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Modelling and Evaluating an Environmental Damage Scenario: Discussing an Assessment Model Predicted Through a Geographical Information System Procedure

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This paper illustrates the main phases of an environmental damage assessment method that is aimed to solve the considerable underestimation that affects the methods used to calculate the reparations amount according to the Italian law and jurisprudence, as they usually consider only the reclamation costs for the damaged areas. This “old” approach can be easily adjusted to the actual context, using, on one side, a scenario approach, on the other side, Geographical Information System (GIS) tools and procedures. After the reference scenarios have been recognized, the model develops a prospective comparison referred to the reduced capability of the environment to sustain the human activities of its three components and to the assessment of “value parameters”, depending on the meaning given to each element, in order to recognize the damage costs. At this stage, the damage value could be measured, on one side, pondering the actual reclamation costs, on the other side, outlining the rareness of each area/ecosystem and the actual failure of restoring the previous configuration in an accurate way.

1. The environmental damage background

The assessment of environmental damages is increasingly challenging, to the level that it has recently influenced several facts, brought to the consideration of the public opinion. Although the Italian law and jurisprudence have significantly evolved, producing an important case history, the methods used to calculate the reparations amount have never evolved in a valuable way and they cannot certainly be suitable, because they generally consider only the reclamation costs for the damaged areas. From the perspective of the authors, this approach cannot be regarded as acceptable, as it considerably downplays the factors that add to the damage several negative side-effects, related to the real inability of restoring the situation to the configuration that it used to have before the harmful events. To solve these problematic nodes, the authors propose to reconsider an “old” approach (Mattia and Miccoli, 1989; Mattia, 2004) and to combine it with a damage analysis developed through the scenarios appraisal (splitting the evaluation, therefore, into the consideration of hazard, vulnerability and exposure factors, in the typical triple conception of the harmful phenomena; see also Menoni, 2005; Menoni and Margottini, 2011), updating the results both in the light of the changes introduced by the sustainability concept (cf. Mattia, 2007), and thanks to the use of GIS tools (cf. Poletti, 2001), that could enable the researchers to draw the frameworks to be analyzed in a simple and user-friendly way.
Moreover, it has to be considered that the environmental and regional Estimate contributes to identify in an explicit way the new value attributes and the techniques to explicit them in monetary units, in

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order to help the local communities in achieving the economic justice they need, even in a simple use action of the natural resources made by different subjects (individual, or collective). For their insightful nature, the environmental goods are to be considered as public assets and, therefore, they cannot be intended as completely private (even in cases of breach of any subject), but they must be recognized in the group of mixed goods, at least for the indirect effects that their use may lead to other assets.

2. The environmental damage assessment model

In the definition of the environmental damage assessment model, with a close reference to the law sources and for the purpose of the definition of a social value of the environment in an immediate estimate sense, it is possible to define three distinct and fundamental components, to which any difference in the utility levels can be traced back, dividing the elements that are immediately observable, and other factors that are inappreciable or, however, too costly (in the meaning of their own value calculation). The first step of the model considers, then, the main environment parts (see also Pinna, 2002; Wart, 2003; Orlando, Selicato and Torre, 2005), that could be connected to the elements of sustainability. Actually, the model is meant to assess the effects that a real or a potential environmental damage might have *a)* on the natural environment, referring to the ecosystems factors (*Y*), *b)* on the social system, that is the local set of socio-economic activities and public health (*H*), and *c)* on the aesthetic-cultural factors and on the landscape (*K*). This concise and simple vision explains the environment characters, which must be considered separately from the interpretative model construction in any configuration, to determine for each of them its social value of use, that cannot only be considered as the utility of the environment as good from the point of view of the State, meant as owner subject that has the right of pretending the compensation for those actions of the environment modification that should not be allowed under the local and international in force laws.
The total utility function, that describes the main elements of the model (*Y*, *H*, and *K*), will be identified as a summation of the differentials existing between the reference scenario and the harmful event:

$$D = \Delta Y + \Delta H + \Delta K \quad (1)$$

The reference scenario could be described thanks to different techniques (referring to the availability of reliable data and the capability of processing their information content), depending, on one hand, on the initial situation (before the harmful event), and, on the other hand, on the greatest bearable damage that each environmental component could survive to. The damage scenario, instead, describes the situation after the harmful event, underlining, thanks to specific alphanumeric parameters, the elements to be used to assess the social value of the environment. Once the two scenarios have been recognized, the further step is a prospective and comparative evaluation of the decreased capability of the environment to hold the activities of its three components (natural, socio-economical, cultural) and to the assessment of "value parameters", depending on the worth given to each element, in order to identify the total damage value. After this stage, the damage value will be calculated not only considering the actual reclamation costs, but also outlining the rareness of each area and ecosystem and the actual inability of restoring the exact previous configuration after the harmful event, even using variables considered as ephemeral, since they are hardly measurable.
The natural damage (*Y*) must be considered in terms of overall change that the effects on directly connected areas can determine: the natural environment is a sort of elastic body, whose deformations, up to a certain limit configuration, are not able to change the well-being levels that are interrelated to the other two components (*H*, and *K*). The model should be based on an actual definition of what could be achieved, however, only at a later time, to changes of a certain configuration, when it should be defined a non-alteration of welfare conditions for the effects produced on the other environmental components: these are issues to be solved in the specific practical application, as these phenomena should be expressed in monetary terms through marginal prices and/or shadow prices, because they could occur in very different forms and some of them do not have an appreciation in the market, in all their different kinds of nature and consistency. For a useful interpretation of these matters, the evaluator should set, in an *a priori* and clearly definition, an expression of the maximum damage to indemnify situations adversely affecting the quality of the natural elements, if carried out in contrary to the decision taken at the legislative level. It is necessary, then, to build the following function of the

maximum acceptable natural damage in a certain area (D_{max}), that considers the relationship between the effects that a potential environmental damage might have on ecosystems (Y) and the factor given by the maximum variations of all the factors and natural elements, that cannot determine variations in the wealth of other environmental components (E_n) and the elements that create value, to be determined in function of the importance that the evaluator would like to give to every single natural element and obviously able to decide the overall value of Y as the pre-determined total damage (ρ_n):

$$D_{\max}^{N} = Y - \rho_1 \Delta E_1 + \rho_2 \Delta E_2 + ... + \rho_n \Delta E_n \quad (2).$$

The second variable, the social damage (H), depends on the effects set from a certain environmental configuration that changes its status because of some illegal actions: for its specific quantification, we should primarily consider the difference of the income streams of tasks routinely performed in two different conditions of environmental quality. The utility flows can only be determined in reference with the same market and with the referring values that are most frequently attributed to the various goods: among many different utility rates that each of the constituent parts of the ecological system can provide to the various possible operators, it should be chosen the one that is objectively suitable to represent the collective needs, in order to let them meet the expectations of many individuals, both in terms of quality and quantity. For the practical application of the evaluation model, it is necessary to identify the components of the ecosystem concerned by the transformation propositions, to which all the actions undertaken in the past by men continuously attributed a sort of economic utility function, considering only those kinds of assets for which an income can be determined. In the second step of this analysis, we could consider all the eventual income modifications (creation, maintenance, or change) to which all the other parts of the system obviously contribute, as each ecosystem can be considered as a set of elements that become direct producers of income flows, according to their specific use, that is usually decided from time to time. These streams, however, depend on the intrinsic characteristics of individual parts, for which it is necessary to form a market, and on the more or less consistent presence of other natural or man-made assets, whose utility cannot be directly assessed in monetary terms, because they are not traded in any market. In addition, every environmental transformation intervention can give the result of slight variations in the utility of this second category of untraded goods: these are the only ones that could be assessed in monetary terms for the social component of the damage, through the difference that the income series related to them have suffered for, as the deteriorating, or the complete downfall of goods out of markets are not always likely to be affected by the negative immediate effects on some system components that produce incomes. The relationship of complementarity that exists between these two categories of goods still exists and, on the contrary, it ensures the maintenance of the pre-existing income streams in most of the damage cases and up to certain levels of modification: in these situations, the goods complementary value (that often reduces the cost of the goods themselves) is still essentially unchanged. Finally, for the purpose of the assessment in monetary terms of the actual size of the damage, it is necessary to introduce a second component in the economic calculation, given by the summation of all costs to be borne to take these goods back at the same characteristics that they used to have before the damaging actions.
The monetary function of the social damage (D_{max}) is then:

$$D_{\max}^{S} = \sum_{i=1}^{s} \Delta R_i \frac{q^{m_i} - 1}{r_i \times q^{m_i}} + \sum_{j=1}^{t} \frac{K_j}{q^{n_j}} + \sum_{k=1}^{p} \Delta R_k \frac{q^{v_k} - 1}{r_k \times q^{v_k}} + \sum_{i=1}^{s} V_{k_i} \quad (3)$$

in which ΔR_i is the variation of the ordinary income flows that is suffered by the good i underlying to the action that takes the ecosystem from the initial situation C_0 to C_1, that is not permitted by the in force laws, r_i is the capitalization rate determined in reference to the reference market for every ΔR_i, K_j is the reproduction cost for the damaged parts of that out of market assets, that even if damaged do not have an effect on income flows of market assets, ΔR_k are the variations of the ordinary income flows that are suffered by people damaged from the environmental transformation action, r_k is the capitalization rate determined for every single ΔR_k, m_i and v_k are the durations of every loss flow and V_{ki} are costs values for the recovery or recomposition of the involved elements.

The esthetic and cultural damage (K) depends on the social values changes that each society attaches to any configuration of the natural or built environment that surrounds it, because of the impossibility of recovery actions to the complete recomposition of it. If V_{c0} is the social and esthetic-cultural value of the configuration before the harmful action of a given environment and V_{c1} is the situation resulting from the event, the esthetic-cultural damage (D_{max}) is expressed by the following formulation:

$$D_{\max}^{EC} = K = V_{C_0} - V_{C_1} \tag{4}$$

in which, of course, V_{c0} and V_{c1} are the social and esthetic-cultural value of the configuration respectively before and after the harmful action. In case of reconstruction actions, it is given by:

$$D_{\max}^{EC} = K = \left(V_{C_0} - V_{C_2}\right) + V_{k_r} + w(V_{C_0} - V_{C_1}) \tag{5}$$

in which V_{c0} and V_{c1} still are the social and esthetic-cultural value of the configuration (respectively before and after the harmful action) of a given environment, V_{c2} is the esthetic-cultural value of the configuration given by the repairs or reconstruction actions, V_{kr} is the actualized intervention cost value and $w(V_{c0} - V_{c1})$ is the damage between the harmful event and the end of reconstruction actions.

3. A proposal for the application of the model

This model is particularly significant, because it could be used not only in judicial terms, but also in decisional terms to direct projects, plans, or programs that could have a modification effect on the environment, yet influencing the attitude that is usually concerning the standard environmental assessment procedures, as the most interesting element in this model is the methodology used in the calculation and simulation of damages according to instance of achieving a balance between environmental, social and economic dimensions of a sustainable development process. Under this perspective, this model could become a sort of common procedure for the assessment of the effects that a single action, project or plan, has on the reference context, developing a flexible and operative procedure for the estimation of the value both of damages and of impacts.

In this perspective, the natural damage should be determined, on one side, calculating the damage effects and the maximum variations of all the factors and natural elements through GIS scenarios (Y and ΔE_n), and, on the other side, the parameters that state the value (ρ_n), i.e. marginal prices and/or shadow prices. The values of Y and ΔE_n could be calculated starting from the data catalogs available on the existing websites created by the Regional Agencies for the information circulation, e.g. the local information system of the Tuscany Region, or of the Lombardy Region. This data sets should be added to the catalogs from the Regional statistic system and from the involved sector and local plans and planning tools, as the Regional informative system on waters (by the Regional Authorities for the environment protection) and the data sets from the Basin authority to be appropriately evaluated through specific models and to be integrated with the informative content of the Regional plans for the protection and rehabilitation of waters. Some other interesting elements to be added to the scenario description are the air quality database produced from the Arpat, to be appropriately evaluated through specific models (see also David Cooper and Alley, 2011; Younessi Sinaki, Tarighaleslami and Jafarigol, 2011; Barany, Bertok, Kovacs, Friedler and Fan, 2010; Camatini, Gualtieri and Mantecca, 2010; Aloyan, Arutyunyan and Yermakov, 2010; Cernuschi, 2007) and to be integrated with the informative content of the “Air quality regional plan”. The pre-damage scenario is determined, then, describing the different environmental components that can be illustrated using the informative content of the corresponding shapefiles: some of this informative contents could be summed up in synthetic indexes (see also Ingegnoli, 2011; Ingegnoli and Giglio, 2005) that condense the information from different data sets in a suggestive paradigm, that weights the capability of the environment to support a specific set of activities, undergoing its negative effects, without losing its capability of reproducing itself. The damage and the comparative scenario could be set in the same way, analyzing the effects that the harmful event has on the environment, changing its capability of reproducing its natural cycles: this facts means the that evaluator should be able to understand how the data set informative context will change after the damaging effects, adapting it to the new environmental configuration.

As regards the calculation of single esthetic-cultural social values, we prooved that the more viable method is the direct poll of population, using different techniques, such as the Contingent valuation method (Mattia and Bianchi, 2000; Mattia, Oppio and Pandolfi, 2010). The surveys could be a significant element of participation that will bring to the determination of the density function of its subjective estimation values (the Willingness to pay, or WTP) and to find the most relevant value levels for the final result, that should be interpreted by estimates extended to all remaining categories of intensity, based on historical behaviors. Actually, as the stated preference (SP) techniques rely on asking people hypothetical questions, looking how they reply to a range of choices (in opposition to the revealed preference (RP) analysis, that is based on people behavior referring to a real choice), they could potentially be applied in almost any valuation context (Pearce, 2002). Additionally, since the same theory of choice is at the base of both techniques, the random utility model, combining stated and revealed preference information could bring in several positive facts to appraisal processes. With different fields of application, all SP models can be used to create a hypothetical market for the valuation scenario, developing a survey campaign that describes the situation, the repayment reasons and the payment vehicle. In this sense, the Contingent valuation method (CVM) is the aimed to ask respondents the amount they are willing to pay for the repayment of the damaged scenario. Other kinds of stated preference techniques that could be used for this purpose are the methods of the Choice modeling approach (choice experiments, contingent ranking, paired comparisons and contingent rating), that also use a hypothetical market, but they are aimed to ask respondents for rankings, ratings or choosing among alternative scenarios defined by a set of several attributes including prices, rather than values (Louviere, Henscher and Swait, 2000).
The social damage, instead, should be calculated as differential between utility functions of different environmental configurations according to the market: among many different utility rates that each of the constituent parts of the ecological system can provide to the various possible operators, it should be chosen the one that is objectively suitable to represent the collective needs, in order to let them meet the expectations of many individuals, both in terms of quality and quantity. In this sense, for the practical application of the evaluation model, it is necessary to identify the ecosystem components concerned by the transformation, to which all the actions undertaken in the past by men continuously attributed a sort of economic utility function, considering only those kinds of assets for which an income can be determined. In the second step of this analysis, we could consider all the eventual income modifications (creation, maintenance, or change) to which all the other parts of the system obviously contribute, as each ecosystem can be considered as a set of elements that become direct producers of income flows, according to their specific use, that is usually decided from time to time. These streams, however, depend on the intrinsic characteristics of individual parts, for which it is necessary to form a market, and on the more or less consistent presence of other natural or man-made assets, whose utility cannot be directly assessed in monetary terms, because they are not traded in any market. In addition, every environmental transformation intervention can give the result of slight variations in the utility of this second category of untraded goods: these are the only ones that could be assessed in monetary terms for the social component of the damage, through the difference that the income series related to them have suffered for, as the deteriorating, or the complete downfall of goods out of markets are not always likely to be affected by the negative immediate effects on some system components that produce incomes. The relationship of complementarity that exists between these two categories of goods still exists and, on the contrary, it ensures the maintenance of the pre-existing income streams in most of the damage cases and up to certain levels of modification: in these situations, the goods complementary value (that often reduces the cost of the goods themselves) is still essentially unchanged. Finally, for the purpose of the assessment in monetary terms of the actual size of the damage, it is necessary to introduce a second component in the economic calculation, given by the summation of all costs to be borne to take these goods back at the same characteristics that they used to have before the damaging actions.
The future development of this methodology could be focused on the implementation of indicators to define the practical procedure to be applied through the GIS tools, identifying a sort of protocol to be easily shared and pervasively used in the different planning activities, with a specific reference, on the one hand, to the evaluation of the damage value in harmful events and, on the other hand, of the impacts of the various functions in regular operation situations. As a matter of fact, such a flexible and

dynamic approach could be made operationally and widely applicable by identifying a significant set of indicators to be used as a guide line, from which starting to create each one of the scenarios to be evaluated by the model itself, moving from common data resources. These indicators could be selected from the huge range of variables described in the massive existing literature referring to all the different topics involved in the three main stages of evaluation, or created on the purpose to integrate that components that since now haven't been satisfactorily described in the current debate.

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