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THEORYOFPOLLUTIONCERTIFICATESPOLICYDEVELOPMENTSANDINDUSTRIALAPPLICATIONS

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I. Introduction

When considering the discussions promoted by the United Nations Climate Change Conference, 2009, in Denmark, we are able to produce the research question: "How to manage scarce environmental resources when our needs regarding consumption are growing at such a strong pace"?

We consider here the idea that the environmental problems of our planet are the result of synergies regarding local environmental problems. The global management of environmental problems will only have some success when resources are also properly managed locally. It is essential therefore, to take hold of our environmental "economato". This is the way forward considering the many layers of institutional arrangements: locally, regionally and globally (e.g. at *country level*, at a *regional-bloc level* and *internationally*). We may consider, for example: Brazil, Mercosul, and the United Nations (or USA-NAFTA-UN; and also Germany-European Community-UN).

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If by one interpretation consumption stimulates production (creating jobs and improving the economy of countries), by another interpretation this same consumption generates higher levels of emissions and pollution (and also greater use of natural resources). It must be mentioned that the systems considering pollution abatements are not 100% efficient (and are also not 100% effective).

When considering for example, the use (exclusively) of regulatory instruments to control water pollution – there is the case of discharge patterns considered in pollutant concentrations [mg/L] – it is possible to observe that this criteria enhances environmental problems. This occurs as it considers only marginally, the volume of water being discharged.

Hahn and Stavins (1991) mentioned that "Some seventy years ago, Pigou (1920) suggested corrective taxes to discourage activities that generate externalities. A half century later, Dales (1968) showed how the introduction of transferable property rights could work to promote environmental protection at lower aggregate cost than conventional standards. From these two seminal ideas - corrective taxes and transferable property rights - a substantial body of research has developed".

Environmental Licenses are given, many times, without an accurate analysis of environmental matters. These matters may be related to private costs or also social costs (*externalities*). There is, therefore, a need for good management where the sustainability of decisions have to be understood under a perspective taking into account *costs* (industrial, commercial, institutional, etc.), and also *savings* (saving the "natural capital" of our planet).

Environmental Management (EM), as suggested here, must consider economic instruments that may make viable the instruments and tools used for this management. The solution, we consider, will be where the "optimum" cost is found (balancing resource needs and consumption with the needs relating to preservation and the limits of environmental degradation).

There is no doubt that management strategies have greater chances of succeeding when "subjectivities" are also reduced. This must be the "objectivity" when dealing with the environment. This objectivity may be found in the "Theory of Pollution Certificates" (Dales, 1968).

Combining the ideas developed by Dales (1968) with modern-day mathematical applications and making use of Operational Research (OR), also helped by "Game Theory" as published by John von Neumann and Oskar Morgenstern in 1944, it is feasible to construct ways in which better environmental management is possible. In this case, EM takes mathematical arguments in order to reduce matters relating to "subjectivities" (including policy and political arrangements). This will promote clarity of objectives and hopefully reduce environmental costs and "*pay-offs*" (for all stakeholders).

This society, as above described, is represented here in this text by an "Industrial Cluster" having water emissions discharged in a "Class II" river (according to the CONAMA Resolution number 357 of 2005). This is our case for study: the actors, players, are respectively, the river, the environmental regulatory agency and the companies of our fictitious industrial cluster.

II. Literature Review

The *Economics of Natural Resources* (ENR) is a trans-disciplinary field of research. Its aim is to consider the interdependence between the human economy and natural ecosystems. Any economic system (within a modern-day perspective and taking into account a contemporary sustainability view), must operate within certain *ecological limits* (protecting the natural resources of our planet for future generations).

ENR connects different disciplines: "natural" (environmental) sciences, "pure sciences", social sciences, and humanities. ENR must consider Geology, Biology, Chemistry, Physics, Economics, Management, Law, Political Sciences (and Institutions), and even History and Philosophy. Only with this holistic view we will create ways in which the environment is better used and better protected ("humanizing" Nature and "naturalizing" the Economy).

The effectiveness of what is called "*cap-and-trade* approach" (a management approach for pollution control, based on economic concessions and incentives for those who reduce their emissions), was developed in 1967 (Burton and Sanjour, 1967). From 1967 up until 1970, the approach was developed by the *National Air Pollution Control Administration* (NAPCA), the predecessor of the American Agency for Environmental Air and Radiation Protection.

Gregório (2009) relates that a central authority, usually a national government or an international body, stipulates a limit (*cap*) to the emissions of pollutants. Credits are granted to enterprises and individuals; these enterprises and individuals must limit themselves to emit what corresponds to their credits. The total of credits must not exceed the limits of the agreed "cap".

The enterprises that need to enhance its emissions will have to buy credits form those who pollute less. There is, therefore, a "credit transfer" (a *trade*) between parts. The result, in theory (and that should reflect also in practice), is that companies needing to enhance their emissions will acquire (as an ordinary business) credits from the less polluting companies. The intended result would be one in which the more polluting companies will be motivated to reduce their negative impacts on the environment (investing in new technologies and promoting needed innovations).

According to the above quoted author, there are similar environmental programs all over the world. In the case of pollutants of the so-called green-house-effect (Carbon, Methane, Nitrogen), the main program is that of the European Union (EU). In the USA there is a national project for reducing acid rain (and there are also some regional programs). Another interesting (global) program is the "Clean Development Mechanism" (CDM), created by the Kyoto Protocol (dealing with reduction of Green-House Gases – GHG). These cases are all models for further development.

For those who adopt *cap-and-trade* practices, the major advantage is that taxes can be set in order to minimize pollution. The "cap" approach allows for a market-driven determination of emission costs (and legal costs).

Other benefits of "cap-and-trade" are:

a) Safety: There is little risk (different from taxation systems) of changes in aliquot (tax rates), which would alter economic conditions and stability.
b) Environmental Certainty: Considering a previously agreed "cap", what may change is the operational cost, but not the total emission. This would also avoid special treatment for "privileged sectors" (politically motivated problems).
c) Emission / Agent Incentives: Individuals and enterprises are stimulated to create new technologies and to find better equipped suppliers (with sound environmental policies).
d) The *cap-and-trade* system allows for economic shock absorption. In times of recession, prices for credit emissions would fall (due to a reduction in consumption, of production and demand for there credits).

North-American experience suggests, also, that quick changes within businesses, and well-developed environmental controls, may be helpful in producing technological innovations (reducing emissions and industrial costs in general).

Those defending taxation increases, on the other hand, argue that:

a) Taxes are simpler to put into practice (when compared to other "systems of commerce" which is dependent on extensive and complex regulation procedures).
b) Due to its complexity, the *cap-and-trade* system will run the risk of being corrupted by politics (lobbies)

and social pressure (litigation and lawsuits). Lawyers and other agents, when standing for this view, would find quicker ways to corrupt the system (being more efficient then regulatory bodies). The examples from North America demonstrate this vulnerability (in practice).

c) There is less consumption of what is (heavily) taxed. If the Government stipulates taxes for labor and capital, why not suspend these taxes in favor of pollution taxation?
d) Decisions regarding strategies for reducing costs of emissions is something that would be better done by individuals and enterprises; which would be better (and faster) than governments.
e) Although it is possible that individuals and enterprises would merely pay more taxes (and not pollute less), this seems highly improbable. The experience from the USA indicates that taxation mechanisms are quite efficient in order to change behavioral patters.

As a conclusion to this part of the text, it may be considered that a viable alternative to promote environmental protection would be by "setting limits" for the degradation of the environment. A *cap-and-trade* system could be adopted, together with two other mechanisms: (a) government monitoring (e.g. via a regulatory agency), and (b) taxation over pollutants and emissions.

Doing so, speculation over prices and emission titles would be avoided; this because the buying of credits in cases of low prices is economically accepted and stimulated. Another incentive would be to change habits (behavior changes), protecting the environment sooner (which is better than leaving things for "future correction").

Burton and Sanjour (1969) consider the use of mathematical models applied to different towns and sources of emission. Their study compares cost and effectiveness regarding different strategies for environmental control. These authors also consider that each individual strategy of pollution reduction was compared with the minimum cost solution. This minimum cost solution was produced by an "optimization" program, where the combination of minimum cost and reduction of polluting sources was identified (considering certain targets which should be met).

According to Helfand, Berck and Maull (2003), physically, pollution occurs because it is practically impossible to have a perfect (non polluting) productive process. Industrial processes are waste producers. Also, when it comes to economic analysis, pollution occurs because it is cheaper to pollute than to operate within a cleaner structure.

The characteristics of each pollutant performs an important role when considering the defining agents considered by environmental policy institutions and practices; this context "frames" what will be done regarding pollution control. Carbon Dioxide (CO_2), for example, presents what is called a "global action" (or global impact), and, therefore, this impact is considered to be similar in all parts of the planet. Pointing out where emissions are (specifically) produced, does not matter.

The political context, therefore, should produce different considerations when dealing, for example, with more "regional" pollutants (such as SO_2, NO_X, and even mercury). The effects of these cited *regional pollutants* are not the same everywhere. The same quantities of a so called *regional pollutant* may cause diverse (greater or smaller) effects within different parts of the planet. The reasons for this are many: water availability (and local hydrology), geological setting, soil and geochemical characteristics, etc. What really matters here is the pollutant itself (this is known as a "Hot Spot" problem).

A Lagrange method is usually applied to determine the minimum cost possible in order to reach the desired objectives (when it comes to total emission conditions). It is possible to use, in some cases, the Lagrange method of optimization to determine required reductions for different countries. These calculations are based on Abatement (reduction) marginal costs; so that the global cost of pollution reduction is minimized.

Under such a scenario, the *Lagrange multiplier* may represent the price taken by the market for a certain pollutant. This is the case in Europe and the USA, when many emissions are considered (institutionally speaking).

Each country will confront its own licensing system price-levels with other countries. This will enable them to make their individual (national / regional) decisions regarding licensing (*e.g.* laws, practices, taxes), in order to minimize their costs. By doing so, there will be more "regulatory conformity", which constitutes another view of the principle of "marginal equivalence" (used by economists in order to decide the most efficient solution for a problem).

III. Methodological Approach

The methodology used here (for this specific research) consisted as a simulation of an Industrial Cluster near a river margin (but outside of its marginal protection zone). The river is a "Class 2" river (according to Brazil´s CONAMA Resolution number 357; 17th March 2005). One of our objectives, therefore, will be to establish a discussion concerning potential polluting activities. The main pollution problem will be that of liquid effluents being discharged into the quoted class 2 river. The main problem is to understand how to reduce polluting discharges into the river.

The environmental control of liquid effluents is performed in accordance to regulatory instruments, considering each (different) industrial activity. The control of pollution sources is usually undertaken in relation to the "receptor body" (*i.e.* the river class 2 in this specific case).

By doing this, society is able to internalize all social costs (due to multiple emissions, not only industrial).

Once the simulation scenario is established, we may consider a control that is the reverse (opposite) to the one being considered: in other words, from the "receiving (affected) body" to the pollutant sources. By doing so, in order to allow a simulation, the quality of water parameter was elected (Biochemical Oxygen Demand – BOD) as our method of analysis. It was then considered that the "water body" under study could receive an excess of up to 5% downstream (from the emission source belonging to the Industrial Cluster).

It is important to know that the criteria allowing for a 5% excess (as quoted above), is only an illustration (taken as example). This percentage may be reconsidered according to different needs not compromising our research conclusions regarding cost-effectiveness between regulatory and economic instruments and conditions.

From data considered for outflow (discharges) and concentrations (measured in BOD´s), a simple model for mass balance was performed, in order to define concentration of discharges for the liquid effluent coming from the Industrial Cluster. The value obtained by such method was used as an environmental marker for the pool of polluting activities present in the Cluster.

When adopting these steps for our research, it was possible to define (for our simulation), uniform levels of control which may be required from each activity of the Cluster (knowing that there is a wide rage of activities). It is then possible to simulate (and apply) only the "standard" value (for regulatory purposes).

Deriving from the values (the targets) considered for the study of the effluents coming from the Industrial Cluster (our environmental goal), and also from individual targets (from each of the enterprises of the Cluster), it was possible to establish a system for comparing environmental cost-effectiveness. This was undertaken in order to compare the situation that can be found (in practice; in the field) with the "Pollution Certificate Theory".

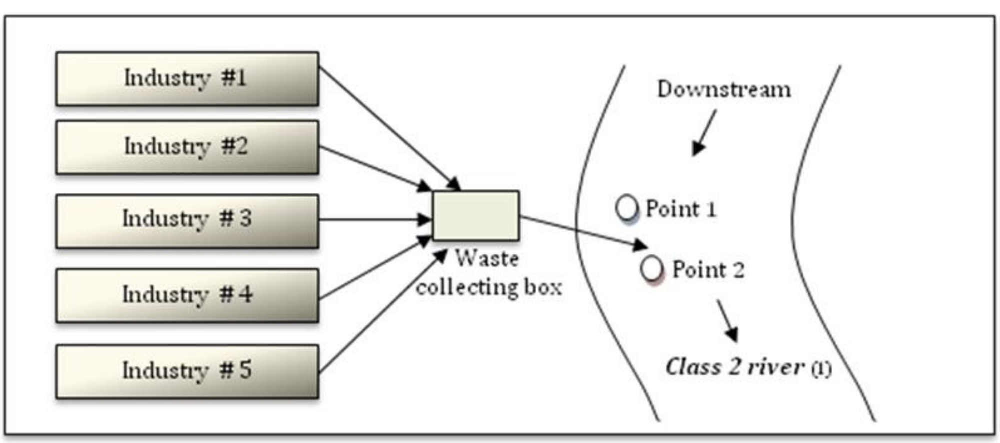
When using the *pollution certificate theory* it was considered that the environmental body (*e.g.* the regulatory agency) would file certificates in a quantity equivalent to the BOD capacity (the allowed limit of discharge for the Industrial Cluster). The distribution of certificates was performed so that each individual industry would be considered (in proportion to the total environment). This allows for negotiation between parts (among these individual enterprises).

The method for reaching the environmental target (at a minimum BOD cost level) allows for individual industries to buy and sell their certificates when convenient.

IV. Environmental Management: the Rules of the Game

Taking hydrological pollution as the "controlling issue" for environmental management practices, we may define, therefore, the strategy of the game. The main condition (main strategy) is to reach optimum levels of water pollution (at the lower possible cost) for those polluting and for those suffering from pollution. This model, when applied in practice, will need to consider *Command and Control (CAC)* regulatory instruments and requirements.

Our "game" constitutes itself by an Industrial Cluster with five individual enterprises or industries (all of them capable of polluting the environment). The pollution under consideration is water waste (hydrological pollution) originating from organic matter. The polluting sources are located on one side of a "river class II" (as already mentioned). See Figure 1.



- According to the Brazilian Environmental National Council (CONAMA), the Class 2 category refers to the river, whose waters may be intended to supply for human consumption.

Figure 1 : Representation of the proposed scenario

In order to allow for an interesting (useful) simulation, different polluting activities are considered. Emissions are of different types (being distinguished according to their industrial typology production factors and sources, and "size" or volume). These activities all present different costs in accordance to their "vocation" (or their possibilities) for pollution mitigation purposes. The marginal costs (for their mitigation), by these standards, as well as their discharge volumes and BOD concentrations (which was selected as tracing parameters), are represented in Table 1.

Table 1 : List of quantitative and qualitative characteristics for effluents derived from the Industrial Cluster; and marginal costs for mitigation purposes

Industry	Discharge [m^3/day]	Effluent BOD [mg/L]	Weight [kg/day]	Mitigation Marginal Cost (US$/kg BOD)[1]
1	100	2500	250	1.60
2	200	2100	420	1.20
3	300	4300	387	1.00
4	400	1200	480	1.40
5	500	600	300	2.00
Total	1500	-	1837	-

[1]The mitigation marginal costs were considered constant.

At an imaginary point, upstream, and near the source of effluent discharge, the BOD concentration would be of 4.0 mg/L. The outflow of the river (at that point) was 2,400,000, m3/day. The BOD just after the place of junction (or confluence) should have a maximum value of 4.2 mg/L (around 5% more; considering the standard for the river-type under scrutiny of 5.0 mg/L). A simple calculation was undertaken to determine the reduction index to be applied to the organic material discharged by the Industrial Cluster.

Under the conditions described, the organic matter at "point number 1" (Figure 1) amounts to 9,600 kg/day. "Point number 2" would have (at most) some 10,086.3 kg/day. The total organic volume (discharge) permitted for the Cluster is 486.3 kg/day. This represents an 82.3% reduction in terms of organic matter – as the average effluent concentration for the Cluster would be 1,826.7 mg/L (while the environmental requirement for BOD discharges would be 324.2 mg/L).

Table 2 : Reductions necessary for achieving defined environmental targets

Industry	Total Discharge [kg/day]	Discharge after reduction index [kg/day]
1	250	44
2	420	74
3	387	69
4	480	85
5	300	53
Total	1.837	325

For managing industrial water emissions, the concept of "uniform and ample control" is applied, considering that reductions can be applied to each case (each industry) inside the Cluster. Table 2 presents results in terms of BOD reduction load (using the required 82.3% index, as mentioned above, for each industry of the Cluster).

V. Economic Analysis: the "Game" with Regulatory Instruments

Judging the environmental effectiveness for applying regulatory instruments as "standard", it was possible to determine cost controls for each industry (of the Cluster). This is done in order to reach environmental goals (*e.g.* as required by the CONAMA Resolution).

In Table 3 we have the final result for each industry of the Cluster (considering a uniform reduction of 82.3% in BOD terms). It is useful to remember that the reduction being applied is that in concentration terms, and not in polluting "volume" (total discharge). This is how the environmental bodies tackle the matter under discussion. This must be further discussed and hence more research requires to be undertaken.

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Table 3 : Organic load, BOD concentration of treated effluent, and total costs for mitigating the BOD´s

Industry	Load of treated effluent in 82.3% [kg/day][2]	BOD of treated effluent in 82.3 % [mg/L]	Mitigation costs for a reduction of 82.3% in BOD [US$/day]
1	44	442.5	204,10
2	74	371.7	257,11
3	69	761.1	196,92
4	85	212.4	342,44
5	53	106.2	305,90
Total	325	-	1306,47

[2] Rounded values. Conversion for US$ with exchange rate, as of May 19th, 2011.

At first glance it is noticeable that the use of standards as water pollution management instruments makes the cost for each industry proportional to their emissions (not considering the cost for controlling each polluting source).

It must be noticed that, once the defined pattern is reached (as defined by regulation and appropriate authorities), there is no reason for industries to pursue greater improvements. The next section will consider this issue.

VI. Economic Analysis Considering the Use of the "Theory of Certificates": Using Economic Instruments

To take advantage of *Pollution Certificate Theory* it was required to use "Nash equilibrium", or the strategic solution by Dunford and Schwartz (1988), where the final interest (and common to all) would be to reach a stipulated environmental target (level) at the lowest possible cost (for each industry). In mathematical terms, the strategic profile to be stimulated may be expressed as follows:

$s^* = (s1^*, \ldots, s(i-1)^*, si^*, s(i+1)^*, \ldots, Sn^*) \in S$, where "S" is a finite conjunct of strategies relating to an utility function "u", in order that "$ui : S \rightarrow R$"; associating gain (payoff), $ui(s^*)$ of a certain industry (gi player), to each strategic profile $s^* \in S$.

For the trial analysis (the testing) of the applicability of the "Pollution Certificate Theory" to the Industrial Cluster, the following sequence was considered:

a) The environmental body (public or private) defines a target (environmental objectives) based on the main uses of water resources receiving polluting effluents.
b) The controlling environmental agency (be it public or private) certifies that it is possible to establish control at only one point of discharge.
c) The controlling body for the environment (public or private) will monitor the flow and the BOD of the effluent (for each industry of the Cluster), in order to define the maximum levels and conditions for organic discharge (for each industry).
d) The environmental agency (public or private) establishes a "maximum organic volume" permitted. Once this is done, the agency will then issue "pollution certificates" with "values" (1 certificate = 1 kg BOD/day), and distribute the "BOD credits" (in proportion to the level of pollution of each industry in the Cluster).
e) The agency (public or private) allows for trade between industries; the companies will trade their certificates (according to their needs). Resulting in a "optimum pollution level" which can be reached (allowing some industries not to reduce their pollution levels).
f) The agency (public or private) allows that the "pollution market" may work freely, not performing individual pollution checks, but only monitoring a single location (which represents total pollution output for the Cluster).

Taking into account Table 1 it is simple to infer that the certificates obtained for each industry (separately), according to marginal costs for BOD mitigation (for each activity), will acquire a value for this "pollution market". This value is an alternative for reaching environmental objectives (targets).

Knowing that the marginal costs for mitigating pollution and the value of BOD certificates are constant in time "t", instantaneous probability analysis may be performed in order to understand cooperation between industries. At another opportunity we intend to perform an analysis with broader time intervals (and with value fluctuations for the certificates, according to their scarcity).

For now the US$ 0,96/certificate value was used, and considering that one certificate is equivalent to 1kg BOD/day. In Table 4 some results immediately after the distribution of BOD certificates (provided by the official agency) are shown.

Table 4 : Initial configuration for the "pollution market" (immediately after distribution of certificates)

Industry	Total Mass [kg/day]	Mass after mitigation (kg/day)	Number of BOD certificates received[3]
1	250	44.3	44
2	420	74.3	74
3	387	68.5	69
4	480	85.0	85
5	300	53.1	53
Total	1,837	325.2	325

[3] Rounded values (the smallest unit for the certificates is 1).

As mentioned previously, one of the main elements used to achieve the objectives (the environmental targets), at a minimum cost (for all industries), is *strategic interdependence* (player g_i). This means that the optimum result is obtained when the "game" is "played" with cooperation between parts, aiming for a common objective (including industries and regulatory agency).

According to marginal costs for mitigation of BOD´s and the market value at an instant "t" (for the BOD certificates), both arbitrated, it is reasonable to advocate that industries number 2, 3 and 4 would have a greater vocation to reduce their pollution output. They would also have a greater vocation to buy certificates. There is a technological limit for BOD mitigation at the instant "t".

Knowing that there is no system for pollution reduction that is 100% efficient, it is also necessary admit an BOD mitigation performance rate (here considered to be 99%). By adopting these considerations we have a sort of "mathematical lock" that disallows a paradox where those industries with smaller marginal costs for BOD mitigation would try to reach zero emission levels (in order to maximize their gains with the certificate commerce). We must remember, therefore, that zero pollution is something impossible (this would only occur when industries ceased to exist).

- Mathematicaly we have

G = {Industry 1, Industry 2, Industry 3, Industry 4, Industry 5}

$s_{Industry1}$ = {buy certificates from Industry 2, buy certificates from Industry 3, buy from Industry 4}

$s_{Industry\ 2}$ = {sell certificates to Industry 1, sell certificates to Industry 5}

$s_{Industry\ 3}$ = {sell certificates to Industry 1, sell certificates to Industry 5}

$s_{Industry\ 4}$ = {sell certificates to Industry 1, sell certificates to Industry 5}

$s_{Industry\ 5}$ = {buy certificates from Industry 2, buy certificates from Industry 3, buy from Industry 4}

The space for pure strategy will be the Cartesian product (S) for the strategies of each of the 5 industries. The determinant of the payoff matrix will be obtained when industry 3 (having smaller mitigation marginal cost), maximizes its sales, initially to industry 5 and, on the sequence, to industry 1. After this (and under the condition that there still is a market for certificate commerce), would come industry 2; and after that, would come industry 4 (maximizing their sales to other industries).

Finally, in the case where there are no certificates available, industries still in need of certificates would have to reduce (to mitigate) their polluting levels (this, therefore, in a non-cooperative manner).

Table 5 and Table 6 present results for the emission and trade of certificates traded, total costs and gains for each industry (after negotiations have taken place and considering the levels imposed by the environmental agency).

Table 5 : Total costs with mitigation of pollution and certificate commerce

Industry	Total certificates received	BOD level to be reduced without commerce of certificates [kg/day]	Total cost with BOD mitigation [US$/day]	Total cost with trade of certificate [US$/day]
1	44	206	329.60	-
2	74	346	502.80	-
3	69	318	386.00	-
4	85	395	670.60	-
5	53	247	44.00	348.75
Total	325	1,512	1,933.00	348.75

Once the results from Table 6 are obtained, it can be noticed that the use of the "Theory of Certificates" for the control of BOD at the hypothetical Industrial Cluster presents greater cost-effectiveness than by simply waiting for the results of regulation.

With the assumptions in this research, the simulation of the sales of carbon credits, as shown in Table 6 the 5 industries cluster generated a total daily saving of US$ 215,96 and the issuance and sale of 325 certificates.

Table 6 : Initial state of the "pollution market" (immediately after the distribution of certificates)

Industry	Total gain with trade of certificate [US$/day]	Number of certificates after negotiations	Total cost after trade (US$/day)
1	-	44	204,10
2	70,07	1	241,28
3	65,27	1	173,76
4	80,62	1	334,63
5	-	278	243,20
Total	215,96	325	1196,97

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VII. Conclusion

From the research, and considering the implications of different economic and mathematical tools, it can be concluded that the regulatory instrument used nowadays in Brazil (and also in other places and countries), does not take into account (and does not take advantage of) economies of scale. This indicates that there is scope for using the Theory of Pollution Certificates (associated to Game Theory).

In this study, by considering a standard level for reduction of pollution (in BOD terms), total cost results for a Cluster (after negotiations) was shown. The results points to a saving of 5.54% of total costs.

With the exception of Industry 1 (which needed more certificates than those available, and, therefore stayed out of the "pollution market"), all other industries of the Cluster beneficiated with the economic instrument presented here. This indicates a stimulus for greater developments in the area of control technologies applied to broad environmental management.

It is obvious that our choice of Industrial Cluster made our research easier to present. The reason for this was simplicity of presentation. Once the basic framework is understood, other (more complicated) cases may be considered. There are limitations of course. For example: in cases of enterprises dealing with radioactive material, the use of negotiation instruments between industries have no sense (and is not recommended).

Legal and institutional considerations are very important to be discussed together with technical, economical and mathematical applications and methodologies.

Finally, our expectations point to more complicated cases. Cases where mathematical modeling (and simulations), may be performed with the aid of computerized processes. By doing this it will be possible to describe more complicated cases and environments, and, therefore, be more realistic. A reality where marginal control costs (and the value of certificates), may freely fluctuate according to market forces.

References Références Referencias

1. Burton, E., Sanjour W., S., 1967. An Economic Analysis of the Control of Sulphur Oxides Air Pollution. DHEW Program Analysis Report No.69. Washington, DC: Ernst and Ernst.
2. Burton, E., Sanjour, W., 1969. A Cost-Effectiveness Study of Air Pollution Abatement in the Greater Kansas City Area. NTIS: PB-227 116/1. Washington, DC: Ernst and Ernst.
3. CONAMA (Brazilian Environmental National Council), 2005. Resolution Nº 357, published March, 17, 2005
4. Dales, J., 1968. Pollution, Property and Prices. Ed. University Press, Toronto.
5. Dunford, N., Schwartz, J. T., 1988. Linear Operators (Part I: General Theory). Wiley-Interscience Publication.
6. Gregório, R., 2009. A Emissão de Poluentes e a Nova Ordem Mundial, In: Monitor Patrimonial (Boletim da AG & Associados Consultores, em 19/08/2009).
7. Hahn R. W., Stavins, R. N., 1991. Kennedy School of Government, Harvard University. "Economic Incentives for Environmental Protection: Integrating Theory and Practice." CSIA Discussion Paper 91-15, Kennedy School of Government, Harvard University.
8. Helfand, G., Berck, P., and Maull, T., 2003. The theory of pollution policy, Handbook of Environmental Economics, in: Mäler K. G. and J Vincent. Handbook of Environmental Economics, R. 1.ed. Elsevier, edition 1, vol. 1, chapter 6, 249-303.
9. Nash, J. F., 1950. Equilibrium Points in n-Person Games, Proc. Nat. Acad. Sci., U.S.A. 36, 48-49.
10. Pigou, A. C., 1920. The Economics of Welfare, first edition, Macmillan & Co., Ltd, London.