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THE ENVIRONMENT POLLUTION IN TERMS OF SYSTEM THEORY AND MULTICRITERIAL DECISIONS

Abstract. *In this paper,the authors present a system of pollution management using system theory concepts. The system is designed as a multilevel control system able to supervise, control and adjust the level of environmental pollution. The coordination of decision problems regarding pollution arising at different levels of the system (European, national and regional) are highlighted and expressed in a formal manner. In order to diminish the degree of environmental pollution by applying efficient policies to control this process, new formulae of risk are given which also take into account the impact of pollution on the health and welfare of the population. An application with the new formula is realized for seven economic polluting units.*
Keywords*: hierarchical system, self-learning control polluting risk degree, multicriterial decision.*

JEL Classification: D23

1.INTRODUCTION

Regarding the affiliation of our country to European Union, it is necessary to align the national and regional development programs to the pollution standards established both at the level of the region, the country and European context. For this purpose it is necessary to monitor permanently this process and its effects, on short and medium term on environment and its socio-economic implications.

To successfully achieve the pollution monitoring process, implies collecting data relating to polluting economic units and polluting factors produced by them, an organization of data to be accessed in timely fashion, a assessment of the risk factors associated with the economic units, taking in account not only environmental effects but also their impact in economic development (regional, national and European). The environment quality management system needs to establish appropriate decision policies, compliance with environmental standards, and quality of life. In order to achieve successfully these goals it is useful to apply a systemic approach and adequate tools such as: data warehouses, multicriterial decisions and relevant indicators for measuring the degree of risk of pollution.

2. THE MANGEMENT SYSTEM OF POLLUTION USING SYSTEM THEORY CONCEPTS

Considering that environmental pollution in a region or country is closely related to the pollution of neighbouring countries and regions, the surveillance, control and adjustment this process can be achieved only through a systemic approach. The management system of the environmental pollution is a complex system that includes many subsystems and has multiple objectives, such as:

- the definition of objectives on short and long periods of time, in terms of development and pollution in the EU, its countries and local regions belongs to every state;
- prioritizing objectives of pollution in order to focus their attention to the key issues of the system;
- defining key problems which condition the attainment of the objectives proposed;
- coordination of the objectives of the different decision levels, in order to achieve the global goal (European Environmental Agency, Ministry of the environment);
- planning actions to be undertaken in order to achieve these objectives and dissemination of information between decision levels of the subsystems and the whole system with the purpose of coordinating all these objectives.

The management system of environment pollution should be designed as a hierarchical-multilevel system able to control and adjust the risk of pollution. This system must be able to highlight at highest level a process of coordination of informational-decisional programmes according to global objectives (EU directives and objectives at national level) and at lower levels to ensure harmonisation of local objectives with global one in order to fulfil them. Pollution control system can be designed as a hierarchical system with four control feedback loops. At higher level operates the European Environment Agency (EEA) which sets out the strategies for each component country taking into account their objectives and its specific condition but also the goals at European level and worldwide.

The next feedback-control loop takes into account the policies developed by the Ministry of the environment (EM_i) in each country and environment regional agencies (ERA). It is necessary to achieve an exchange of relevant information's in a timely manner between subsystems lying at this level that control this process, which involves a selection, an aggregation of information and implementation of the established decisions.

The third feedback loop refers to regional environmental agencies and local environmental units E_j (which can also be work-station). At this level, a large amount of information must be collected, selected, mixed and processed in order to be sent to important information as well as detailed but relevant information to the regional agency for the environment.

The fourth feedback loop takes into consideration the reactions and impacts between economic unit (EU_j) responsible for the polluting factors *p* and the environment in which it operates.

There is a powerful interaction between these four control loops that must be controlled and directed. For this purpose, the management system of environment pollution should be regarded as a multilevel-control system *adaptive and self-control*. Adaptability, in this case implies changes of inputs and changes of its internal structure. As shown in the work /7/ adaptability through inputs imply changes of rules and standards for polluting factors and its values (for example: alert threshold, admissible threshold) also changing the level of penalties and/or subsidies for economic units responsible for pollution. Adaptability by structure means in our case to create new organizations to monitor better the environment at european, state, regional level, and developing new strategies and policies in order to diminish the pollution level and to achieve a more rigorous control.

The property of the system of being self-learning implies learning from past experiences and the capability to make self corrections based on previous decisions. For this purpose, the use of a data warehouse which store the history of pollution, contributes to fulfil this aim. In Figure 1, are used some symbols of decision trees representation especially for the decisions taken at higher levels and are represented the four control loops of management system of environment pollution.

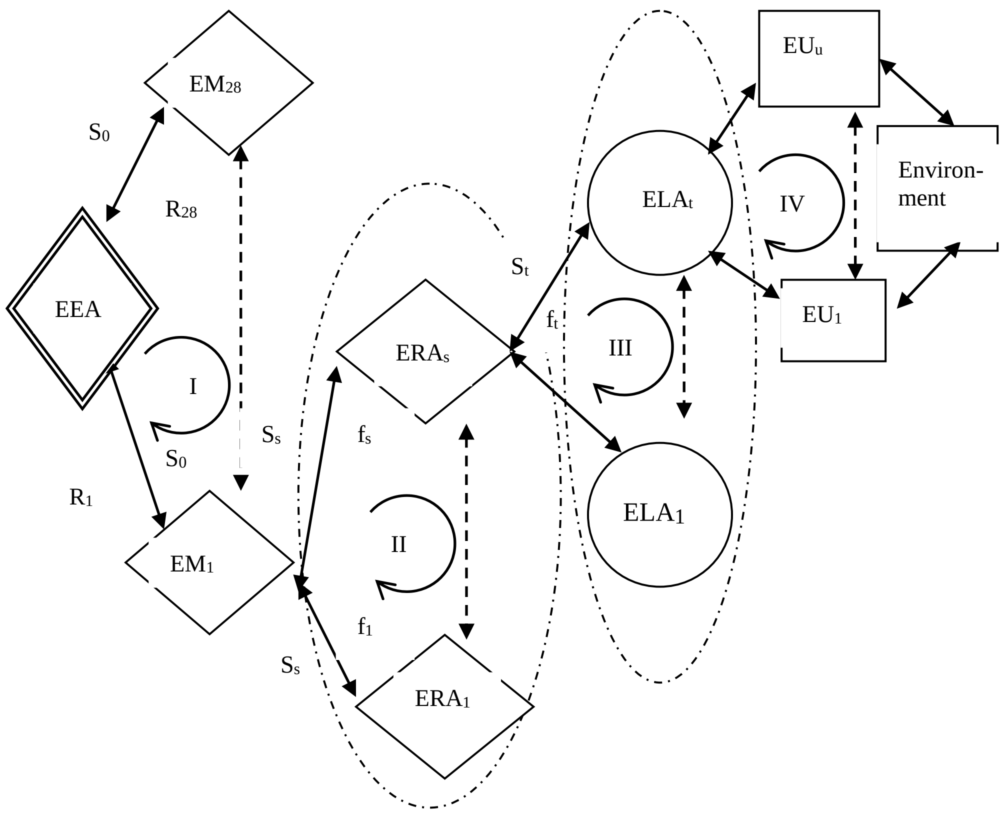


Figure. 1. The structure of the feedback loops to monitories the management system of pollution

Within each control feedback loops, in order to obtain the desired output, it is necessary to solve a couple of decision problems whose solutions are inputs for lower-level decision makers. A coordination between decision problems on different hierarchical levels of control loops must be realised. To realise this purpose, must exist an exchange of relevant and useful information in a timely manner, must exist between the decision-makers of the hierarchical levels (corresponding to the four loops) and their reactions obtained through feedback. Using the concepts of systems theory, the types of coordinations and subordonations mentioned above may be expressed formally.

Let be:

D_0-the set of decisions problems at the unit on the highest level (European Environment Agency);

S_0-vector of solutions of the decision problems on the upper level (strategies, policies, directives, standards of pollution, etc.);

R_i-reaction entries received by the unit on the upper level from the subsystems lyed on the lower levels (ministries of environment, regional and local environmental agencies);

RI - the set of all reaction entries where: $R_i \in RI$;

$P(S_0, D_0)$ - action done by the system lyed on the upper level, defined for all pairs (S_0, D_0);

C - coordinate input vector given by the decision unit on the higher level;

D_i - decision problems at lower levels (at the level of the Ministry of environment, regional and local agencies);

S_i - the solutions of the decision problems D_i of lower-level subsystems;

$\overline{D}(C)$ - the set of decision problems $\{D_1(C), D_2(C), \ldots D_n(C)\}$ of systems located on lower levels, dependent on coordinating entrance C, which is an input vector for these systems, where *n* is the number of them;

f_i - the reactions received from lower-level subsystems;

K_0 – command unit on the upper level which realize an adaptation of the decisions for each level what is it immediately below;

$P(S_i, D_i)$ - the action taken by subsystems on the lower-level (Ministry of environement or regional and local agencies).

To point out that the output S_0, produced by the decision unit on the higher level, must be adapted according to the specificity of each subsystem to which it is transmitted, and this is achieved through a decoder system K_0. In our case K_0 is represented by the set of procedures and rules which are responsible for the adaptation of the solution of the decision problem of on higher level S_0 (European Environment Agency) to the requirements of lower-level subsystems (Ministry of environment, regional agencies).

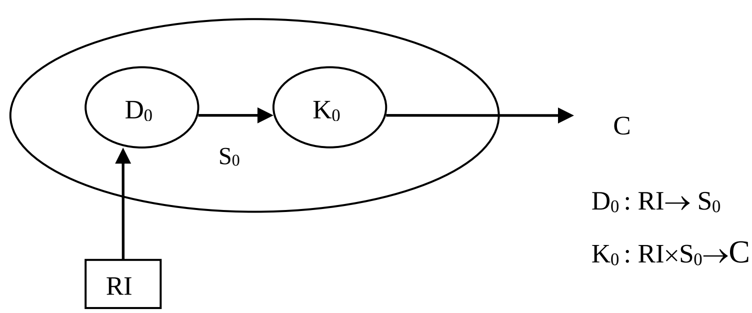


Figure 2. The decision system of the European Environment Agency

In Figure 2 we can see the structue of the decision system at the highest level.

If we consider the decision problems of lower-level subsystems, then apply their solutions in practice, in turn, this requires an adaptation realized by each subsystem (Ministry of environment, regional and local agencies) where they will be implemented. This adaptation is done by a subsystem K_i with the decoder role which take into account the coordinate entry C, given by the upper level, but also of the reaction vector transmitted by the decision-makers on the lower level to the physical subsystems where the solutions must be applied. Formally, these relationships may be expressed as follows:

$K_i : C \times fi \rightarrow m_i$ - the decoder on the lower level;

$d_i : C \times fi \rightarrow s_i$ - the decision unit on the lower level;

$m_i = K_i\ (f_i\ \ d_i(C, fi\ ))$ - the control which is applied to the subprocess;

$A_{0i}{:}s_i{\times}fi \times C \rightarrow R_i$ - adapter between the decision units on the upper level and those on the lower levels, which realize a selection, filtration and aggregation of information.

To decision unit d_i is assigned a family decision problems $D_i(C, f_i)$, with the set of decisions defined in such a way, that for each pair (C_i, f_i), the output $s_i = d_i(C, f_i)$ is the solution of the problem $D_i(C, f_i)$. Each decision unit d_i select from the coordinator input C the information acoording to its specifications.

The decoder generates control inputs adapted for subprocess *i* which is determined by solution s_i of decision problems d_i and feedback information f_i provided by the lower levels. In our case K_i realize a transposition of the directives, rules and standards of the Ministry or regional, local agencies in concrete actions that lead to the fulfillment of their objectives.

In Figure 3 is represented the decision subsystem on lower level.

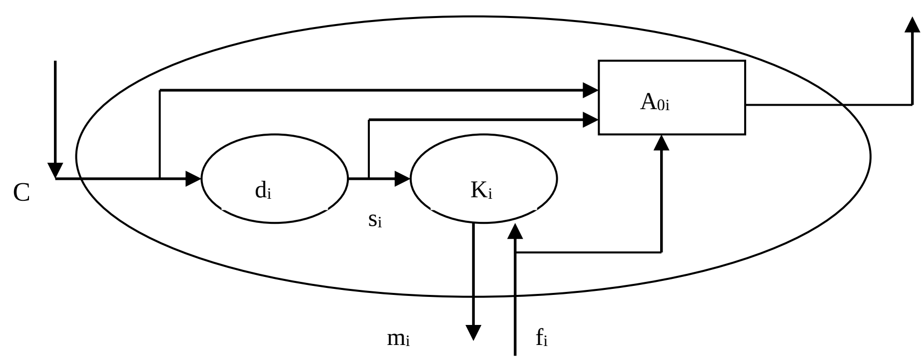


Figure 3. The decision subsystem of environmental ministries, regional and local agencies

Considering the above stated we can highlight a coordination relating to the decision unit on the upper level and another to the decision problem of the whole system (which include all its subsystems). For example, in our case it could be divergences between the objectives of each regional environmental agency and the objectives of the ministry of environment which take into consideration all regions. Thus the enviromnental ministry may impose new rules or standards for a certain region considering the importance of its production for the country or the European Union, and by the other hand restrict the pollution standards for another region in order to respect the level of pollution imposed to country. Coordination regarding the decision problem of the unit on the upper level is expressed as follows:

$$(\exists C)(\exists s)\ [P(S, \overline{D}(C)) \text{ and } P(C, D_0)]$$

So this coordination requires that actions must be taken in such a way that exist solutions to the decision problem of the upper unit for coordinated input C and the set $\overline{D}$(C) of the decision problems of lower-level will have also solution. The dependence of the decision problems on the higher level of the output of the decision unit on the lower level can be expressed as follows:

$$P(C, D_0) \Leftrightarrow (\exists s)[Q_0(C,s)],\ C \in \Re,$$

where:

- $Q_0(C,s)$ is an action defined for all pairs (C, s) in the space defined by the CxS
- $S= S_1\times S_2\times\ldots\times S_n$, the Cartesian product of the solutions of the decision units on lower-levels;
- $\Re$, the set of all coordination entries.

This condition indicates that the coordinated input C solves the decision problem of higher unit only if there exists a solution s_i that correspond to lower unit, such that the condition expressed through the action of Q(C, s) to be satisfied.

Coordination relating to the decision problem viewed as a whole (in the case the strategies and policies set by the EU, the ministers of the environment of the countries, taking into account their objectives as well as certain social desideratum concerning the human factors involved in the process) is achieved if the decision problems of lower-level subsystems are coordinated towards the decision problems of the units on the upper levels and these have also solution. This means that the coordinator (main control system) can influence the lower units so that their resulting actions satisfy the global decision problem.

$$(\exists C)(\exists s)[P(s, \overline{D}(C)) \text{ and } P(\Pi_m(S_i,D))],$$

$S = S_1 x S_i - S_m$ – cartesian product of solutions for the decisional problems of subsystems on lower levels;

$\overline{D}$ (C) – the set of decisions of lower-level units;

$\Pi_m : S \rightarrow M$ where M (m_1, m_i.........m_k) the set of input commands.

$\Pi_m(s_i,D)$ - the actions taken by the decision units on lower-level, where Π_m is transform function of solution in cotrol inputs m_i applied to subprocesses of economic unit.

The decision problems of the multilevel system take into account two aspects, on the one hand finding solutions to reduce the risk of pollution at the level of the region, country, city, ecnomic unit and on the other hand the right quantification of the quality of the founded solutions.

3. USEFUL INSTRUMENTS TO EVALUATE THE DEGREE OF RISK: INDICATORS OF RISK, DATA WAREHOUSES, MULTICRITERIAL DECISIONS

Accurate quantification of the degree of risk asociated with the polluting economic units with directe implications at the local, regional, national and european level requires a knowledge of the history of their pollution. If we take into account the interaction between the areas of pollution seen in terms of the degree of resolution of the analysis, it is necessary to collect a large volume of information, to store and access them efficiently. For this purpose, the use of data warehouse facilitates quick and efficient access to data series on different periods of time (years, months, days) with hifghlighiting the supplier locations (economic unit, locality, region, country) as well as the types of polluting factors of environment.

Time, location, polluting factors mean dimensions which is one of the specific data warehouse concept. The values of measured data regarding pollution, their frequency, the set of values exceeding permissible threoulds, the pollution established standards, formulas for calculation of the degree of risk for polluting factors emited by economic unit, represent measures used in the data warehouse.

These measures reflect the qualitative aspects of data and are used in decision making by the factors that respond to every hierarchical level of control and adjustment of pollution process.

The third concept that characterizes a data warehouse referes to facts, which are represented by the set of measures that quantify pollution and together with the dimensions, identify the context in which they occurred. Facts about data stored in tables allow connection to the information in the dimension"s table. An effective tool to visualize and analyze multidimensional data in a data warehouse, is OLAP system. This system allows construction of new scenarios by answering questions like "what if", while data warehouses answer to questions such as "who?", "why?", "where?", "when?", "how?". OLAP system facilitates a multidimensional perspective of data, an orientation in time (time intelligence) necessary to compare and to analyse data. In our case we can visual with this tool a certain polluting factor produced by an economic unit which operates in a specific location and time moment, all data that caracterize it, which will then be used to determine the risk of pollution.

If we don't use the information regarding pollution from data warehouses, we can lead to an incorrect measurement of the degree of risk both for polluting factors and economical unit . Also, in this case it doesn't exist the posibility to adjust coefficients used in the formulas of the degree of risk such as: the threshold of permissible and alert level, penalities asigned to the economic unit depending on its pollution history, etc.

Taking into consideration the formulas proposed by the authors in the paper /7/ for quantify of the degree of risk of pollution, we use only the third measure of risk (second degree), and fourth measure.

The authors propose a new measure risk associated to pollution factor *p* and polluting economic unit *j*. We take into account also the intensity and importance of the pollution's impact on population health and the influence of products realized by economic units (UE_i) regarding the welfare of popullation.

To quantify the impacts of pollution on population's health we take into consideration the reports of the Health Ministry regarding the number of illnesses caused by polluting factors. The notifications (warnings) sent to our country since 2012 regarding overpassing of the level of noxa (especially in Bucharest) compared to the European average, led to the payment of important penalties with deadline 2014.

The lack of adequate measures to reduce the level of pollution (especially in Bucharest) had direct implications for the increasing number of diseases, especially lung cancers, compared to the European average. Based on these considerations it is necessary and useful to introduce a new term β_{pj}^{s} that quantify the impact of polluting factor *p* on population health, in the formula of risk (third type, second degree).

Thus, the new formula of the risk factor *p* issued by the economic unit *j* which is placed in region *s* become:

(1)
$$\bar{r}^{s}_{pj} = \alpha_{1j}\ f^{ad}_{p} \sum_{k\in A_1} \left(q_{pk} - q^{admis}_{p}\right)^2 / q^{admis}_{p} +$$
$$+ \alpha_{2j}\ f^{al}_{p} \sum_{k\in A_2} \left(q_{pk} - q^{alert}_{p}\right)^2 / q^{alert}_{p} + \beta^{s}_{pj}$$

where:

(2)
$$\beta^{s}_{pj} = \theta_p \frac{NB_s}{NT_s}$$

NB_s - total number of illnesses due to the polluting factor of *p* from region *s*;

NT_s - total number of inhabitants in the region *s*;

θ_p - the weight assigned to the impact of polluting factor *p* in population health;

The computed risk for the enterprise *j* in region *s* is in turn modified taking into account the efficiency of the enterprise as such its contribution to national, regional budget:

(3)
$$\bar{r}^{s}_{j} = \gamma_j \sum_{p\in P} \rho_p \bar{r}^{s}_{pj} + \delta^{s}_{j}$$ where:

γ_j - is the incentive/penalty factor that takes into account the company's pollution history,

ρ_j - weight that quantify the impact of economic unit *j* over the environment and the period during it actions,

$\bar{r}^{s}_{pj}$ - the risk of polluting factor *p* produced by economic unit *j* in region *s*,

δ^{S}_{j} - quantifies the weight of economic unit *j* in the region *s* to national budget and to welfare of population from the same region *s*.

For the assessment of δ^{S}_{j} we use multicriterial decision techniques which take into account economic indicators (turnover of the economic unit and the number of employees) to quantify the degree of their efficiency. Thus, for an economic unit that exceeds an established level of efficiency we will consider $\delta^{S}_{j} < 0$, and for an economic unit below this level, $\delta^{S}_{j} \geq 0$.

Such a high contribution to budget can determine the decision factors to reduce the degree of risk associated with the economic unity *j* of the region *s*. In the quantification of δ_j^S for all economic units lying in a same region must be made a balancing such that a diminishing of δ_j^S for an economic unit *j* lead eventually to an adjustment of δ_j^S for other economic units in the region so that the region's pollution level is not exceeded.

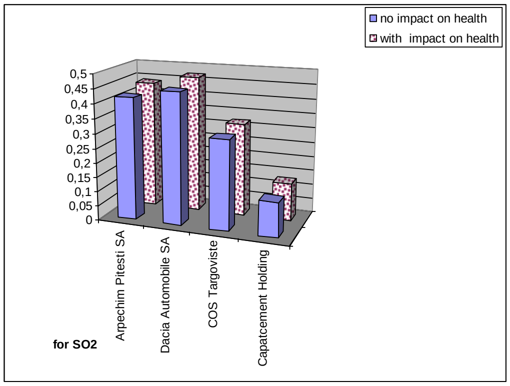
4. APPLICATION OF THE NEW MEASURES OF RISK

Taking into account the four economic units analyzed in paper /7/ namely Automobile Dacia SA, Arpechim –Pitesti SA, C.O.S. Targoviste, Carpatcement Holding SA and the new formula of risk (which consider the impact on health population) for polluting factors as: SO2 (sulphur dioxide), NO (nitrogen oxide), NO2 (nitrogen dioxide), CO (carbon oxide), PM10 (dust), results a change in the values of risk associated to each polluting factors.

In figure 4, there are illustrated the new results. In the evaluation of β_{pj}^s which is present in formula (1), data were collected from the National Center for Statistics and Informatics in Public Health and from regional departments of public health. The values of θ_p (see formula 2) have been determined taking into account the intensity of danger in health of the polluting factor *p*. Comparing these new values of the degree of risk to those in the paper /7/, for the same period of time we can say the following:

- we can observe a growing of the value of risk for polluting factor powders emitted by C.O.S Targoviste with 10%, Carpatcement Holding SA with 6%, while for Automobile Dacia SA and Arpechim Pitesti SA was recorded a growth of 7%;
- for factor sulphur dioxide (SO2), the value of risk determined with new formula, indicate an increase of 2% for both factories Dacia Automobile SA and Arpechim-Pitesti SA and insignificant variations for the other two economic units;
- for the other polluting factors, the new values risk were not computed because it did not exist conclusive data to measure their effect on population health.

In Figure 4 are represented for the four economic units, in comparison, the risk values (with and without effect on health) of polluting factors sulphur dioxide, powders for the time period 2009-2010.



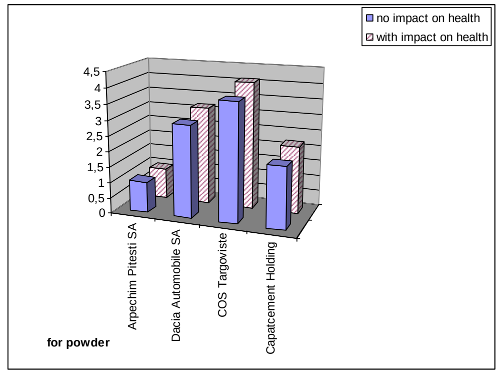


Figure 4. The risk values (with and without effect on health)

Using risk formula (3) which quantifies the level of risk assigned to economic polluting unit *j*, which include the coefficient δ_j^S, we can make a more consistent analysis if the number of analyzed economic units is increased and extend the time period. For this purpose the analysis period was extended from the second quarter of year 2010 by the end of year 2012. We have considered new polluting economic units, with a similar profile of production to those examined in paper /7/. We excluded Arpechim Pitesti SA because it has been closed in 2011. The polluting economic units considered in this study are: OMV Petrom, Dacia Automobile SA, ArcelorMittal Galati, Targoviste, C.O.S. Carpatcement Holding SA, Lafarge Cement, Azomures, and for the period 2009-2012.

In order to evaluate δ_j^S were taken into account in this paper, only the data relating to turnover and number of employees of economic units, above mentioned, on an extended time period, taken in views the difficulty to access other type of data and their purchasing costs. Turnover indicates the contribution of each economic unit *j* at the regional or national budget and the number of employees quantifies its contribution to the welfare of the population by number of created jobs. To determine the values of δ_j^S we have considered different weights for the two indicators (75% turnover, 25% number of employees) and we used a multicriterial decision algorithm with cardinal preference criteria (Topsis method). A more substantial analysis will take into account other criteria that define better the contribution of the polluting economic units to welfare. The method used to obtain a ranking of economic polluting units taken in study in terms of turnover and the number of employees, point out for each economic unit the distance to the optimal one. We can also determine the distances between the polluting economic units, which will be used in assigning accurate values to δ_j^S.

From the analysis of yearly values of turnover, we observed a 20% growth in the time period 2009-2011, with a slight decrease of 3% in year 2012 for Dacia Automobile SA as well as insignificant fluctuations in the number of employees. For units OMV Petrom and Azomures turnover raise from one year to another namely 14% respectively 39%**.** For COS Targoviste, it was observed an important increase of turnover for the period 2009-2011 (44%) and a significant decrease in year 2012 (55%) while the number of employees is reduced by 32% in the same period. For economic units Carpatcement Holding and Lafarge Cement were identified for both indicators small variations during the period 2009-2012. Concerning economic unit ArcelorMittal the growth of its turnover was on average 14**%** yearly during the period 2009-2011, and continues to growth with 16% in 2012, but the number of its employees decreases each year reaching in year 2012 a value with 39% smaller than in 2009.

The values of efficiency level (e_j) for economic units obtained applying Topsis algorithm and the corresponding δ_j^S are given in the table below:

	OMV Petrom	Dacia Automobile	Arcelor Mittal	Lafarge Cement	Carpat Ciment	Azomures	COS Targoviste
e_j	1	0.741	0.262	0.0045	0.0073	0.0477	0.024
δ_j^S	0.45	0.33	0.12	0	0	0.02	0.01

The established level of efficiency for the economic units is in our case 0,22, and taking into account the results in the table above for the first three units δ_j^S will be subtract from the its risk degree of pollution (see formula 3), for the next two units $\delta_j^S = 0$ so they maintains the same value of polluting risk. For the last two analyzed economic units, there is an insignificant growth of risk degree because δ_j^S has very small values.

Figure 5 illustrates the values of the risk degree in the air pollution, for the analyzed polluting economic units, in the time period 2009-2012, based on modified formula (3). The value assigned to δ_j^S take into account, one side the results obtained using Topsis algorithm, and on the other side, the scale of risk values for economic unit j without δ_j^S.

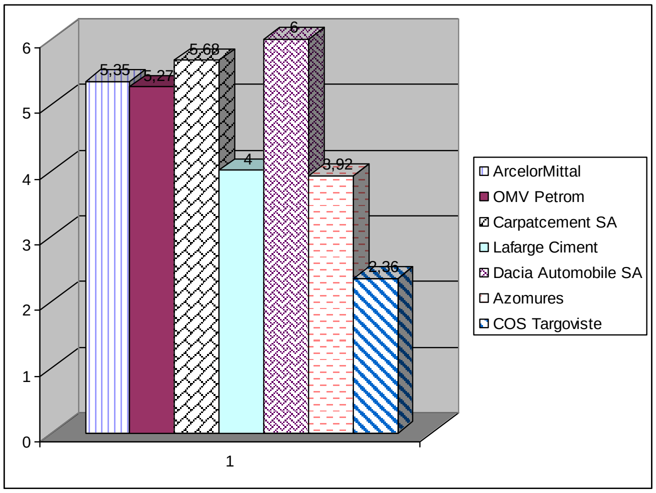


Figure 5. Degree of polluting risk for economic units

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