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MATHEMATICAL MODELS ISSUES OF ENVIRONMENTAL MANAGEMENT

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Abstract
Today the world is facing, more and more, different sources of pollution, the most affected areas being the proximity of big industrial centers (e.g.: chemistry, mining and metallurgy, machinery building etc.). Baia Mare industrial area is a typical one for such a situation. To maintain a clean and healthy environment in Baia Mare city and in the surrounding areas, important costs are needed. The usefulness of the mathematical models consists in the possibility of mathematical processing of industrial parameters evolutions, with relevant interpretations on various influences and their correction for achieving the set goals (maximizing financial efficiency, environmental protection with the compliance of legal requirements etc.).
Keywords: pollution, damages, remediation costs, remediation technologies, mathematical models, regression analysis.
JEL Classification: C25, Q53, Q57.

1. Introduction

The phenomenon of environmental degradation - is the sum of some processes that are in continuous interaction: population growth and the emergence of large urban areas, industrialization, development of animal husbandry and chemical processing of agriculture, the development of transport and even the development of tourism etc.

Not only industrial activities, well known as pollution-generating industries, such as energetics, metallurgy, chemistry, cement and building materials industry, but also other industries are polluting, such as light industry (textile, leather) and food industry.

Even agriculture became a source of environmental pollution, being mechanized and chemicalized, by using more and more pesticides, some of which are extremely dangerous poisons.

Of course, the ideal would be for us to have an environmentally clean (nonpolluting) industry, designed to work under the following principles:

- To use mainly renewable resources,
- To reduce wastage of raw materials, auxiliary materials and fuels,

- To recycle, both within their own installations and within others downstream, including refurbishing parts and equipment, and
- To manufacture machinery and technological equipment with small consumption of fuel and energy , with a life cycle as long as possible.

Recycling - as a profitable business of waste recovery, is one of the most effective ways to preserve these non-renewable resources, by lower consumptions of fuel, energy and raw materials used in the production of goods. If the recovery of wastes is carried out effectively, then this kind of activity contributes substantially to saving raw materials, energy and financial funds (which may receive another destination), contributing in the same time to the reduction of environmental degradation.

However, in market economies, the consumption and the price formation mechanism, choose those technologies that lead to the production of goods, those that generate the maximum profits. Consequently, the most profitable technologies will impose on market, even if they are more "aggressive" and contribute to environmental degradation.

In the future, industrial technologies will have to respond in an increasingly way to the demands required by environmental regulations, these being more and more stringent.

2. Literature review of Sustainable Development

The concept of sustainable development has been rigorously defined in 1987 by WCED - *World Commission on Environment and Development*, as:

"Sustainable development, necessary to ensure the needs of the present generation, must be based on clean technologies, which does not compromise the needs of future generations".

Within the overall framework, represented by the above definition, attempts were made to correlate sustainable development with the concern to ensure the fundamental "3 - Es" (Ardelean, 2007):

- ***E****nvironmental integrity* (maintaining environmental integrity)
- ***E****conomic efficiency* (further promote economic efficiency), and
- ***E****quity worlds* (equity for all citizens of the planet, the poor must be given priority to access competitive and clean technologies).

The goal of sustainable development is ecological security of the planet, in fact of our civilization, on long term.

As indicated, past generations and present generations used technologies more or less pollutant, in the development process, affecting the quality of the environment (air, water, soil), without having the "agreement" of future generations (Heinshon, 2009).

We are not allowed to take, the right to a clean and healthy environment, the right to enjoy, as much as we do, the beauties of nature: vigorous forests, clean water, clean air, all these allowing the maintenance of biodiversity on our planet, to those who will populate the planet over hundreds and thousands of years.
Based on more than alarming reality, regarding pollution and environmental degradation of the natural environment, the main **principles of sustainable development** are:
- Destroying the soil, should not exceed its regeneration capacity,
- Deforestation, should not exceed their recovery rate,
- CO_2 emissions should not exceed the fixing natural ability of the carbon,
- Fishing should not exceed the regenerative capacity of fish species,
- Extinction of species, should not exceed the pace of their evolution,
- And we would add, eliminating the wastage of raw materials, fuels and energy, by using new clean and performing technologies (Veyre, 2005)

Key indicators show that most environmental factors of our planet are deteriorating rapidly. For example, soil degradation and continuous deforestation, reducing this way the capacity of the soil and vegetation to absorb and store water.
The result is soil erosion. The forests that covered 40% of Earth's surface, are now only 25%, the biggest losses were incurred after 1950 (D'Humieres, 2012).
The content of CO_2 in Earth's atmosphere has increased by approximately 25% in the last century, being the main greenhouse gas, keeping the solar heat on the ground, thus contributing to climate change of the planet.

3. Environmental Management

Environmental management - located in the interdisciplinary area, aims to provide solutions to overcome the current environment crises, by:
- Assessments of environmental damages, as a consequence of economic activities,
- Monitoring the pollutants and the key pollution factors,
- Solutions of pollution prevention, of environmental degradation and degradation of its regenerative capacity, including the assessment of pollution prevention costs,
- Assessment of costs for rehabilitation (reconstruction works) of degraded areas, but also the costs of environmental protection due to current and future economic activity,
- Promotion of industries and green technologies, nonpolluting, whose usage take place in harmony with nature, following the principle of "sustainable development",
- Foundation of efficient decisions regarding environmental management and natural resources, namely locating man in the position of a partner of nature, not in the position of "master" of it, and

- Last but not least, increasing concerns for improving the legal framework, especially for law enforcement, including penalties provided for therein.

What is Environmental Management ?

This question can be answered based on the following **directions**:

- Developing evaluation techniques in monetary terms of the damages, caused by pollution and destructive human activities,
- Choice of ways to protect the environment and the rehabilitation of degraded areas,
- Developing methods of analysis, as decision support in choosing the paths of economic development,
- Designing, selecting and applying instruments and environmental policies,
- Necessity to move from the wasteful development model of world economy, to the model of "sustainable development", using nonpolluting environmental technologies, with reduced consumptions of energy and raw materials, given the limited features of resources and the finite dimensions of the planet - hence the possibilities of natural regeneration.

4. Economy - Ecology

Considering that damages assessment in monetary terms is virtual, some effects of pollution, such as: the reduction of comfort and working capacity, soil degradation, the pollution of water and air etc., can range completely different values, from one moment to another, according to the evaluators and the attitude of community members towards pollution and its effects.

At the same time, the effects of pollutants accumulate over time. From here, of course arise the difficulties to calculate and to forecast them.

In the relationship of *"economic-ecological"* equilibrium, should be considered both economic criteria, as well as ecological ones, economic activity being the main cause of pollution and environmental degradation.

The assessment foundation of environmental damages - is necessary for establishing the priority directions in the allocation of funds for projects to protect and rehabilitate the environment. As the balance analysis between *economy* and *environment* deepens, it is necessary to seek a complex set of solutions circumscribed to the requirements of sustainable development concept.

In the same time we also must extend the **stakeholders' involvement**, who can contribute to promote new concepts, with better results in combating environmental pollution by:

- Informing and educating the public through the media, and young people through the education system,
- Involvement of non-governmental organizations,

- Environmental research and the organization of scientific meetings,
- Publications in professional journals etc.

Pollution - as the deterioration of environment, requires costs for rehabilitation of degraded areas, and for environmental protection, costs for new technologies, nonpolluting ones.

To protect the environment in the conditions of increased stringency, the costs increase exponentially, reaching very high values, sometimes unbearable by the local community. Therefore, it can lead to radical measures, with the alternative of stopping the activity of the companies having the largest share in polluting the area, plants that remove pollutants with a highly toxic degree into the atmosphere and water.

The worsening of ecological crisis, forces a rethink of economic development policies, in a perspective of reconciliation and harmonization with the environment. Because technology is deeply involved in environmental crisis, it is clear that significant technological changes will be needed in order to satisfy future needs.

The rise of the Greens (environmentalists) is considered one of the most important events at the end of the century. They entered the Parliament in all Western European countries. It should be noted that the population has surpassed the politicians' interest for environmental protection; three out of four citizens consider environmental protection an urgent problem.

In the Netherlands, Germany, Sweden, and Finland, environmental protection exceeded the interest for combating unemployment, in the major social problems.

5. Issues of Environmental Management in Baia Mare Area

The world faces today an increasing number and variety of pollution sources, the most affected areas being the ones near the large industrial centers (e.g.: chemical plants, mining and metallurgy centers, building materials, construction machinery, but also the light industry and food industry etc.)

The Baia Mare industrial area is a typical area for such a situation. To maintain the environment clean and healthy in Baia Mare and the surrounding areas are required significant costs for pollution prevention and reconstruction of degraded areas.

Is the local community able to support these costs? Or finally, the alternative will be closing all companies responsible for pollution.

In the current circumstances, the world is increasingly exposed to pollution phenomena, lots of areas being affected by pollutant emissions of industrial centers of mining and metallurgy, chemical industry, energy, building materials and light industry, including the food.

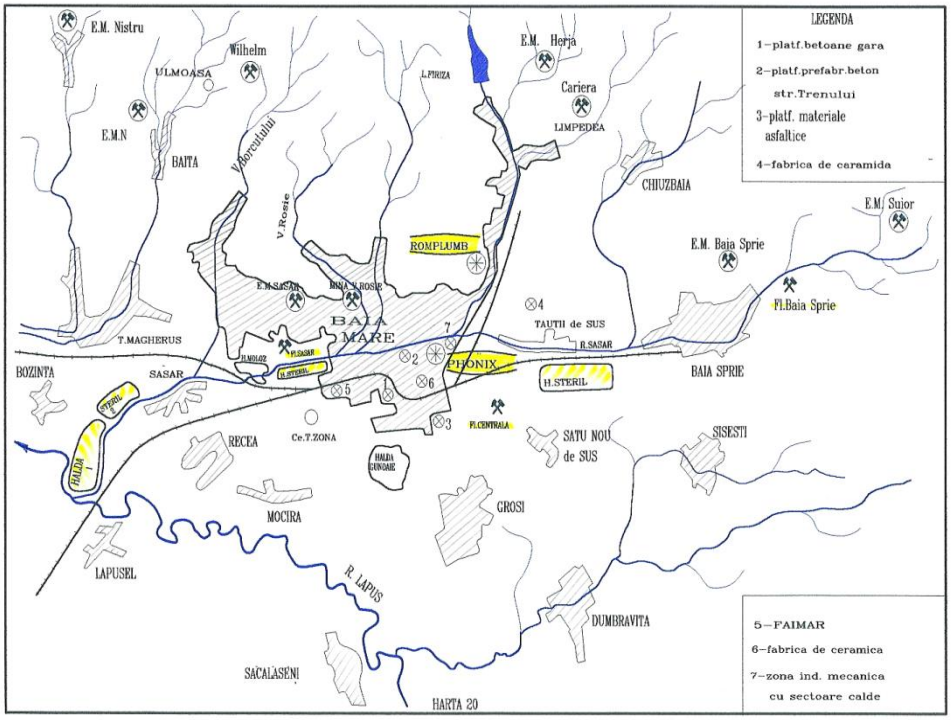
Baia Mare industrial area is typical for such a situation. To reduce the pollution and the effects of environmental pollution in Baia Mare and the surrounding areas, it is

necessary to develop a program of effective measures and important financial costs for both reducing pollution and for the ecological reconstruction of degraded areas. Starting from the reality that you cannot build anything healthy in a sick environment, the paper aims to inventory pollutants and pollution sources, their effects and the costs assessment that the local community has to incur in order to have a clean and healthy environment, under the increased requirements due to the membership of the European Union.

5.1. Brief description of Baia Mare area

Baia Mare industrial area is concentrated in the eastern part of the city. The industrial structure developed taking into consideration the tradition of old mining and non-ferrous metallurgy center: Cu, Pb, Au, Ag, Se etc.

Complementary, in the last 30-40 years have developed: machinery construction, building materials, fine mechanics - car parts and light industry. Recently, in the western part of the city, new investments were made for textiles, wood processing factories - including furniture production, meat industrialization, breweries and spirits etc.



The map of Baia Mare

The whole industry, besides its positive role in supporting the economic and social Baia Mare metropolitan area with a population of approx. 200,000 inhabitants, is (by pollutants released into air and water) also a source of pollution, among which we can mention: SO_2, industrial dust containing Pb, As, Cd, Mn, Cu, Zn, acidic wastewater containing heavy metals, organic substances etc.
Air pollution occurs slowly, but progressively on large expanses, the deposits on soil accumulating over time, causing soil contamination with heavy metals and acidification with its fertility decline.
To reduce air pollution in the Baia Mare area were built two dispersion chimneys:
- CUPROM plant in 1996, with a dispersion chimney of 350 m height,
- And ROMPLUMB plant in 2002, with a dispersion chimney of 120 m height.

5.2. The Effects of Pollution

Pollution effects are felt economically and socially, by reducing the agricultural production (cereals, vegetables and fruits), pasture and forest degradation, and also by impaired health of people. Relative to the latter aspect, specialists assessments show decreased life expectancy of the inhabitants of the most affected areas with 10-12 years.
The soils in the vicinity of the two metallurgical plants (CUPROM and ROMPLUMB) even up to 7- 8 km around, were affected by pollutant dust deposits and acid rains, agricultural land fertility is greatly diminished and in some areas, fertility is reduced to zero.
The excess of heavy metals (Pb, Mn, Cu and Zn) in the soil, determines an increase of these metals in the content of vegetables and fruits. At the same time, at the content of over 2000 ppm Pb in soil, the phosphorus content decreases sharply - basic element in the development process of plants.
It is known that there is a close link between the chemical composition of plants and soil in which they grow, through the osmotic processes of plants, being retained some elements from the decomposition and alteration of rocks and minerals from soil, and also from the pollutants deposited from the atmosphere, or the ones that were brought by polluted water.
Thus, in addition to the main nutrients: Na, K, P, S, Ca and Mg, the plants retain heavy metals such as: Pb, Cu, Zn, Mn, etc. The increased uptake of metals is also due to the acid pH, which causes a greater geochemical mobility of soil elements (Ilie, 2007).
Heavy metals are bio accumulative, their quantity increasing over the years in the body, leading to decreased physical and intellectual capacity of the affected people. Sulfur dioxide, sulfuric acid aerosols, unburned hydrocarbons and particulates in the atmosphere, seriously damage vegetation, fauna and human health.

As a result, healthcare and medical treatment is 20-30% higher than the national average, and for those who live around the metallurgical industry platforms, the health status is precarious. The drinking water from the distribution network and from the peoples wells also has a higher content of heavy metals and organic substances. After the accident in January 2000, from the "Aurul" lake, the water from some wells in Bozanta, 9 km from Baia Mare had also cyanide content.
The effects on animals are also apparent, the horse being the most affected, whose life in the polluted areas by the activity of non-ferrous metallurgy, is reduced to half. Migratory birds are rarefied, up to extinction, the best example being the swallow. Also the insects are a good indicator of pollution, the bees die when they collect pollen from infected flowers with harmful agents. The orchards around the city, well known over time, have reduced their areas and production - especially exports, due to heavy metal content of fruits and lower quality of fruits.
According to media, surfaces totaling 20,000 ha are sensitive affected by industrial pollution, of which 15% severely.
The effects of pollution are also aesthetic, buildings get dirty and degrade faster, due to the "gray" industrial dust and the acid rain.

5.3. The Forests and Grasslands

The forests in the vicinity of Baia Mare city are extremely varied, changing their composition and appearance, from the depression area, to the mountainous area, from South to North and East to West, over a range of 200 to 1500 m altitude, with an economic, health, recreational and decorative role.
The forest ranges subunits that manage the suburban forest near Baia Mare (Baia Sprie, Baia Mare and Somcuta Mare Forest Districts), summaries an area of over 20,000 hectares.
Although the forest vegetation is traditionally a support of the economic development and of the local population health, now a part of the forests present fragility due to anthropic factors that affected their structure and strength. These forest ecosystems can be irretrievably destroyed, with serious consequences on the environment and on living conditions.
People have used and exploited the forest for thousands of years, without worrying about its regeneration, but now we must take action to revive it, before it's too late, to recover what has been destroyed.
The spread pollutants in the atmosphere - especially SO_2, aerosols of sulfuric acid and heavy metals particles - affect forest vegetation causing them irreversible pathological changes. The forest area affected by pollution is approximately 13,750 ha (60%), of which are affected powerful and very powerful - about 1420 ha (Nistor, 2011).

The grasslands surrounding the forests were also degraded, vegetation losing its floristic diversity, with a tendency to become monofloral (grasses), with diminished economic value, the land being affected in the same time by erosion.
Due to pollution, in the Baia Mare area, the complex metabolic phenomena lead to reduced growth of trees, estimated at 20-30%, representing up to 20,000 m^3 / year, loss of wood.
The destabilizing factors, have anthropic base, caused primarily by mining and metallurgical activity with the release of toxic pollutants in the atmosphere, the formation of dumps and disposal of contaminated mine water at the soil surface, chaotic grazing, including destructive tourism by breaking trees or causing fires.
And because that is not enough, in recent years the chestnut culture is severely affected.
After many and repeated works of replanting forest vegetation in the polluted suburban area, the forest looks like a mosaic of species over degraded soils. The volume of afforestation carried out during 1970-2010 in the polluted areas, is about 220 ha, with species more resistant to pollutants: acacia, chestnut, oak etc., given the degraded soil conditions, being supported by terraces and fences.
In most of the rehabilitation cases of degraded lands, it is necessary to form a vegetation cover, cultivation of legumes or planting of shrubs. Usually among the used grasses, legumes are also used, which have a high capacity to fix atmospheric nitrogen, among them clover being the most common. Clover is a better fertilizer than chemical fertilizer treatments, because it supplies azote gradually and continuously.
Although the stabilization of degraded land is made in the first part against erosion, more efficiently by grassing, then shrubs can be planted. Trees (on hard soil, not on sandy soil) may end up giving a commercial production if the species are well selected. They can be planted in abandoned quarries, on mine waste dumps, so as to contribute to the rehabilitation of the landscape. Flotation waste dumps - because they are not sufficiently stable, tailings being a very fine powdery material - are stabilized by grassing and planting of shrubs. Trees don't have good conditions for growing; they can be easily overthrown and uprooted in case of storm.

6. Mathematical Models. Issues of Environmental Management

CUPROM and ROMPLUMB plants from Baia Mare, together with the Copper plant from Zlatna and the Pb-Zn plant from Copsa Mica, are the most harmful, by polluting the atmosphere with SO_2 and with fine powders of Pb, As, Cd oxides etc.
For pollution reduction, efforts took place several years, consisting of technological improvements, use of remediation equipment (particulate filters, or conversion of gaseous components) including chimneys of dust and gas dispersion, the one from CUPROM of 350 meters height - the highest in Europe.

The works to mitigate pollution damages have included:
- First step: filters were set up, reducing the pollution by approximately 30% - the equivalent of 3.50 million Euros,
- Second step: equipment for the conversion of gas were mounted, pollution reduction reaching approximately 50% - the equivalent of 1.65 million Euros,
- Third step: the use of dispersion chimneys, 120 meters high at ROMPLUMB and 350 meters height at CUPROM, pollution being reduced by 90% - the equivalent of an additional 0.70 million Euros.

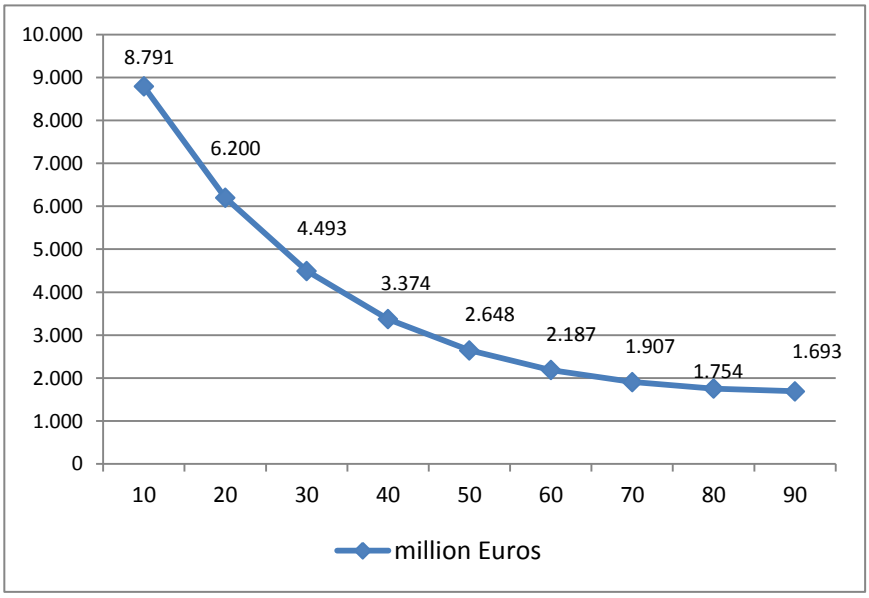


Figure 1. Damages caused by pollution

To calculate the damages caused by pollution, the algorithm was determined by regression analysis:

$$Y = 0{,}048(1{,}024^{x} + 243x\,1{,}042^{-x}) \quad \text{- million Euros} \qquad (1)$$

The damages caused by pollution decreased with the amount of pollutants released into the atmosphere. Estimated damages refer to the damages of agricultural crops in the area: cereals, vegetables and fruits. The damages towards forests and the ones that affect human health were not estimated - these damages being much more difficult to estimate, requiring long periods of time, for monitoring and statistics.

The costs of remediation are for purchasing and operating the dust retention equipment (mechanical filters, wet filters and electrostatic filters), but also for the conversion of SO_2 into H_2SO_4 - an acid used in the chemical industry.
The more we want a more advanced remediation, the higher the number and performance of remediation equipment, and also the costs will be.
To calculate the cost of remediation, the algorithm was determined:

$Y = 0{,}048x1{,}063^{x}$ - million Euros (2)

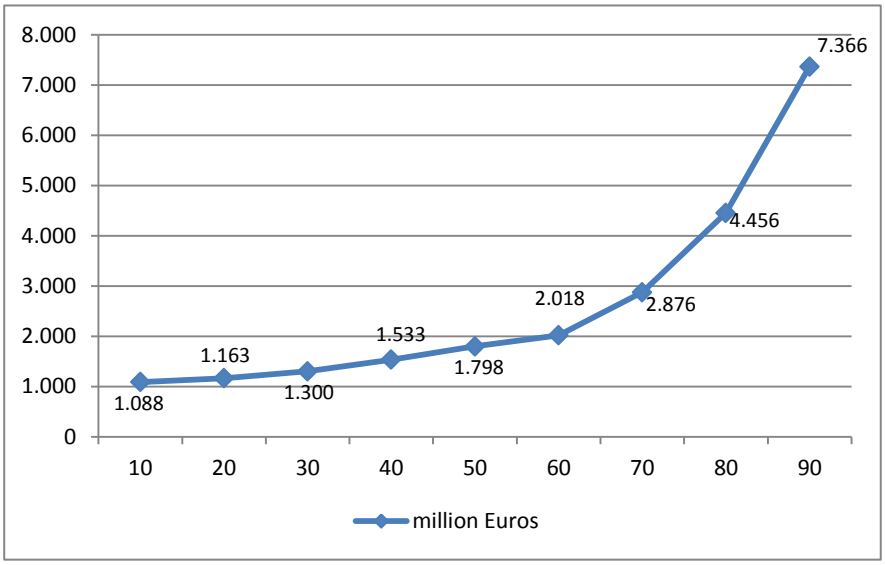


Figure 2. The remediation costs

Once the pollutants are retained in the dust filtration installation, they can be placed in the technological process for the recovery of contained metals (Cu, Pb, Zn ... Au, Ag, Se, etc.). Their value, plus H_2SO_4, obtained by converting SO_2 is over 2 million Euro per year - which is represented by the curve with saturation trend in Figure 3 and the equations:

Logistics function: $Y=a(1+e^{b+cx})^{-1}$ (3.1)
Gompertz function: $lgY= lga+(lgb)c^{x}$ (3.2)

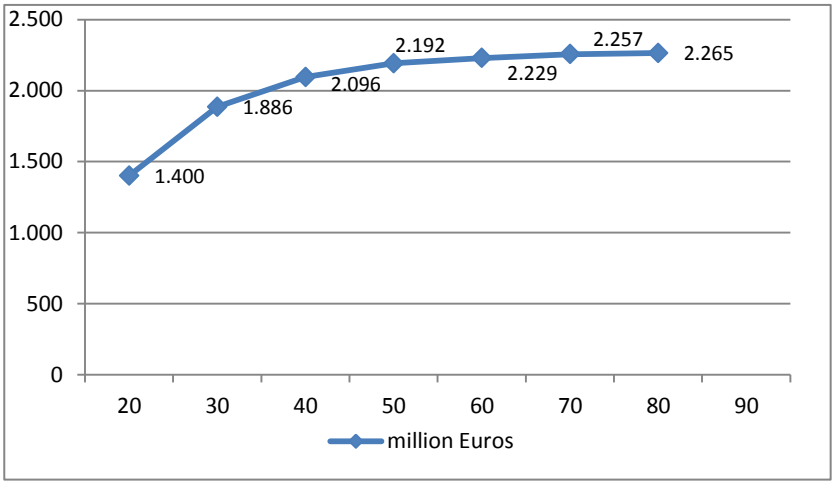


Figure 3. The profit resulting from the capitalization of recovered pollutants

Figure 4 shows the remediation costs curve and the profit curve from the capitalization of pollutants recovered in the remediation installations. From the evolution of these curves it can be observed - the maximum achievable profit (Euro 1.607 million) at 35% degree of remediation, and the equivalence (equalization) of remediation costs with the profit at 63% degree of remediation.

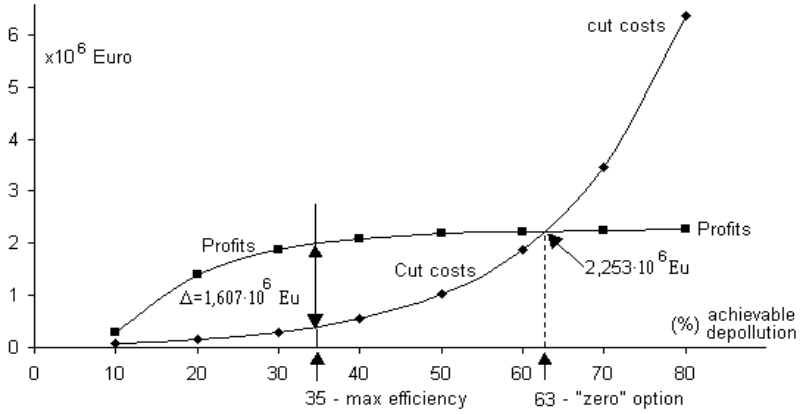


Figure 4. Remediation (cut) costs and the profit by depollution

Of course, environmental regulations do not recommend these low yields of remediation, requiring from metallurgical plants increased financial efforts for remediation of over 90% - according to EU rules.
Relatively to the conversion of SO_2 into H_2SO_4, Figure 5 shows the conversion efficiency depending on the percentage of SO_2 in the gas. The curve shows an inflection point at 1.33% - SO_2 point which is given by the second derivative of the function, representing the conversion degree, and a point of maximum at 3.59% - SO_2, the maximum conversion efficiency being 98%.
The calculation algorithm of conversion is:

$$Y=11,89(2x+0,8x^2-0,2x^3) \quad \text{- percent} \qquad (4)$$

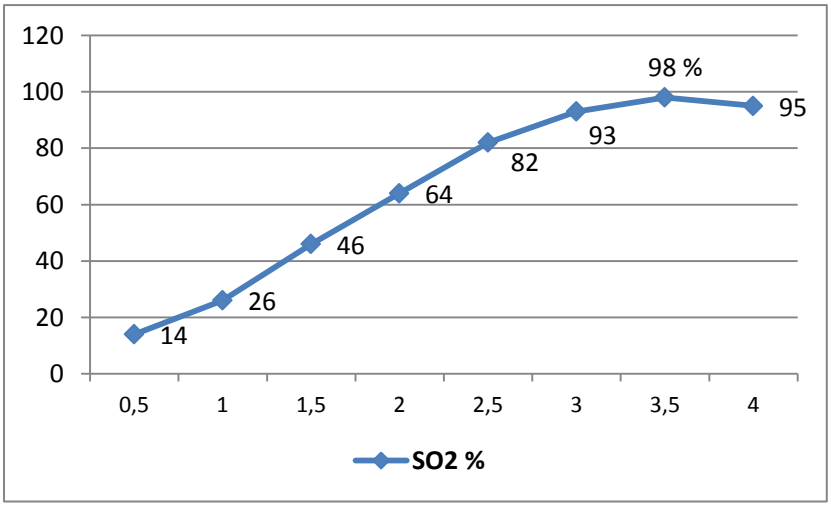


Figure 5. The conversion efficiency of SO_2 into H_2SO_4 based on the % SO_2 in gases

SO_2 - is an extremely aggressive pollutant for nature; H_2SO_4 is a strong acid which is used in chemical fertilizer industry.

Conclusions

The mathematical models presented in the paper, faithfully reproduce the industrial data, having an unquestionable utility.
The usefulness of the mathematical models consists in the possibility of mathematical processing of industrial parameters evolutions, with relevant interpretations on various influences and their correction for achieving the set goals

(maximizing financial efficiency, environmental protection with the compliance of legal requirements etc.).
Mathematical algorithms allow an accurate determination of industrial processes developments, by deriving first order the maximum points of presented curves are obtained, and second order derivatives establishing the inflection points, where the character / nature of increase or decrease of the studied phenomena changes.

References

1. Ardelean, A. (2007). *Management ecologic*. Timisoara: ServoSat Publisher
2. Heinsohn, R. J. (2009). *Sources and Control of Air Pollutio.,* New Jersey: Prentice Hall Edition.
3. Veyret, Y. (2005). *Le developpment durable: approches plurielles.* Paris: Editure Hatier.
4. D'Humieres, P. (2012) *Le developpment durable. Le management de l'entreprise responsable*. Paris: Editions d'Organisation.
5. Ilie, P. (2007). *Elemente de protectie a mediului in industria miniera si metalurgica.* Buletinul Stiintific, Facultatea de Mine si Metalurgie, Universitatea de Nord Baia Mare.
6. Nistor, I. (2011). *Padurile din Maramures*. Baia Mare: Editura Proema.
7. Pop, V. (2013). *Ecological Management in Baia Mare Industrial Area.* Volumul XV, nr. 3/29, 2013 - Management intercultural, Jurnal bianual de cultura manageriala, Fundatia Romana pentru Inteligenta Afacerii - Iasi.