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THE LACK OF ECONOMIC ENVIRONMENTAL DAMAGE VALUATION – A CRITICAL REVIEW OF FUNDÃO DISASTER.

MAGLIANO, M. M.; ANGELO, H. R. The lack of economic environmental damage valuation – a critical review of fundão disaster. **CERNE**, v. 26, n. 1, p.75-87, 2020.

HIGHLIGHTS

Economic valuation is an understandable measure of environmental damages and can enlighten legal decisions and settlements to the due reparation.

The inexperience of Brazilian institutions led to establish a monetary value to reparation settlements without none of the available economic approaches.

This critical review presents the main issues of this process and alternatives to calculate lower limits to the reparation of the damages.

ABSTRACT

Critical events such as the disruption of the Fundão tailings dam, considered the biggest technological disaster in Brazil and the biggest of its category in the world, test the responsiveness of organizations in charge of protecting the environment. In the process of assign liability for damage, lawsuits initially proposed were replaced by settlements negotiated between companies, state agencies and the Public Prosecution Service, which previously have stipulated amounts for mitigation actions and environmental compensation. The economic valuation of environmental damage, despite being a tool capable of assisting in the quantification of environmental compensation, has not yet been adequately used in the initiatives to hold the Fundão dam case accountable. Preliminary diagnoses of the disaster have not sufficiently detailed the estimated economic values for environmental and socioeconomic repair, nor have they distinguished between the repairable damage and the irreparable ones that must be compensated. Due to the lack of clear definition of who is responsible for the economic valuation of environmental damage, Brazilian environmental protection institutions have not developed standardized procedures for this purpose, except in an incipient, experimental or particular way for certain types of damage. The implementation of civil liability settlements based on inaccurate diagnoses and values can compromise their effectiveness and perpetuate, without compensation, the damage to Brazilian environmental heritage.

Keywords:

Economic valuation

Environmental liability and settlements

Fundão-SAMARCO tailing dam

Environmental damage assessment

Historic:

Received 26/04/2019

Accepted 27/01/2020

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DOI:

10.1590/01047760202026012640

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INTRODUCTION

The biggest technological disaster in Brazil's history occurred in Germano industrial complex of the private mining company SAMARCO, in the municipality of Mariana, state of Minas Gerais (MG), on November 5, 2015, when the structure of Fundão dam collapsed.

The disruption resulted in the release of approximately 43.8 million cubic meters of tailings from the iron ore processing, reaching 1,469.16 hectares of marginal lands to the river Gualaxo do Norte and river Carmo (IBAMA, 2015), of which 835.38 hectares are of permanent preservation areas, located in the first 77 km downstream of the ruptured dam (IBAMA, 2016). The water bodies were flooded by tailings along approximately 680 km in the river Doce basin (Fundação Renova, 2017a), reaching estuarine, coastal and marine ecosystems in the Atlantic Ocean, in the municipality of Linhares, state of Espírito Santo (ES). In this pathway, the mud flooded the villages of Bento Rodrigues and Paracatu de Baixo, in Mariana (MG), and Gesteira (Barra Longa - MG), killed 19 people and caused the destruction or degradation of aquatic and terrestrial ecosystems. The tailings wave destroyed productive rural areas, caused water pollution – affecting the supply of approximately 500 thousand people in 40 municipalities, disrupted structures such as bridges, roads and the reservoir of the Risoleta Neves hydroelectric power plant (known as the Candonga Hydroelectric Power Plant) and compromised important activities in the river Doce Valley (Minas Gerais, 2016).

According to Carmo et al. (2017) and Fernandes et al. (2016), who described and comprehensively illustrated ecological and socioeconomic damage, Fundão's collapse was the largest environmental disaster in the world mining industry, both in terms of the volume of tailings dumped and the socioeconomic magnitude of the damage. The disaster demonstrates many of the diverse impacts of mine wastes and alerts to how can the potentially severe impacts of mine wastes and the risk of such disasters be reduced (Hudson-Edwards, 2016). Although not yet described in scientific literature, a new dam collapse on January 25, 2019, near the city of Brumadinho, in the same state of Minas Gerais, caused the death of at least 214 people, still with 91 missing, and almost completely destroyed the valley of Ferro Carvão river. Friehe and Langlais (2017) report that environmental hazards of this magnitude have the potential not only to destroy entire ecosystem segments but also to permanently increase the vulnerability of other segments.

Critical events also test the responsiveness of organizations responsible for protecting the environment. Several public institutions have acted in post-disaster situations according to their competencies, drawing up reports, applying fines, investigating possible crimes and demanding action from those responsible for the disaster. As it has not been possible to avoid or mitigate the environmental damage caused by the event, the repairing and compensatory measures are being demanded, especially through judicial means or by settlements approved by the courts.

The valuation of environmental resources has served as support for stipulating the value of environmental damage as a result of legal proceedings (Castro, 2015; Mota and Bursztyn, 2013).

In particular, economic valuation of damage is a useful tool for estimating incidental costs or externalities of activities, as well as to improve the mechanisms of liability impute and payment of damage repair costs (Percival, Coopers and Gravens, 2012; Einsenberg (2015); Phelps (2015). However, in the case of the Fundão dam, several damage values were considered and defended judicially, without any study of economic valuation of damage being disclosed. On the other hand, in the judicial processes to impute liability, there was no definition about which compensation metric (for lost services, resources or values) should govern the repair of damage.

Moving forward in a process of liability of polluters, through settlements that stipulate repair values without valid economic methods, compromises their reliability and effectiveness. No matter how good the economic and ecological evaluation efforts are, liability will not fully repair the losses that have occurred in the individual, social, environmental, economic and institutional contexts. This study aims to analyze the actions taken in the field of valuation of ecosystem resources affected by the disruption of the Fundão dam, presents paths to estimate the values lost in tailing dam disasters, and to discusses its possible consequences for the effectiveness of environmental liability and reparation.

MATERIAL AND METHODS

The present study examined the administrative and judicial procedures as well as reports and documents produced by the institutions involved in the civil liability of the Fundão dam disruption, regarding the economic valuation of environmental damage. The bibliographic and documentary research analyzed the documents made available on internet by the institutions dealing with

liability assignment and valuation, once the entire lawsuit was not available for the public by the courts. A critical review of the adopted procedures was produced based upon the scientific literature on economic environmental damage valuation. Results were presented considering that not all foreseen measures were not yet implemented.

RESULTS AND DISCUSSION

The necessary economic valuation of damage

The application of the polluter pays principle requires that the effects of pollution be measured in order to establish an equivalent payment or repair. According to Gastineau and Taugourdeau (2014), environmental repair can be done through ecosystemic compensation (by resource-to-resource or service-to-service equivalence) or by monetary compensation, when the affected parties are monetarily contemplated and both can be implemented simultaneously.

By opting for the economic valuation of damage, the ecosystem goods and services that have been sacrificed have their monetary value estimated through appropriate methods. Then, the reparation and compensation measures are budgeted based on that economic value. The implementation of the measures can be done in a consensual way (by agreement between the parties endorsed by a Court) or by determination of the Justice. Restoration cost estimation support the polluter pays principle, since there are no assessment parameters for both the polluter and the judiciary, regarding the financial capacity of the polluter to bear the costs of recovery. Turner et al. (2003) reinforce the importance of valuation to generate a better and more comprehensive information base for decision-making processes.

From the point of view of official environmental protection agencies, the economic valuation of damage is indispensable due to the determination of Brazilian environmental legislation (Federal Law 9605/98, articles 19 and 20), which establishes the need to set the minimum value for repair of environmental damage. Among the initiatives of civil liability impute of the dam breaking of Fundão, no economic valuation studies of the environmental damage were presented, in order to support a technical decision by the Brazilian Justice. Instead, the terms of the main liability settlement signed (TTAC-Union, described below), without any economic study, has previously defined monetary amounts to be invested over the next 15 years, with a discharge clause (clause 6, item XXVI) after the execution of

the programs and projects, which were prepared by the representatives of the company responsible for damage itself. The implementation of a settlement, based on a budget defined in the absence of valid economic methods, can compromise its effectiveness and perpetuate, without compensation, the damage to Brazilian environmental heritage.

Economic valuation of environmental damage and the liability lawsuits.

The recent history of tailings storage facilities failures shows that the events have been rarer and more serious, to the point that the losses cannot be covered by insurance. There is no organized industry attempt to pool these losses in the context of a risk management loss prevention program, and no political jurisdiction issuing permits is large enough to prefund a low-frequency high consequence loss of this scale. The inevitable result is either the government pays or the damages go unremediated (Bowker and Chambers, 2015).

In order to avoid impunity, the process of civil liability entails three steps to be taken: i) the investigation to identify the polluter; ii) measurement and characterization of the pollutant load, its effects and means of mitigation or reversion; and (iii) the calculation or estimate of the quantum to be paid in the remedial and compensation measures. Simply put, according to Caballero and Soto-Oñate (2017), the questions are Who, How and How Much?

According to Belchior and Primo (2016), the first stage of identification of the polluter is already clarified referring to the civil liability of SAMARCO, which benefits from and is responsible for the risk-generating activity. Therefore, regardless of whether there is guilt (*lato sensu*) on its part or of the fact that the activity developed by the company is lawful and allowed by the state, there is strict liability.

The second stage of characterization requires an intense technological work of the geosciences and the biosciences, such as the efforts of environmental monitoring (Golder Associates, 2017) and scientific research (Fernandes et al., 2016; Garcia et al., 2017; Miranda and Marques, 2016). This stage aims to identify and measure the consequences of the chemical load of the tailings, the effects of the mud wave energy dispersal and the changes of matter and energy flows on the individuals, species, ecosystems and social groups affected by the disaster. This is a timely step to present the alternatives for mitigation or reversal,

when possible, aiming at the primary objective of full compensation of damage.

The third step consists in the estimation of reparation and/or compensation value for the damage measured in the previous stage of characterization. As discussed by Pearce (2007), the economic value of the environment refers to human preferences and well-being and it can be measured through appropriate methods. In the other hand, the loss of value of environment depends on the extent and reversibility of damage and can be assessed by adequate methodologies to capture variations in availability ecosystem services to the society affected by the disaster.

The repair actions must aim full replacement and transitional compensation until the complete restoration of ecosystem services, interrupted by degradation. In the case of adopting the resource-to-resource or service-to-service approach in the reparation settlement, cost estimation of mandatory repair components is more important for the polluter, who will have to assume them according to the sufficient technologies chosen, than to the persecution agencies of the State. However, as the liability assignment strategy was to establish a monetary value for damage, the need arises to audit the correct application of the amount of resources defined by damage estimation. Expensive and inefficient projects can consume allocated resources, without the full restoration of the sacrificed goods and services.

Despite the many initiatives taken at the state level in Minas Gerais (MPMG, 2016), two main lawsuits of competing and conflicting civil liability assignment were led to court at the federal level: a Public Civil Action, in November 2015, led by the Federal Attorney General's Office (AGU) besides federal and state representatives, hereinafter referred as ACP-Union ; and another Public Civil Action, proposed by the Federal Prosecutor Service (MPF), in April 2016, referred here as ACP-MPF .

In these two lawsuits, the third valuation step, seemingly, has been anticipated in relation to the second one (regarding the measurement of the damage), probably in order to timely achieve the objective of ascribing liability of the offender in the judicial processes. Considering the magnitude of the damaging event, civil liability - including remedial measures, compensation, and prevention for future disasters - will involve large financial resources that tend to discourage the polluter from fully complying with the liability for damage.

In the ACP-Union, there was a demand for compensation in the amount of approximately 20 billion Brazilian Reais (R\$ 20,204,968,949.00) , or

approximately US\$ 5,2 billion, calculated upon attached documents (not available online for public). In the ACP-MPF, the early estimate of the economic valuation of the damage was justified only on the comparison with another well-known environmental disaster in the Gulf of Mexico. As referred in the ACP-MPF, on 04/20/2010, 4.9 million barrels (780,000 cubic meters) of oil spilled in the ocean due to the leakage and explosion of the oil exploration platform DeepWater Horizon, controlled by British Petroleum - BP, resulting in an expectation of indemnity sums about US\$ 43.8 billion, by settlement with the parties involved only in civil reparations.

The MPF requested compensation equivalent to the Deepwater settlement, considering that “unless one wishes to assume that the millimeter of the environment in Brazil is worth less than in the United States, it is inadmissible that the assessment of the environmental damage caused by the undertakings concerned falls short of that amount”. ACP-MPF points out that it is a “prima facie” value and recognizes the difficulties in comparing the effects of different events, considering the possibility of future adjustment of value, after independent study.

The duplication of civil liability initiatives through two concurrent lawsuits reveals the lack of standardized procedures in Brazil, as well as a possible overlapping of attributions. The Transaction and Conduct Adjustment Settlement signed by the AGU (TTAC-Union), involving the companies responsible for the disaster and the agencies and entities responsible for law enforcement, was called “agreement among the guilty parties” by Souza (2018), since gather those who acted and those who omitted themselves favoring the occurrence of the disaster. The disparity between the preliminary values claimed in the ACP-Union and the ACP-MPF shows that the concerned people and the environment don't have equivalent importance or value in the two lawsuits, or that the institutions have not adequately converted the present and future welfare variations in monetary estimates.

[The settlements enacted for environmental recovery – a critical review of the valuation approach.](#)

Large technological disasters create a challenge for those sectors that create risk in providing sufficient compensation. In these sectors, the likelihood and extent of damage are very difficult to estimate (Liu and Faure, 2018). The effectiveness of assign liability for damage in cases of large environmental impact requires the creation of mechanisms that guarantee the long-term financing of recovery actions. Long-term recovery

planning should consider the economic sustainability of the entity responsible for environmental recovery. Agreements between the State and the polluter are therefore more feasible than a judicial imposition without the acquiescence of the payer and without the guarantee of due reimbursement.

Values negotiated in court settlements are definitely not equivalent to formal markets, nor do they represent the assessment of environmental damage, although they may hold similarities. The parties accused of the harm see in the settlement the alternative of recover the damage in exchange for reducing administrative, civil and criminal penalties, decreasing impairment to their own image, which in the end represent costs to be minimized. On the other hand, because of the public nature of the goods and services produced by the environment, one or more representatives of the State or society (legal representatives of the federated entities or the Public Prosecutor) argue that the compensation negotiated in the settlement is sufficient to restore the quality of ecosystems affected and, therefore, to extinguish the case. To this aim, the possible biases of the perspective of impunity by the accused party and the lack of commitment to the integrity of the environment by the representatives of the public authority must be overcome.

The two main public civil lawsuits to reach social and environmental reparation (ACP-AGU and ACP-MPF) led to the discussion and enactment of settlements between the public authorities and the companies responsible for the disaster, which will be discussed hereafter. Other preliminary settlements for emergency purposes were enacted, but they do not take part in the scope of this study.

The Transaction Term and Adjustment of Conduct - TTAC-Union

The ACP-AGU was interrupted on February 3, 2016, due to a settlement called Transaction Term and Adjustment of Conduct (TTAC-Union). This agreement, signed by representatives of government (from the Union and the States of Minas Gerais and Espírito Santo), and the companies SAMARCO Mineração, Vale and BHP Billiton Brasil, defines the beginning of reparation and assumed a central role in the discussion and implementation of the environmental recover. The settlement, negotiated by Federal Attorneys (AGU) and without Prosecutor's (MPF) consent, is underway through 22 socio-economic programs and 20 socio-environmental programs to be implemented between 2016 and 2030. The settlement decided to create a private institution, called the Renova

Foundation, controlled by SAMARCO, which is responsible for implementing the 42 TTAC-Union programs.

The clauses of the TTAC-Union (e.g. clause 226) do not discriminate precisely the amounts to be invested between compensatory and the repairing measures, for the recomposition of socio-environmental damage resulting from the disaster. Although the compensatory measures have amounts defined in the SAMARCO financial reports, the repairing actions are not expressly budgeted for lack of sufficiently detailed projects at the time of signature of the settlement. As the immediate effect of the disaster is the dispersion of millions of cubic meters of tailings, causing strong restrictions for agricultural utilization and even for the environmental recovery of affected areas (EMBRAPA, 2015), compensation costs may exceed the limits initially set in the settlement.

According to the Renova Foundation (2017), resources to restoration do not have a maximum value limit and the necessary the repairing actions should be implemented and should not be limited to the annual deposits preliminarily established in the TTAC-Union. However, the settlement enacted (Clause 231) set forth that, as from the year 2019, the sum of annual deposits will be defined in a sufficient amount and compatible with the forecast of execution of the projects for that year, respecting the limit of US\$ 925,45 million (R\$ 3.6 billion) (Clause 232). This limit could be exceeded in case of compensation arising from the technical or environmental non-feasibility of any project previously implemented by the restoration program.

The previous definition of compensation amounts, without the prior delimitation of damage considered irreparable, is an approach that compromises the compliance with legislation and the effectiveness of environmental repair measures. Choosing compensation before reparation may be more convenient and less (or more?) costly to the parties and also less effective to the restoration of discontinued environmental services. The individualization of specific compensation measures, such as the financing of the environmental sanitation program for several municipalities (collection and treatment of waste and disposal of solid waste, Clause 169) seems convenient for the government that articulated the settlement. In this case, the investments to provide these sanitation services to the public are transferred to the private sector, as a result of the disaster and its consequences. However, it lacks quantitative parameters that demonstrate equivalence with the value lost in irreversible damage.

According to Dornelas et al. (2016), the TTAC-Union contains issues of concern for effective reparation of damage, since the total budget of US\$ 5,14 billion (R\$ 20 billion) foreseen in the settlement was not based on technical studies for establishing the extent of damage and the amounts necessary for their repair, compensation, and mitigation. The authors also question the Foundation's autonomy in the governance of the settlement. In the context of this governance, it is possible that the Foundation seeks to adopt actions which costs fall within the limits set forth in the settlement, to avoid renegotiation on the obligations, with a clear conflict of interests with its maintainers and their respective shareholders.

A judicial motion for clarification filed by the MPF questioned the legitimacy of the settlement approved based on the ACP-Union, for several reasons. Among them, the following stand out: 1) the intention of the settlement to be exhaustive in relation to the event and its effects, despite controversial issues regarding competence for homologation of the settlement; 2) the lack of satisfactory presentation of the methodology for calculating compensation; 3) the absence of a socio-environmental diagnosis of the damage that justifies the establishment of a budget of US\$ 5,19 billion (R\$ 20.2 billion) for the settlement, which only actually agreed to US\$ 1,05 billion (R\$ 4.1 billion) for the three years following the disaster, with costs of emergency actions already included; 4) lack of technical data to justify the decision to extend reparation over a 15-year period, limiting the effectiveness of the programs to the pace of the annual deposits, which were still not defined; 5) the lack of participation of representatives of those affected, whose rights were transacted by third parties. The TTAC-Union had its homologation annulled by a decision of the Regional Federal Court, on August 18th, 2016 .

The Term of Conduct Adjustment - TAC Governance, proposed by MPF and MPMG

The MPF signed two main settlements with the companies responsible, out of a total of three planned, for the repair and compensation of damage. The first one was enacted on January 18th, 2017 with the main objective to obligate the polluters to bear the costs of hiring expert technical staff to subsidize MPF in the diagnosis of socioeconomic and environmental damage. This partial agreement is an initiative concurrent with the settlement led by the AGU, and was called the Preliminary Agreement Term (TAP), which intends to subsidize the elaboration of the third agreement, called the Final Conduct Adjustment Term – TACF. This final settlement must contain the definitive

obligations of those responsible for the disaster in order to repair the socioeconomic and environmental damage.

The TAP lays down that the diagnostic phase will occur until at least June 2019 and also stipulates the obligation to provide guarantees of US\$ 565,5 million (R\$ 2.2 billion) to repair the damage. There is no express mention in the TAP about the presentation of the economic valuation of environmental damage. After more than 2 years of execution of the actions enacted in the TTAC-Union by the Renova Foundation, on June 25, 2018, the Term of Conduct Adjustment (TAC-Governance) was signed by MPF, validating and enhancing some features of TTAC-Union. The TAC-Governance modifies the management of recovery measures, strengthening the ways of participation of those affected and enabling the renegotiation of the terms of the TTAC-Union. The TAC-Governance maintains the 42 reparation programs and actions already in progress.

The new TAC-Governance, which precedes the final agreement - TACF, reinforces the principle of full reparation of damage caused by the rupture of the Fundão dam as required by Brazilian law. However, it does not rediscuss the budget for damage reparation, still fixed at up to US\$ 3,05 billion (R\$ 11.86 billion), according to the actions set forth in the TTAC-Union. There is no discussion about how far from each other could be the budgets between the desired full reparation and the 2016 TTAC-Union agreed values. Souza (2018) argues that the renegotiation of agreements for better governance of the reparation of damage is a positive fact and was the natural path in the context of the Brazilian judicial system. However, it has been too time-consuming and still could not identify the population affected and measure the damage.

The TTAC-Union, restated by the TAC-Governance, ordinarily stipulates financial limits for the programs and actions, without clearly diagnose the environmental and social damage of the Fundão dam rupture. So, if there is no precise survey of the damage caused, nor the measures necessary for effective reparation, how can one establish limits of values for the programs and actions? Either a resource-to-resource or service-to-service metric is adopted for effective reparation and compensation, or the economic valuation of damage is used to estimate the financial amounts to be spent on the repair. It does not make sense to opt for the early valuation of the damage, without a precise diagnosis of the damage occurred.

The delimitation of liability in monetary values, both in lawsuits and in the commitments set forth in the

settlements, is perhaps the main criterion for decision making between signing the agreement or facing legal action by the shareholders of the polluter companies. Despite the great difference between the costs for reparation in the legal actions proposed by the AGU (US\$ 5,2 billion) and MPF (US\$ 43,8 billion), which would represent different dimensions of damage, the new TAC-Governance did not change the clauses that dealt with the values of repairing and compensatory actions. Table I summarizes the main actions proposed by the AGU and MPF related to the assessment of the social and environmental damage of the Fundão dam failure.







By promoting the renegotiation process over a period of 24 months, the TAC-Governance establishes that the parties of TTAC-Union, in compliance with the presumption of good faith and fair dealing, shall respect the principles and limits established in that instrument (clause 95). However, it is expected that the pursuit for integral reparation, widely highlighted in the TAC-Governance and Brazilian legislation (Federal Law 6.938/81, art. 4, item VII), will be confronted with the possible budgetary limitation contained, and supposed to be respected, in TTAC-Union (R\$ 11,86 billion).

Rodgers Jr. (1995) discusses the human relationships in the composition of well-known long-

term environmental settlements in the United States and alleges that the deception and self-deception can make some widely heralded environmental settlements lose their luster. In the process of building and implementing settlements, they suffer from representation deficiencies that mean some interests will be left out; prediction shortcomings that distort social and environmental realities; validation lapses that immunize happy assumptions from the tests of time; and direction difficulties that can send future events along unsavory trajectories that are difficult to undo. But according to the author, the good news is that all of these phenomena are manageable, which means that long-term environmental settlements need not necessarily founder on the shoals of narrow constituencies, poor prognostication, monitoring deficiencies, and directional shortcomings.

Souza (2018) points out that the most worrying aspect of the TAC-Governance is the effects of the creation of two potentially conflicting instances, the Public Prosecutors' Experts and the Companies' Experts, who are each responsible for may serve as a basis for renegotiation proposals in the Thematic Chambers. In a settlement, when there is a process of consensual resolution of a collective conflict in progress, it is not appropriate to stimulate a "duel of experts", which does

TABLE I Timeline of the main actions proposed by the AGU and MPF related to the assessment of the social and environmental damage of the dam of the Fundão dam.

FUNDÃO DAM COLLAPSE	
NOV 05 2015	The beginning of initiatives for liability impute of the disaster effects
	AGU MPF
	ACP-AGU
NOV 30 2015	Total amount requested: ~ US\$ 5.2 billion
	Value based on preliminary and undisclosed estimates of environmental authorities.
MAR 02 2016	Signature of the TTAC-Union settlement, which marks the beginning of recovery actions by the Renova Foundation.
	Amount agreed between US\$ 2.43 and US\$ 3.05 billion, of which US\$ 0,92 billion in compensatory actions and up to US\$ 2.12 billion in the repairing actions
APR 28 2016	The total amount requested: US\$ 43.8 billion
	Continuation of implementation of the 42 TTAC-Union programs
JAN 18 2017	TAP-MPF to contract socio-environmental diagnosis, to be delivered until June/2019.
	
JUN 25 2018	TAC-Governance - validates and perfects the TTAC-Union, maintains the execution of the 42 socio-environmental programs, reinforces social participation and respects the agreed limits.
	
NOT DEFINED	Execution of the TAC-Governance
	TAC-Final, which must record the definitive obligations of those responsible for the disaster to repair the socio-environmental damage

not fit as a strategy for the consensual resolution of a conflict. The author suggests the revision of this strategy, aiming at consensual choices about which institutions will make the technical studies, the scope, the methodologies and the use of the results, in order to conclude the evaluation in the expected term of 2 to 4 years.

Looking at the list of requests and arguments contained in public civil actions and comparing them with the terms of the settlements enacted, referring to Rodgers Jr. (1995), it's clear to identify the biases of representativeness, prediction, and direction in negotiating settlements of environmental impacts. According to the author, the decision to “settle” requires the decision-maker to discount real tangible gains by indeterminate prospects that optimistic predictions about the future of biodiversity may not be confirmed. There would also be a non-trivial perspective that the few actors in the negotiation can find equilibrium points in a settlement that leave the environmental damage unattended.

The TAC-Governance contains the commitment to extinguish the public civil action that gave rise to the TTAC-Union and to partially extinguish the ACP-MPF, on what was agreed upon. Considering the fact that there are no definitive studies regarding the economic valuation of damage, society should be aware of the future quantification of full reparation. Despite the “good faith” principle in TAC-Governance, the redress actions shall not be limited to the values already established in the TTAC-Union, only to respect the limits dealt with in the TTAC-Union. With regard to the ACP-MPF, the liability of public agencies responsible for the supervision and authorization of the mining activity have not yet been the subject of public discussion and judgment. Thus, the experience of the disaster shall be also utilized to improve the policies and procedures of environmental protection agencies.

Lower limits to damage reparation

Although entire reparation of damages is mandatory according to Brazilian legislation, precise estimations of the whole physical, biological or socioeconomic damages are not trivial. Convert these estimations to monetary values is also enforced, when possible, by criminal law in Brazil, but different techniques could lead to disparate values, that hamper Justice decisions.

The economic value of environmental damage can be estimated by methods derived from economic theories of consumer welfare (individual preferences, stated or revealed), identification and market valuation of goods and services, or the opportunity cost of preserving

a natural ecosystem. Therefore, as discussed by Pearce (2007), monetary estimations are not established for valuing the environment per se, but they try to capture the value attributed by the people, in their choices, to the “use” of environmental resources as provision of resources, regulation of environmental conditions, support for economic activities and cultural function. The total economic value of an environmental good is made up of those “use values”, for example, recreational use of a resource, and “nonuse values”, which reflect the fact that individuals may value resources for reasons unrelated to their use (Pearce and Seccombe-Hett, 2000).

The stated preference approaches are the only ones capable to estimate the Total Economic Value (use + nonuse values) of ecosystem services. In the other hand, revealed preference and production function approaches are suitable to inform variations of availability (or quality) of some services due to damages. In this sense, although both of them cannot estimate the non-use values, valuation is applied to the outcome (output, impact, response) of the production function (Pearce and Seccombe-Hett, 2000).

The lack of studies about the total economic value of the damages resulted in a lawsuit filed based on a weak scientific basis, and moreover, a settlement that represents less than 60% of value initially proposed (US\$ 3.05 of U\$ 5.2 billion). While non-use and option values are still controversial for justice aims, direct and indirect use values are easier to estimate and to associate with the public losses. Non-market valuation is generally produced based upon structured questionnaires, carefully designed to capture the public's willingness to accept compensation. However, due to the methodological complexity and the biases expected in these techniques, they do not seem to be suitable for a preliminary value, or a lower limit to be used in a settlement for damage reparation, based on production function approaches.

The following cost-based methods, used to measure the direct and indirect use values are then suggested for a preliminary monetary damage estimates in the Fundão Dam case, according to equivalent studies: Market Prices Approach – MPA (Gan et al., 2011), Dose-Response Method – DRM (Fisher et al., 2017), Replacement Cost Method – RCM (Notaro and Paletto, 2012), Preventive Expenditures Method – PEM (Urana and Hodge, 2006) e Opportunity Cost Method or Sacrificed Income Method - OCM or SIM (Nikitina, 2019), all of them also briefly described in CARSON et al. (2003). Each of these approaches are suitable to different categories of environmental damage valuation, under the conditions of analysis and data availability. Table

2 presents the suggested approach, the information that would be required and the possible suppliers, related to water resource, ichthyofauna, socioeconomic and flora.

All this data could be requested by authorities to the suggested institutions, which are familiar or sensible

to those economic effects, and then properly analyzed to avoid gaps and overlaps. The sum of these economic estimates could be the lower limit to the economic value of damage repairation. The negotiations to settlements shall occur to discuss intangible values that certainly was damaged by the disaster.

TABLE 2 Suggested approaches, applicable methods, and the possible data suppliers, related to water resource, ichthyofauna, socioeconomic and flora, to estimate lower limits to damage repairation.

WATER RESOURCES		
REQUIRED INFORMATION	APPLICABLE METHOD	POSSIBLE SUPPLIERS
1. The marginal cost of water treatment in order to reduce turbidity and metals for legally acceptable levels, after the return of water supply services, and estimative of extraordinary expenses to water treatment.	DRM	Sanitation companies that supply the affected municipalities
2. Cost of emergency distribution of potable water to the population during the affected period.	RCM	Municipal government and sanitation companies that supply the affected municipalities
3. Loss of net revenue by sanitation companies, during the affected period.	SIM	Sanitation companies that supply the affected municipalities
4. Loss of revenue from electricity generation, during the affected period.	SIM	Operators of the river Doce basin hydropower plant
5. Cost of alternative water supply supported by industries, during the affected period.	RCM	Industrial associations and watershed committee of the Doce river
6. Loss of revenue from other water users in the watershed, during the affected period.	SIM	River Doce watershed committee
7. Estimated dredging cost for the recovery of the active capacity of the reservoir of the Candonga hydropower plant.	RCM	Hydropower plant operators
8. Cost of the restoration of water springs and tributaries reached.	RCM	Companies that provide recovery services for degraded areas.
ICHTHYOFAUNA		
REQUIRED INFORMATION	APPLICABLE METHOD	POSSIBLE SUPPLIERS
9. Volume and value of fishery (potential and used), measured by fishery effort inventory.	MPA	Research institutions and fishermen's associations
10. Loss of income of fishermen until the (possible) reestablishment of fishery stocks.	SIM	Fishermen associations
11. Cost of establishment of breeding sites and cost of feeding (proxy value of benthic community)	RCM	Fish farmers associations
SOCIOECONOMIC		
REQUIRED INFORMATION	APPLICABLE METHOD	POSSIBLE SUPPLIERS
12. Reconstruction costs of affected cities, roads, and bridges.	RCM	Municipal government and infrastructure departments of affected municipalities
13. Loss of revenue from trade taxes and industries affected, discounting the economic recession in the period.	SIM	Municipal government and trade and industry associations of affected municipalities
14. Loss of revenue with tourism and leisure in the river Doce and estuarine region.	SIM	Municipal government or tourist offices of Linhares city and the lower region of the Doce River
15. Loss of income of rural producers in the watershed, up to the Candonga hydropower plant.	SIM	State Institute of Technical Assistance and Rural Extension - EMATER
16. Restoration cost of destroyed rural facilities	RCM	State Institute of Technical Assistance and Rural Extension - EMATER
17. Loss of market value of rural properties affected by extravasation of tailings.	OCM	State Institute of Technical Assistance and Rural Extension - EMATER
18. Loss of market value of urban properties (lots) in the marginal areas of the river.	OCM	Finance government departments of affected municipalities
19. Recovery costs to rural and commercial activities damaged by the destruction of their means of production.	RCM	Commerce, industry and agriculture associations of affected municipalities
20. Loss of income of families due to the lay-off period or regional economic recession	SIM	Finance government departments of affected municipalities
FLORA		
REQUIRED INFORMATION	APPLICABLE METHOD	POSSIBLE SUPPLIERS
21. Costs to Reshape, revegetation and restoration costs of riverside ecosystems.	RCM	Hydropower companies that performed revegetation of APP of reservoirs borders under similar conditions
22. Value of wood and firewood corresponding to the biomass suppressed.	MPA	Open source
23. The estimated cost of removal and proper disposal of dispersed tailings.	MPA	SAMARCO
24. Building costs of slope containers in the legal Permanent Preservation Areas - APP along the riverbanks.	PEM	SAMARCO

Although these approaches can present damage value proxies, suggested as lower limits to reparation, it is clear that the other values such as ecosystem services of terrestrial fauna, pollinators, and microfauna; option value of environmental resources and intrinsic value of living beings and other natural resources were not considered, because they require more complex techniques, considering the above assumptions for settlement. The interim loss in value from the time of the incident until full recovery from the injuries is also considered a standard measure of damage that should be accounted (Jones and Pease, 1997).

The institutional (in)experience in the economic valuation of environmental damage

The importance of economic valuation to suit the liability for environmental damage contrasts with the low experience, the lack of definition of legal competencies and the absence of a framework of economic measurement of damage in Brazil. The Brazilian scientific literature does not reflect the existence of institutional protagonism or debate about the best way to value, hold accountable and compensate for environmental damage.

Such scenario results in fragile liability assignment to polluters and to the public authorities in charge to guarantee the integrity of environmental heritage. Hupffer et al. (2012) argue that in case of State liability for environmental damage, through action or omission in the face of precautionary and preventive principles, society should not be doubly penalized with the effects of environmental damage and with a possible loss from the tax revenues spent to reparation. The Brazilian institutions that act at the federal level for the protection of the environment have not yet standardized procedures for economic valuation of damage to the environment. Existing economic valuation methods in use are still incipient, experimental or specific types of damage.

Among the documents published by federal institutions, the Brazilian Institute for Environment and Renewable Resources - IBAMA, an agency with administrative responsibilities, has developed a model for the economic valuation of environmental impacts in conservation units (IBAMA, 2002) to estimate monetary compensation due to linear and punctual projects in Conservation Units. Such compensations are not calculated after specific and limited environmental damage, but derives from the National System of Conservation Units (SNUC) (Federal Law 9.985/2000), which establishes the obligation of financial compensation

for enterprises with significant environmental impact, through funding to conservation units.

In the civil context, the MPF published the Handbook of Valuation of Damage to the Environment and Cultural Heritage (MPF, 2014). Despite its suggestive name, this publication presents guides to collect social and environmental information for field surveys and expert investigations of 12 types of events harmful to the environment, including dam disruption. This information aims to help future judicial procedures for economic valuation of damage. However, it does not discuss how to use such information in methodologies for economic valuation of damage.

Brazilian Federal Police, responsible for criminal enforcement, does not have any official papers published in order to standardize valuation procedures, although criminal forensics perform the economic valuation of hundreds of environmental crimes per year. Nevertheless, specialists cannot evaluate about 25% of the requests, arguing operational impediments, difficulties elaborating inventories, lack of practical or consensual procedures for valuation, the insignificance of area size, and lack of definition of the future use of degraded areas. In addition, the valuations carried out, although mostly based on methods accepted by the scientific community, do not follow a standardization and are not yet effective in calculating all parcels of use and non-use values of the environmental resource (MAGLIANO, 2013).

Other methods published by state or regional institutions are generally self-produced for restrict purposes by the organizations, such as the procedures published by the Environmental Company of the State of São Paulo - CETESB (Marcelino et al., 1992); Public Prosecutor Service of the State of São Paulo - MPSP (CONCAUMA, 2012);

In Brazil, there is still no institutional discussion about which approach to environmental valuation (service-to-service, resource-to-resource or value-to-value) should be implemented and under what circumstances, probably due to the absence in adopting an economic valuation in environmental disasters of national relevance. The Brazilian institutional inexperience in economic valuation of environmental damage is exemplified in the process of liability impute of the rupture of the Fundão dam. Even the agency responsible for elaborating the diagnosis in a huge disaster is not clearly defined for the assessment or restoration of degraded resources.

The United States Agency for Oceanic and Atmospheric Administration (NOAA) has developed well-

tested methods to assess injuries and impacts on natural resources. In past cases, losses have been measured in ecological terms - for example, the number of hectares of damaged habitat or the number of animals - which can be translated into potential restoration projects by resource-to-resource equivalence. When damages do not translate easily into a specific restoration project, financial resources can be provided as compensation to be applied later when a suitable restoration project is identified (NRC, 2012).

However, these assessment approaches focus more on the implicit value of habitat or organisms than on the ultimate value of the resource to humans and therefore may not capture the full value provided by the ecosystem. There is growing recognition that adopting an ecosystem services approach, linking changes in ecosystems to consequent changes in human well-being, would help lead to better-informed management and policies, and may offer more approaches to restoration projects (NRC, 2012).

The structure for the recovery actions planned in TTAC-Union includes a myriad of instances created specifically for the case of the Fundão dam collapse, due to the lack of a formal structure to manage the effects of the event. Among the various instances and roles created by the settlement and its complements, stood out: the creation of a private foundation, maintained by SAMARCO, with the purpose of elaborating and executing all the recovery measures (Renova Foundation); the establishment of an Interfederative Committee (CIF), composed exclusively of public authorities representatives, to monitor and supervise the results of the Foundation; the establishment of the Expert Advisory Panel, with the objective of providing technical consulting; the hiring of Experts by the Foundation, for manage, evaluate, prepare and/or implement programs and projects; independent external auditing, with multiple functions of both accounting and financial nature as well as environmental activities and compliance. All these instances were established without public debate and without the participation of the Public Prosecutor, an institution that has, ultimately, the mission of seeking civil liability and reparation for damage to the environment.

Complementing that staff, in TAC-Governance technical advisors, observer forum, local commissions, technical chambers, regional chamber, articulation of regional chambers, the chamber of renegotiation, managers of financial resources (for the affected group and for CIF) and Public Prosecutor's Experts were also created or designated. In all instances, the participation

of representatives of those affected was reinforced in the instances originally created in the TTAC-Union or in those created by the TAC-Governance.

The technological failures of dams and the insufficiency of the state action in the law enforcement and licensing of polluting activities favor the scenario for the occurrence of new disasters, as actually happened in the Corrego do Feijão mine facilities of Vale Corporation, in Brumadinho – MG, Brazil, on January 25, 2019, and raise two questions. In the probable and unwanted case of one more disaster, should the governance model of liability and reparation follow the under construction experience of the Fundão dam collapse? Could official environmental protection institutions, whose responsibilities have been demanded in the ACP-MPF, be able to learn from the consequences of this disaster to improve their performance?

CONCLUSIONS

The world's biggest tailing dam disaster has killed 19 people, produced environmental and socio-economic damages and losses on an unprecedented scale in the country, and added a legacy of experiences to the institutions that dealt with its effects. 3 years later, after the second and recent tailing dam collapse, that killed at least 214 people, the public still do not know what values have we missed in those disasters.

Accurate damage diagnoses and value estimates for repair or compensation were still not produced, preventing the correct application of the polluter pays principle. Due to the lack of a clear definition of competence for the economic valuation of environmental damage, Brazilian environmental protection institutions have not developed standardized procedures for this purpose, except in an incipient, experimental or specific types of damage.

This circumstance, in the case of the rupture of the Fundão dam, led to the proposition of two distinct lawsuits, one headed by the AGU and another by the MPF, which currently converge to a single provisional settlement. This liability pact is delimited by poor-defined monetary values spent in technological alternatives for remediation chosen by the Renova Foundation.

For scaling the current settlement, monetary values that are not strictly related to the effects described in the preliminary damage reports were used. The amounts pleaded in the liability lawsuits were drastically reduced on the celebration and renegotiation of the agreement between the parties. Several approaches, gathering cost-based methods related to water resource, ichthyofauna,

socioeconomic and flora, were suggested as a reference to establish a lower limit to damage reparation.

As an alternative to monetary valuation of damage, compensation could be provided for the amount of ecosystem services that were no longer offered as a result of the collapse of the dam, until the full restoration of the environmental repair measures, throughout the settlement in execution. The mere implementation of recovery measures, e.g. revegetation or decontamination, at first, does not compensate for the equivalent deficit in ecosystem services that have not been provided for its users between the collapse and future complete recovery.

The new governance of the settlement broadens the participation of those affected and emphasize the technical conclusions of “experts” of both parties in the reparation of damage. If this new governance structure can guide the reparation of the socio-environmental impacts of the disaster, with the freedom to eventually review the limits of budgets already agreed, the society will take advantage of the experience of the tragic event to improve the liability assignment and the valuation of environmental damage in Brazil.

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