Recebido: 06-10-2023 | Aprovado: 30-10-2023 | DOI: https://doi.org/10.23882/rmd.24184

# Economic valuation of hydroelectric dams' safety: Evidence from France

## Avaliação económica da segurança das barragens hidroelétricas: Evidências de França

**Malzi Mohamed Jaouad**,
Research Laboratory in Energy, Environment and Resource Economics (GREER) at the Faculty of Law, Economic and Social Sciences of Cadi Ayyad University, Morocco. (mohamedjaouadmalzi@gmail.com)

**Belhaj Naoufel**,
Faculty of Law, Economic and Social Sciences of Mohammedia, Hassan II University Casablanca, Morocco. (belhaj.naoufel@gmail.com)

**Koraich Almahdi**,
National School of Commerce and Management, Abdelmalek Essaadi University, Tangier, Morocco. (koraichalmahdi@hotmail.com)

**Abstract:** This paper aims to develop an economic approach that enables electricity generation companies to analyze and quantify the economic gains of complicated activities particularly the safety of hydroelectric dams. The method is based on calculating the costs avoided due to the implementation of safety mechanism. The specification of this method is founded on a solid literature regarding the economic assessment of the monetary value of complicated services. The results of this paper highlight the importance and the significant influence of safety activities in reducing costs, reaching approximately 26 million Euros. The results also shed light on the importance of the safety device to fight fatal accidents and ensure public security.

**Keywords:** Dams, Hydraulic safety, Financial valuation, Cost avoided method.

**Resumo:** Este artigo visa desenvolver uma abordagem económica que permita às empresas de produção de eletricidade analisar e quantificar os ganhos económicos de atividades complicadas, particularmente a segurança de barragens hidroelétricas. O método baseia-se no cálculo dos custos evitados com a implementação de mecanismo de segurança. A especificação deste método baseia-se numa sólida literatura relativa à avaliação económica do valor monetário de serviços complicados. Os resultados deste artigo destacam a importância e a influência significativa das atividades de segurança na redução de custos, atingindo cerca de 26 milhões de euros. Os resultados também esclarecem a importância do dispositivo de segurança para combater acidentes fatais e garantir a segurança pública.

**Palavras-chave:** Barragens, Segurança hidráulica, Avaliação financeira, Método de custos evitados.

## 1. Introduction

Hydroelectric dams are "living structures", functioning permanently to generate electricity and are often exposed to natural phenomena (flood, temperature, climate change etc.), thus, they require special care and enhanced monitoring.

Indeed, unlike nuclear power plants, hydroelectric dams include only a single and unique "physical" line of defense, which explains the need for predicting risks through implementing solid risk prevention tools, particularly daily auscultation.

The safety, the security and all environmental aspects of different power plants, are of particular interest for power energy producers. Because, the major challenge is to ensure optimal power production along with controlling for the dysfunctions and accidents that might threaten the safety system, especially when the dam exceeds twenty meters in height (in France about 200 dams exceed 20 m of height and 450 exceed 10m).

In fact, dam safety management has evolved gradually to meet the need of reducing fatal accidents and incidents causing economic losses, social and ecosystem damages. To manage these risks, the operator implements a safety device gathering a set of adapted measures to eradicate the risk or mitigate its severity and dangerous impacts.

Based on some observed disasters, several studies have been carried out in order to analyze and estimate social economic and environmental losses. However, it seems to be very difficult task to associate a market value to services provided by certain variables such as safety, security and environment. The key point of this paper is to fill this gap in the literature by applying an economic approach which provides the hydroelectric power generators with important tools to figure out how much does it cost a total or partial failure of a dam. Thus how much money they avoid to spend (implicitly money they win) while undertaking safety activities.

### 1.1. Dam safety regulations

Hydroelectric plant's operators are obliged to respect legal and regulatory requirements. This obligation becomes severe toward very dangerous dam categories. In 2015, the French law has typically classified dams according to their height (H) and the volume of water stored (V).

Class A: H ≥ 20m and H2*√V ≥ 1500

Class B : H ≥ 10m and H2*√V ≥ 200

Class C : H ≥ 5m and H2*√V ≥ 20

The regulation enforces the owners and operators to ensure the safety and security of hydraulic dams to minimize the risks threatening the continuity of ecosystems, by implementing both punctual and continuous monitoring measures.

In fact, every dam has to be equipped with an auscultation device in order to ensure effective monitoring. The results of this device are reported to the regulator in form of monitoring and auscultation reports in a time interval, which differ according to dam category:

**Table 1** Duration of reports and studies by dam's type

| Dam’s type | A | B | C |
|---|---|---|---|
| Monitoring report and technical visit | Once a year | Once every 3 year | Once every 5 year |
| Auscultation report | Once every 2 years | Once every 5 year | Once every 5 year |
| Hazard studies (Full Technical Exam) | Once every 10 years | Once every 15 year | - |

In this paper, we apply the avoided cost approach to analyze and estimate the economic value of safety activities.

The remainder of this paper is structured as follows. Section 2 presents the methodology. The results are given in Section 3. Section 4 contains concluding remarks and suggestions for future research in this field.

## 2. Methodology

It is very complicated to give a market value to certain variables such as safety, security and environment. However, there are some non-market valuation methods, particularly regarding the assessment of environment and ecosystem value. These approaches are divided into two categories: the Revealed Preference Theories such as the hedonic pricing, travel cost method, replacement cost and the avoided damage cost method, and the Declared Preference Theories like the contingent valuation method.

On one hand, the Revealed Preference[1] Theories deduce environmental services value from existed situations and decisions taken by individuals. They consist of examining environmental user's behavior and then deduce their preference or the value they attribute to environment.

On the other hand, the Declared Preference[2] Theories are techniques of estimating the demand function based on individual responses to hypothetical scenarios (survey techniques).These methods lead to adopt ex-ante perspectives and aim at maximizing the utility function. They provide a monetary valuation of demand parameters and can be combined to other methods for demand forecasting.

The two theories presented above have provided an added value in determining social cost while no market price is available, and are particularly applied in environmental issues.

To overcome the difficulty of calculating the gain behind safety activities, a cost avoided approach was applied in this study.

By definition, an avoided cost is an additional expense that operator avoids to support by taking adequate measures. This approach, which will henceforth be called the Cost Avoided Method (CAM), assesses gains related to safety and security activities by counting the costs involved in case of their misapplication or absence. Concretely, this requires answering the following question: what would be the economic costs incurred by the company (the operator) if safety and security activities were not applied?

On the basis of this purely accounting approach, we can assess both the cost of damage avoided through safety and security mechanism, and calculate the replacement cost of a damaged component.

[1]Richter, M. K. (1966)

[2]Sen, A. K. (1971).

In fact, the CAM must reflect as accurately as possible the cost avoided by the company through safety and security activities. Moreover, it should, as far as possible, respect certain criteria to be solid, not denied or questioned:

- Objectivity assumptions: the calculation must be based on reliable, verifiable and non-manipulable assumptions;
- Simplicity: the calculation must be justifiable and easily explained to both professionals and the public;
- Continuity: in our analysis, the method adopted must be repeated during several years.

It worth reminding that, although our analysis is inspired by environmental approaches as mentioned above, the assessment contains total gain behind safety and security activities including economic, social, human and environmental gains.

**2.1. Potential impacts:**

The absence of safety activities could generate several dangerous consequences leading to different possible scenarios.

We assume that the monitoring activities of hydraulic dams, diagnosis and analysis of measures, or safety studies, are not correctly carried out or totally unrealized. Thus, some consequences to consider:

- Regulatory impacts: fine and penalties;
- Impacts to the operator: water level drop, total operating loss;
- Social and environmental impacts: damage to goods and ecosystems;
- Physical impacts on the dam: the dam can be damaged;
- Human impacts: life loss risk.

**2.2. Assumptions**

Before estimating probable scenarios, we would prefer to make some plausible assumptions that will be of major importance for our analysis, particularly for the very serious scenarios.

- The total average production of the hydropower energy of the concerned company is 50 TWh;
- The number of hydropower plants operated by the concerned company: 400;

- The average annual electricity production per power plant: 125000 MWh (author's calculation based on real data (total hydro power production in France /total power plants in France);
- The average number of victims affected by a dam failure: 200 individuals (calculation based on previous accidents);
- The percentage of loss of life among victims: 10% (Minimal percentage);
- The statistical life value in France is estimated at 2,4 Million €/life (according to OECD).

### 2.3. Possible scenarios

When the safety activities are poorly carried out or not realized, three main scenarios are conceivable, starting with the least serious to the most dangerous scenario:

***Scenario I:*** the government imposes a fine on the hydroelectric power operator;

***Scenario II:*** the government imposes special review procedures involving a loss of production;

***Scenario III:*** dam failure implicating whether human loss risk, total operating loss, damage to the dam or damage to goods and ecosystems.

## 3. Results

### 3.1. Scenario I: Fine and penalties

In the first scenario, we assume that the operating company does not respect the regulation. Taking as example not transmitting the monitoring / auscultation reports within the deadlines already defined by the regulator (see details above in § Dam Safety Regulation).

According to the French hydraulic energy law of 16.10.1919, the lack of respect for the regulation exposes the operator to a fine of 75 000,00 €.

### 3.2. Scenario II: Special review procedures

In the second scenario, we also assume that the operating company does not respect the regulation, but the regulator considers it as very dangerous to pursue the operation of the dam in the present circumstances. Consequently, the regulator forces the operator to adopt Special Review Procedures which puts the operator under operating constraints. Thus, this would take two major forms:

- Water level drop;
- Complete drainage of the dam.

The present scenario might cause either a total or a partial production loss. In this case, we assume four sub-scenarios per level of production loss calculated based on Eq.1 bellow:

$$\mathbf{AC} = \mathbf{P} \times \mathbf{L} \times \mathbf{Ep} * \qquad (1)$$

**Based on Epex Spot Electricity Exchange data.*

Where **AC** refers to the avoided costs, **P** is the annual total production, **L** is the percentage of total potential loss and **Ep** is the average electricity prices per MWh.

<u>Potential loss of 25% of annual production:</u>

Avoided cost for potential production loss incurred by the hydropower plant estimated at 25%:

$$125000 \times 0.25 \times 33.544 = 1048250 \ (2)$$

<u>Potential loss of 50% of annual production:</u>

Avoided cost for potential production loss incurred by the hydropower plant estimated at 50%:

$$125000 \times 0.5 \times 33.544 = 2096500 \ (3)$$

<u>Potential loss of 75% of annual production:</u>

Avoided cost for potential production loss incurred by the hydropower plant estimated at 75%:

$$125000 \times 0.75 \times 33.544 = 3144750 \ (4)$$

<u>Complete drainage causing total production loss:</u>

Avoided cost for potential production loss incurred by the hydropower plant estimated at 100%:

$$125000 \times 33.544 = 4193000 \ (5)$$

Total weighted average loss of Scenario II:

**Table 2** Probability distribution of each level of production loss

| Level of production loss | Probability |
|---|---|
| 25% | 0,7 |
| 50% | 0,1 |
| 75% | 0,1 |
| 100% | 0,1 |

$$[1048250x0.7]+[2096500x0.1]+[3144750x0.1]+[4193000x0.1]=1677200\text{ €} \quad (6)$$

Although the decision of lowering water levels depends totally on the regulator and considered as exogenous factor to the operator, the probability realization of the first sub-scenario (potential loss of 25%) is very high compared to the other three sub-scenarios. The intuition behind the use of this probability distribution can be explained by the fact that the operator takes all safety measurements and prepares technical documents needed to avoid strong abatement of water level that might cost the operator more than 25% of production loss.

### 3.3. Scenario III : Dam failure

This third scenario consists of a dam failure. This is the most serious scenario whose possible causes can be listed as follows:

- The absence or weak monitoring system and auscultation measurements not able to prevent dam failures;
- Poor flood forecasting or paralyzed warning systems;
- Defective mechanical system of the hydroelectric dam;

The above-mentioned factors would generate brutal flowing of water downstream and the realization of this scenario would have serious human, social and environmental impacts along with consequences on the operator and the hydroelectric power plant. Explicitly, this would result in total loss of production or a complete concession loss, potential loss of human life, serious damage to the dam and its entire environment including housing, land, farming nearby, etc.

These consequences can be gathered according to their scope perimeter, namely internal and external consequences.

### 3.4. Internal impacts:

The internal impacts are closely related to the dam component and the operator. They concern potential loss of operation and damage to the dam, which can be calculated as follows:

Total loss of production: 125000x33.544 + 4193000 (7)

Damage to the dam (dam failure): Estimated at 200 000 000 € as average investment cost for dam construction (because of the difficulty to get such information, the construction cost of Rizzanes dam is given as a reference, estimated at 200 000 000).

**External impacts:**

This concerns impacts that affect the external environment of the hydraulic dam (human, social and environmental impacts).

Human life loss estimated at: 2450000 x 20 = 49000000 € (8)

Where 2,45 M is the life statistical value in France according to the Organization for Economic Co-operation and Development and 20 is the number of people exposed to the risk of loss of life weighted by the probability of risk occurrence estimated at 10% (200*0,1).

Damage to property and to the environment which is very variable as the cost would vary between millions (321 809 489€: accident cost of ***Grand Dixence*** dam in Swiss) and billions of Euros (5,6 billion € : the cost of two dam failure of ***Bento Rodrigues*** in Brazil).

By adding the various internal and external costs of scenario III, we get the total cost as follows:

[4193000+200000000]+[49000000] = 253193000* € (9)

* Without counting the cost of compensation for social and environmental damage that might be imposed by the regulator.

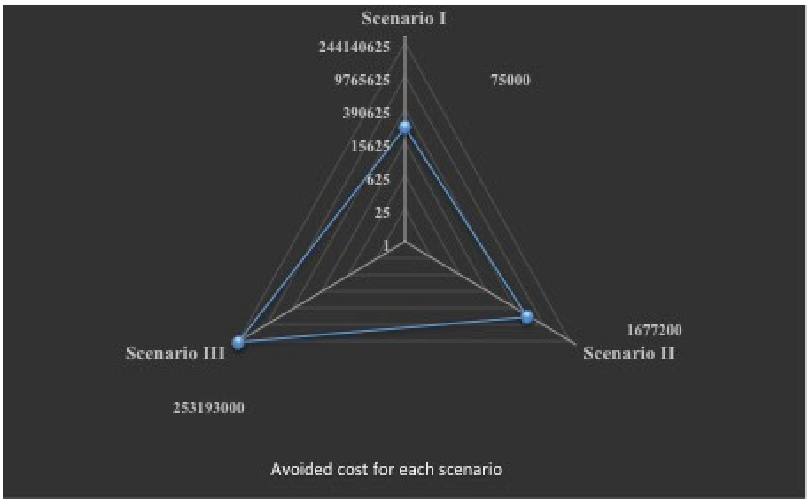


**Figure 1** Added cost for each scenario

### 3.5. Weighted total of the three scenarios

***Probability distribution:***

**Table 3** Probability distribution of each scenario

| Scenario | Probability realization |
|---|---|
| Fine and penalties | 0,6 |
| Special review procedures | 0,3 |
| Dam failure | 0,1 |

***Wighted average:***

[75000×0,6] + [1677200×0,3] + [253193000×0,1] = 25867460€ (9)

## 4. Conclusion

Based on this analysis, it is obvious that safety activities avoid huge economic losses. The different scenarios mentioned in this analysis, formulated by increasing level of gravity, are the main proof. On average, these activities enable the operator to avoid costs of up to 26 Million EUR along with the cost of repairing social and environmental damages.

In fact, this analysis is considered as a first working element for the economic valuation of capital gains from activities difficult to quantify. Thus, the results can be developed. Future research in this field would be able to complete the study by reinforcing its weak elements. To this end, several improvement tracks are conceivable. First of all, given its importance, it is very necessary to take into consideration the company's image in the calculation. In addition, it would be very interesting to integrate the notion of dam's classification and conduct analyzes for each category (A, B, C).This would provide more detailed and in-depth view of the gains behind safety activities. Furthermore, it would be beneficial to carry out a survey with data collected tools such as survey and interviews in order to get essential and precise inputs for the analysis. For example, it is very important to get data about the exact number of people located below the dam, the willingness to pay for reducing the risk of life loss of the population placed near the hydraulic power station, the willingness to pay to preserve the environment and the costs incurred by the population in case of a dam failure. The survey will reduce the use of standard values and thus refine the results of the analysis.

**References**

Alberini, A. (2005). What is a life worth? Robustness of VSL values from contingent valuation surveys. *Risk Analysis: An International Journal*, 25(4), 783-800.

Ashenfelter, O. (2006). Measuring the value of a statistical life: problems and prospects. *The Economic Journal*, 116(510), C10-C23.

Atkinson, G., & Mourato, S. (2015). Cost-benefit analysis and the environment.

Barthélémy, F., Martin, X., & Nicolazo, J. L. (2004). La réglementation en matière de sécurité des barrages et des digues. Conseil général des mines.

Bateman, I. J., & Willis, K. G. (Eds.). (2001). Valuing environmental preferences: theory and practice of the contingent valuation method in the US, EU, and developing countries. Oxford University Press on Demand.

Blomquist, G. C. (2004). Self-protection and averting behavior, values of statistical lives, and benefit cost analysis of environmental policy. *Review of Economics of the Household*, 2(1), 89-110.

Bowles, D. S., Anderson, L. R., & Glover, T. F. (1998). The practice of dam safety risk assessment and management: Its roots, its branches, and its fruit. In its Roots, its Branches, and its Fruit. Proceedings of USCOLD 1998 Annual Lecture.

Boxall, P. C., Adamowicz, W. L., Swait, J., Williams, M., & Louviere, J. (1996). A comparison of stated preference methods for environmental valuation. *Ecological economics*, 18(3), 243-253.

Brown, C. A., & Graham, W. J. (1988). ASSESSING THE THREAT TO LIFE FROM DAM FAILURE 1. *JAWRA Journal of the American Water Resources Association*, 24(6), 1303-1309.

Carlsson, F., & Martinsson, P. (2001). Do hypothetical and actual marginal willingness to pay differ in choice experiments? Application to the valuation of the environment. *Journal of Environmental Economics and Management*, 41(2), 179-192.

Carson, R. T., Flores, N. E., & Meade, N. F. (2001). Contingent valuation: controversies and evidence. *Environmental and resource economics*, 19(2), 173-210.

Cheng, S. T. (1993). Statistics of dam failure. Reliability and uncertainty analysis in hydraulic design. ASCE, New York, 97-105.

Cost, E. U. R. O. C. O. N. T. R. O. L. (2013). Standard Inputs for EUROCONTROL Cost Benefit Analyses.

De Blaeij, A., Florax, R. J., Rietveld, P., & Verhoef, E. (2003). The value of statistical life in road safety: a meta-analysis. *Accident Analysis & Prevention*, 35(6), 973-986.

DeKay, M. L., & McClelland, G. H. (1993). Predicting loss of life in cases of dam failure and flash flood. *Risk Analysis*, 13(2), 193-205.

Hanemann, W. M. (1994). Valuing the environment through contingent valuation. *Journal of economic perspectives*, 8(4), 19-43.

Hanley, N., Wright, R. E., & Adamowicz, V. (1998). Using choice experiments to value the environment. *Environmental and resource economics*, 11(3-4), 413-428.

Hartford, D. N., & Baecher, G. B. (2004). Risk and uncertainty in dam safety. Thomas Telford.

LaBelle, J. E. (2000). What do accidents truly cost? *Professional Safety*, 45(4), 38.

Persson, U., Norinder, A., Hjalte, K., & Gralén, K. (2001). The value of a statistical life in transport: findings from a new contingent valuation study in Sweden. *Journal of Risk and Uncertainty*, 23(2), 121-134.

Rico, M., Benito, G., Salgueiro, A. R., Díez-Herrero, A., & Pereira, H. G. (2008). Reported tailings dam failures: a review of the European incidents in the worldwide context. *Journal of hazardous materials*, 152(2), 846-852.

Salmon, G. M., & Hartford, D. N. D. (1995). Risk analysis for dam safety. In International *Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts*, 6(32), 284A.

Seed, H. B., Lee, K. L., & Idriss, I. M. (1969). Analysis of Sheffield dam failure. *Journal of Soil Mechanics & Foundations Div*.

Viscusi, W. K., & Aldy, J. E. (2003). The value of a statistical life: a critical review of market estimates throughout the world. *Journal of risk and uncertainty*, 27(1), 5-76.