pollution (for example the Environmental Guard in Romania).

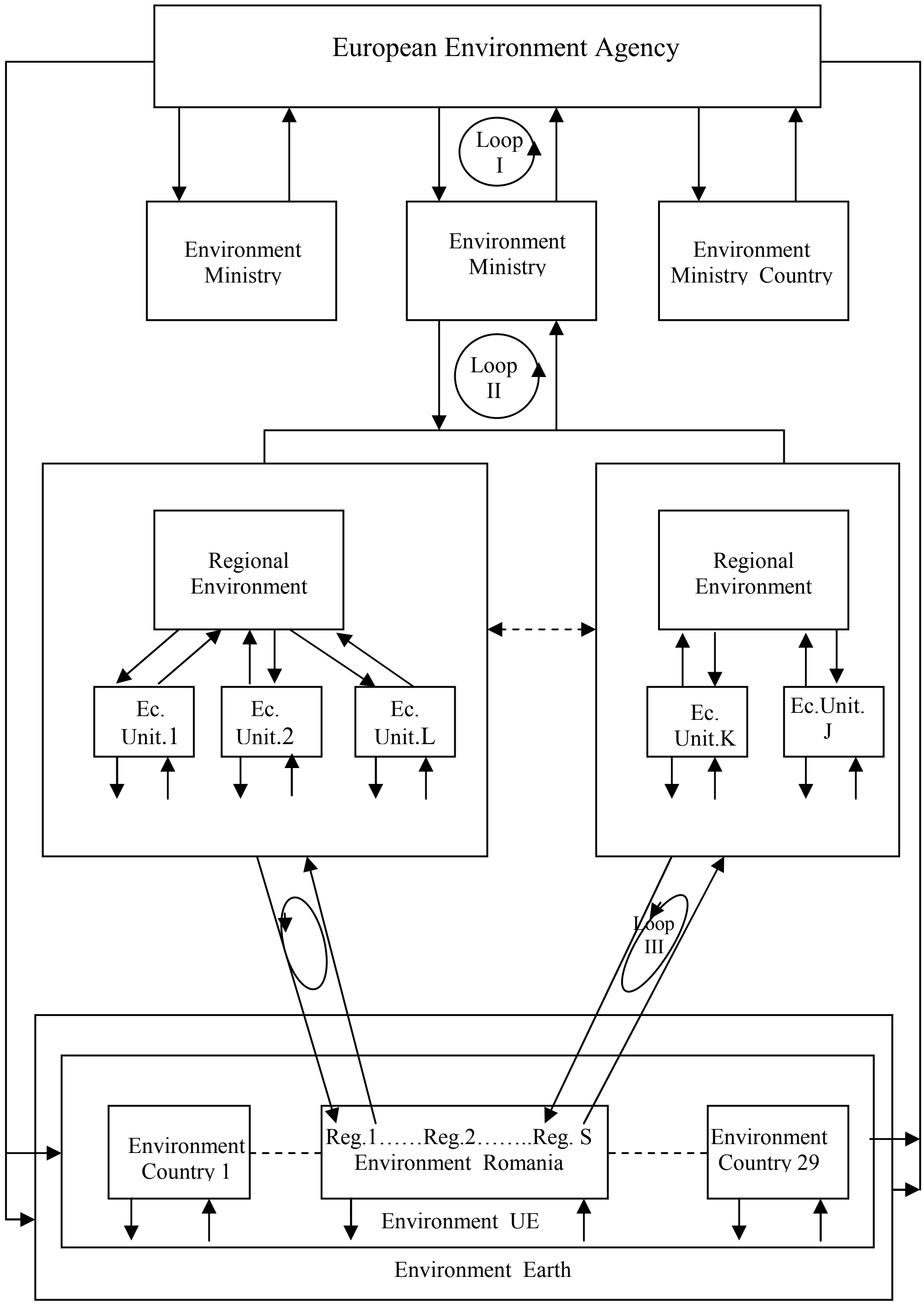

Figure 1. Multilevel cybernetic system for pollution control

It is the responsibility of the Environment Ministry to set and constantly adjust these standards, taxes and penalties, in concordance with the results of experimental tests, and the changes that appears in European strategies and standards. Also, this ministry must carry out preventive actions regarding the degree of pollution risk represented by each economic unit, and for this propose it must analyze current but also historical data. To attain this objective, it is necessary to reorganize the existing data base of the Environment Ministry in ***a data active warehouse***, and use performance tools (like ***OLAP***) *to visualize in multiple planes* this information.

The control at the lower level is realized one hand by every polluting economic unit, and on the other hand by the Environment Ministry which takes into account the objectives of these economic units.

The main objective of the polluting economic unit is to obtain a maximum profit, respecting the standard for pollution imposed by the Environment Ministry. Pollution is considered an externality by each economic unit, and in order to maximize its benefits it tries to internalize the effects of pollution. For the purpose of diminishing the negative consequences of pollution, at the level of each economic unit and at the level of the whole region, the environment ministry can change its environmental policies.

We propose that the environment ministry implement a variable strategy for penalties applied to economic units if the region has a high degree of pollution, or if an economic unit repeatedly surpasses the admissible pollution standards, because the cumulative effects of some polluting factors can't be easily eliminated. Also a degree of risk assigned to each economic unit is proposed.

In the next paragraph we analyze in detail the activities and phenomena which take place at this level.

3. CONTROL THE OPTIMAL PRODUCTION OF AN ECONOMIC UNIT TAKING IN VIEW THE DEGREE OF POLLUTION RISK ASSIGNED TO IT

Each economic unit has, as its main objective obtaining a maximum profit. In order to fulfill this objective it is necessary to analyze deeply how this profit is obtained. In building the profit function, we must consider the volume of production that would be realized, the production costs involved, the costs implied by the pollution rights, the penalties paid for surpassing the admissible standards of pollution, the degree of risk assigned by the Environment Ministry to the economic unit.

The structure of the production costs depends on three main factors, namely: the volume of production y_j, the volume of pollution, and the degree of risk r_j. assigned to it by the Environment Ministry In order to reduce the production costs, one must invest in new, less polluting technologies, or take out insurance policies for pollution risk, in order to avoid paying high cost penalties.

The diminishing of costs paid by the polluting economic unit for: the pollution rights, the penalty costs (which depend of the risk factor r_j) or insurance rates can be controlled also by the enterprise itself, by analyzing the historical data of the economic unit related to these factors. The existence of a data warehouse which contains all this information, and easy access to it by the polluting unit itself, enable it to monitor this control process in order to take the best decisions for obtaining the maximum profit. Taking in view all these considerations, the profit for the economic unit j can be expressed by the following function:

$$\Pi_j = p_j y_j - CT(y_j, q_j, r_j) - \theta_j q_j - \varepsilon_j r_j$$

where :

- $p_j y_j$ represents the benefits obtained from selling the volume of production realized;
- $CT(y_j, q_j, r_j)$ the production costs which take account of the volume of production and pollution but also of the risk of pollution assigned to the specific economic unit;
- $\theta_j q_j$ the costs for bought the pollution rights;
- q_j the volume of pollution for the economic unit *j;*
- $\varepsilon_j r_j$ the penalty costs paid by the economic unit *j* .

For defining the different risk measures, we introduce the following notations:

S – total number of regions in the country; $s \in S$ - the index for region;

J^s - the number of economic units situated in region *s*;

P – the number of polluting products; $p \in P$ - the index for the type of polluting product;

N – total number of samples taken in $[t, t+1]$ time interval;

q_p^{admis} - the admissible level of pollution for polluting factor *p*;

q_p^{alert} - the alert level of pollution for polluting factor *p*;

$A_1 = \{i \in N / q_{pi} > q_p^{admis}\}$ the lots of samples for polluting product *p* which are overtake the admissible level q_p^{admis} and n^{ad} = card A_1, ;

$A_2 = \{j \in (N - A_1) / q_{pj} > q_p^{alert}\}$ the lots of samples for polluting product *p* which are overtake only the alert level q_p^{alert} and n^{al} = card A_2 ;

$f_p^{ad} = n^{ad} / N$ - frequency of violation the admissible level of polluting factor p;

$f_p^{al} = n^{al} / N$ - frequency of violation the alert level of polluting factor p;

α_1 - weight assigned to violation of the admissible level in calculus of the risk ;

α_2 - weight assigned to violation of the alert level in calculus of the risk ;

ρ_p-weight assigned to noxious the polluting factor regarding environment. Using these weight we can take into account the negative impact of polluting factor regarding to the quality of environment (such as the quantity of nitrogen oxide which is set free in air affects the ozone layer);

γ_j - penalty factor which take into account the history of the risk values assigned to economic unit j along a period of many years (1-5)

r_{pj}^s - the risk connected to polluting product p which is produced by the economical unit j situated in region s;

r_p^s - the risk connected to polluting product p for an entire region s;γγ

r_j^s - the risk connected to economic unit j situated in region s taking into account all its polluting products;

r_p - the risk connected to polluting product p for an entire country.

where:

$$r_p^s = \sum_{j \in J^s} r_{pj}^s, \qquad r_j^s = \gamma_j \sum_{p \in P} \rho_p r_{pj}^s, \qquad r_p = \sum_{s \in S} \sum_{j \in J^s} r_{pj}^s$$

$$r_{pj}^s = \alpha_{1j} f_p^{ad} \sum_{k \in A_1} \left(q_{pk} - q_p^{admis}\right) / q_p^{admis} + \alpha_{2j} f_p^{al} \sum_{k \in A_2} \left(q_{pk} - q_p^{alert}\right) / q_p^{alert} \quad (1)$$

These measures of risk allow us to classify the polluting economic units from a region or from a country, considering the noxa which are set free in air, water or earth by them, and also their historical data.

Taking in view how the time interval for data analysis was defined, one can apply some controls to diminish the degree of risk. In the formula that expresses the measure of risk, *the authors propose to take into account the following elements:*

- the frequency of violation of the admissible and alert level of polluting factors established by the Environment Ministry for each polluting product;
- the distance from the levels;
- the samples number collected in the considered period;
- the weights α_{1j}, α_{2j}, ρ_p.
- the penalty factor γ_j assigned to economic unit j

Through the weight ρ_p we can take into account the negative polluting impact of each polluting factor for the environment for a long period of time.

Through γ_j we create a tool for the Environment Ministry to stimulate or punish the economic unit regarding the pollution produced by it considering the data collected for many years . Usually the value of γ_j is 1, but if the economic unit surpass often the standards imposed, then we take greater value depending of the sternness of pollution produced by it. If it come out a reduction of pollution for the economic unit j in the period analyzed (1- 5 years) then γ_j take values less then 1.

In case a repeated violation of the allowed pollution levels takes place, to counteract these effects one may:

- consider a much restrictive risk level (ex: the second upper moment);
- modify the admissible level q_p^{admis} or alert level q_p^{alert};
- increase the total punishment amount at the local level;
- control the pollution risk at the different hierarchical levels (Environment Ministry, development or administrative region, economic unit).

In order to ground up its tactics vis-a-vis its costs (production costs, penalties costs, pollution costs), each economic unit j must undertake a sensitivity analysis of the profit function regarding the volume of pollution produced and the degree of risk assigned to it by the Environment Ministry. Such each economic unit must solve the following program:

$$\max \Pi_j = p_j y_j - CT(y_j, q_j, r_j) - \theta_j q_j - \varepsilon_j r_j$$

$$y_j = f_j(x_j, q_j)$$

where: $x_j = (x_{j,1}\ x_{j2}, \ldots x_{jl})$ is the vector of production factors and $q_j = (q_{j1}, q_{j2}, \ldots . q_{jl})$ is the vector of polluting factors used by the economical unit j;

Substitute y_j in Π_j expression, we will obtain the following problem:

$$\max \Pi_j = p_j f_j(x_j, q_j) - CT(f_j(x_j, q_j), q_j, r_j) - \theta_j q_j - \varepsilon_j r_j$$

The optimal first order conditions are:

$$\frac{\partial \Pi_j}{\partial x_{ji}} = 0 \qquad \forall i = 1, n \qquad \Rightarrow p_j = \frac{\partial \mathrm{CT}(y_j, q_j, r_j)}{\partial y_j}$$

$$\frac{\partial \Pi_j}{\partial q_{pj}} = 0 \quad \forall p \in P \qquad \Rightarrow \quad \theta_{pj} = -\frac{\partial \mathrm{CT}(y_j, q_j, r_j)}{\partial q_{pj}}$$

$$\frac{\partial \Pi_j}{\partial r_j} = 0 \qquad \Rightarrow \quad \varepsilon_j = -\frac{\partial \mathrm{CT}(y_j, q_j, r_j)}{\partial r_j}$$

On observes that θ_{pj}, ε_j represents the marginal costs of the pollution and the risk, for each economic unit j. In order to realize a good balance between the investments costs which lead to decreasing the production costs (by introducing new technologies, developing new research in this field) and the degree of risk on one hand and on the other its profit, the economic unit must take adequate decisions. For a good substantiation of these decisions, one must analyze the current and historical data regarding the pollution of each economic unit in useful time. For this aim, we propose the reorganization of the existing transactional data base of the Environment Ministry, in a data warehouse which enables through

OLAP technology to rapidly analyze this data, with the possibility of a multidimensional visualization grouped by subject, domain and period of times.

The dimensions considered in the multidimensional model are: - time (with its members year, month, day), - location (with its members development region, administrative region, town, enterprise, address), - experimental collected data, (with its members types of test in air, water, earth, name, code, location of collection, time of collection, frequency), - pollution factor (with its members type of pollution factor in air, water, earth, category of polluting factor, code, name, measurement unit, alarm threshold, maximum acceptable level).

The considered measures are: the number of measures that surpass the alarm threshold, the maximum acceptable level, the computed value of the risk.

In the next paragraph, an example is given to illustrate better this facts.

3. CASE STUDY

We consider the pollution produced in region Arges, where the main polluting economic units are: the chemical enterprise S.C. Arpechim, and the car enterprise DACIA S.C. Arpechim is responsible for 90% of the pollution in region Arges , Dacia for 5%, and the others economic units for the remaining 5%. The polluting factors taken into consideration are nitrogen oxide, carbon dioxide, carbon monoxide, particle pollution, and metals. The analysis is undertaken for a period of four months, namely January, February, March and April 2008, and the samples collected by the regional department vary from one month to another, but to establish the degree of risk assigned to each economic unit a period of one year and a half is considered. Analyzing the data for this period, the Environment Ministry establishes γ_j for enterprise Dacia to value 1 and for enterprise Arpechim 1.5. The standards imposed by the Environment Ministry for each of the 5 polluting factor in air is also given, and using two measures of risk, namely the partial upper moment of first degree given by the formula (1), and number of samples that surpass the admissible level and alert level, we obtain the following results illustrated in figures 2 and 3. We observe that the powders represents the polluting factor with the highest value of risk and it is greater for Arpechim.

If we compute the value of risk assigned to Dacia and Arpechim with α_1 = 1, α_2 = 1, and ρ_p= 1 for $\forall$ p, we obtain r_1 = o,657 and r_2 =1,608 also more bigger Arpechim o.819. Considering now different values for ρ_p namely (1.5, 1.2, 1.3, 1.25, 1 in order in which the polluting factors appear in the graph) we obtain for Dacia r_1 = o.8197 and for Arpechim r_2 = 2.o127.

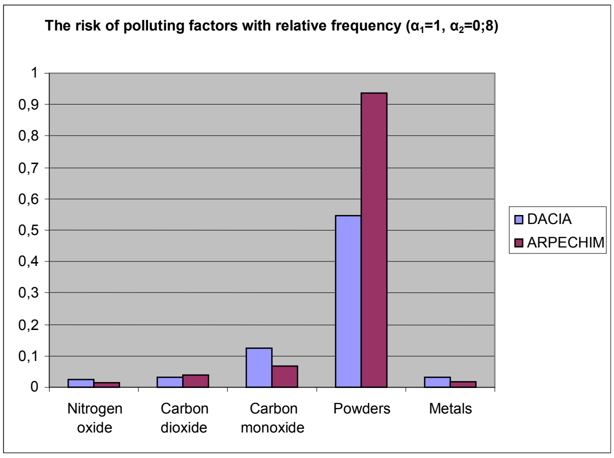

Figure 2

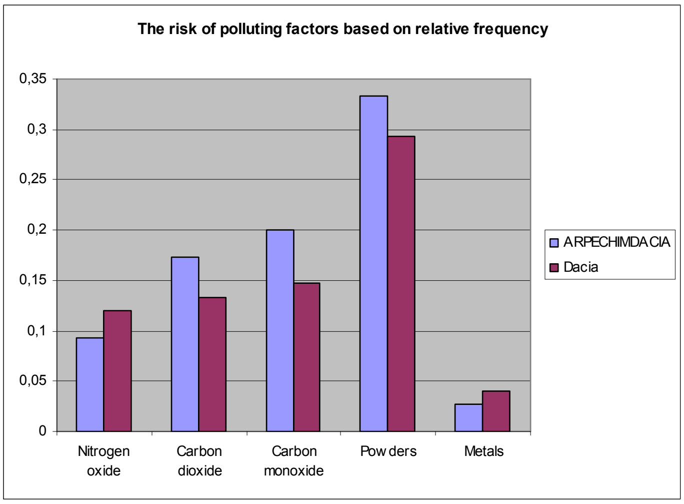

Figure 3

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