An economic model of risk assessment for water projects

Antonio Nesticò, Gianluigi De Mare and Gabriella Maselli

ABSTRACT

The projects that concern water resources are characterized by the multiple risk rates – even extra–financial – that significantly affect their concrete feasibility. Although the risk assessment is decisive for expressing economic convenience judgements on these project initiatives, the decision-maker does not have precise references to determine whether the residual investment risk is acceptable. Thus, the purpose of the paper is to overcome the limit set by characterizing a model for the acceptability of project risk, also considering the plurality of environmental effects that the water projects generate on the community. The idea is to integrate the logic 'As Low As Reasonably Practicable' (ALARP) into the procedural schemes of Cost–Benefit Analysis (CBA). In accordance with this principle, widely applied in high-risk sectors such as those of industrial engineering, a risk is ALARP when the costs to further reduce it are disproportionate to the obtainable benefits. The application of the model to an irrigation reconversion intervention in a Municipality in the Province of Salerno (Italy) shows that the ALARP logic defines a general way of thinking and can contribute to the definition of effective forecasting protocols. In this sense, the proposed methodology becomes a useful support for environmental decision-making. (The paper is to be attributed in equal parts to the three authors.)

Key words | ALARP principle, Cost–Benefit Analysis, economic evaluation of projects, risk assessment, water projects

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INTRODUCTION

For the purposes of a correct and transparent allocation process of financial resources to projects in the water sector, it is important to analyse and assess all the risks that can affect the overall performance of the individual intervention. In fact, the investments that concern water resources inevitably determine environmental effects, often with consequences also in the energy field. One thinks, for instance, about the technologies for the production of energy required by wastewater treatment plants. In fact, these technologies generate financial repercussions, which must be verified to establish with what probability the costs can be balanced by the benefits (Nesticò *et al.* 2018a). The study of project risk can be done using specific techniques, to be implemented in order to establish both the effectiveness of the possible risk mitigation options, and to measure the residual risk, that is the one that persists despite the mitigation actions undertaken. In this regard, European regulatory guidelines recognize the centrality that risk analysis must have in the economic evaluation of civil investments and, consequently, of water projects (European Commission 2014). In particular, Regulation no. 1303/2013 of the European Commission (EC; European Commission 2013) specifies that the risk analysis in support of the Cost–Benefit Analysis (CBA) is required in cases where exposure to the residual risk, namely that which persists despite the mitigation strategies undertaken, is still considerable. Nevertheless, it can also be performed due to the project size or in relation to the availability of data necessary for the analysis. However, there are two main limitations of the risk analysis techniques generally used in practice: (1) it is often difficult to take into account in the CBA the extra-financial (i.e. environmental and social) risk rates which in the case of investments in hydraulic works are significant; (2) there

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are no strict and objective criteria to determine whether the investment risk and the residual risk are acceptable to the investor or to the community.

In an attempt to overcome these limits relating to traditional economic feasibility studies, the purpose of the paper is to define a risk management protocol in the economic evaluation of investments for civil works such as water projects. This can be done by integrating the ALARP logic into the procedural schemes of the Cost–Benefit Analysis, according to which a risk is tolerable only if 'As Low As Reasonably Practicable'. Defined by the British Governmental Agency Health and Safety Executive (HSE), and generally applied to high-risk sectors for health and safety issues, the ALARP principle defines a risk as 'tolerable' when the costs to reduce it further appear disproportionate to the benefits obtainable. An intervention can be defined as 'practicable' as long as its technical feasibility is demonstrated, while 'reasonableness' implies the need also to consider extra-monetary aspects such as social, cultural and environmental ones. In other words, any risk reduction intervention is ALARP if 'reasonably' feasible and sustainable in a broad sense, thus allowing operating a triangular balance between risks to be reduced, costs to be incurred and benefits to be pursued (Ale *et al.* 2015). To understand how the ALARP principle can support *decision-making*, it is necessary to clarify in which phase of the *risk management process* it can intervene.

The risk-management logical-operational process is divided into the following phases that are closely interrelated to each other (Melchers 2001; Zio 2007; Meyer & Reniers 2013):

1. *Definition of the objectives of the risk management activity.* This is a question of representing the strategic context in which the process takes place, and therefore of clarifying which evaluation procedures are intended to be used to achieve the goal, i.e. to avoid failure of investor.
2. *Identification of risks.* This concerns the study of the sensitive variables of the system, i.e. those that appreciably influence the riskiness of the project.
3. *Analysis of the detected risks.* This consists of observing how the sensitive variables of the system can interact with each other, therefore envisioning every possible risky scenario.
4. *Quantitative risk assessment.* This phase involves the quantitative estimation of the risk in probabilistic terms. This is an activity necessary to define the actions aimed at risk management.
5. *Risk treatment*. This translates into the identification and subsequent application of planned interventions to the project in order to mitigate the risks identified.
6. *Assessment of residual risk*. This consists of the probabilistic estimate of the residual risk, i.e. the one that remains despite the planned mitigation strategy.

The application of the ALARP principle to the decision-making process can become an integral part of steps 4 and 6 as it allows establishing whether the risk of failure is acceptable to the investor. In other words, an approach to measure risk and verify its acceptability before and after mitigation interventions, using criteria that are methodologically consistent and easily repeatable, is proposed. This is with the aim of clearly presenting the results of the evaluations to the decision-makers responsible for the selection of water projects (Liang & van Dijk 2010; Santos Goffi *et al.* 2019; Nesticò & Maselli 2020a, 2020b).

The paper is structured in the following four sections. In the second section, we analyse the approaches and evaluation techniques on which the research is based, specifically the ALARP logic and the Cost–Benefit Analysis, with the aim of understanding how the ALARP can become an integral part of a decision-making process structured according to the CBA. The third section describes an innovative economic model for the acceptance of the residual risk associated with water projects; the model is useful for the efficient allocation of resources and therefore for the selection of the best-performing design alternatives. In the fourth section the model is validated on a case study, that is an irrigation reconversion intervention in the Province of Salerno (Italy). The final section returns the conclusions of the work, showing possible future research ideas and outlining the relevant implications that this evaluation approach may have in terms of economic policy.

METHODS

This research proposes an innovative approach of risk assessment for projects in the water sector, where the CBA is integrated with the ALARP logic (De Mare *et al.*

2018; Nesticò *et al.* 2018a). In this way it is possible to express a judgement on the acceptability of the investment risk and of the residual risk, the latter represented by the risk that remains following the adoption of pre-established mitigation measures. It is therefore necessary to illustrate the logical-operative principles underlying both ALARP logic and CBA. This is to understand how, when jointly used, they can become a fundamental tool of investigation in the economic evaluation for projects of the water sector and thus to orient the decision-making process.

The ALARP principle in decision-making

The As Low As Reasonably Practicable (ALARP) principle is closely related to the concept of the social or individual risk maximum acceptable (French *et al.* 2007). Already widely discussed in *Reducing Risks, Protecting People* drafted by the Health and Safety Executive (HSE 2001) with the aim of providing guidelines for the tolerability of nuclear risk, it is currently used in decision-making processes concerning safety and health. According to the ALARP principle, it is necessary to reduce the risk to levels as low as reasonably practicable. It is founded on the idea that a risk-reducing measure shall be implemented unless it can be demonstrated that the costs are in gross disproportion to the benefits gained (Aven 2015). In other words, any ALARP risk mitigation intervention must be 'reasonably' sustainable (French *et al.* 2007; Jones-Lee & Aven 2011; Nesticò *et al.* 2018a, 2018b).

HSE defines the ALARP principle that expresses the obvious criterion that, as the risk increases, the mitigation costs to make it tolerable are progressively higher. In the ALARP approach three risk regions are identified. The three risk regions are separated by two thresholds:

1. the 'broadly acceptable' separates the acceptability region of the risk from that of tolerability or ALARP;
2. the 'limit of tolerability' separates the ALARP zone or risk tolerability from that of unacceptability.

If the risk falls within the region of 'broadly acceptable' no mitigation intervention is required; if it is contained in the ALARP area, the risk is tolerable only if it is impossible to reduce it further or if the costs to mitigate it are disproportionate; if it is in the region of unacceptability, the risk must necessarily be mitigated, making it at least ALARP.

In accordance with the ALARP principle, it should be pointed out that 'zero' risk is not a viable option, so that the 'broadly acceptable' threshold is considered as a 'security level', i.e. the specific risk is acceptable within certain limits. The 'limit of tolerability' threshold, on the other hand, represents the beginning of a region with high risk, but which does not imply a certain catastrophe. In other terms, a risk is tolerable if it falls within the ALARP area, i.e. if the costs for its minimization are greater than the expected costs if damage occurs (Ale 2005; Aven & Abrahamsen 2007; Jones-Lee & Aven 2011; Yasseri 2013; Aven 2016). To better understand the ALARP principle refer to Figures A1 and A2 in the Supplementary Material.

Within ALARP, to quantify the disproportion between costs and benefits obtained from the risk mitigation intervention, it is necessary to estimate the Implied Cost of Averting one Fatality (ICAF). This indicator, which represents the cost or investment made to save additional life, is given by the ratio between the cost of the investment made and the expected decrease in the number of fatalities following the mitigation:

$$\text{ICAF} = \frac{\text{Cost of mitigation measure}}{\text{Reduction in potential loss of life}} \qquad (1)$$

The ICAF estimated for the proposed option is then compared with reference ICAF values, specific according to the sector of intervention, in order to verify whether there is a disproportion between the costs for risk mitigation and the improvements pursued. In this way, it is checked whether the residual risk is tolerable, where risk tolerance means 'the willingness to live with a risk so as to guarantee some benefits' (HSE 2001, 2014a, 2014b, 2014c).

In light of what has been described, we understand that one of the limits of ALARP logic is that it is based on purely qualitative and holistic principles. This can lead to uncertainty and unpredictability in the decision-making process. Moreover, 'the principle may not give clear guidance when decisions require not just a cost/risk trade-off, but also a trade-off between different types of risk' (French *et al.* 2007).

On the other hand, the ALARP approach is increasingly used to solve risk management problems, such as land-use planning in the immediate vicinity of industries or dams, landslide risk management or risk assessment in the gallery (Morgenstern 1995; ERM-Hong Kong Ltd 1998; Ho *et al.* 2000; Leroi *et al.* 2005; Porter *et al.* 2009). It is clear that the ALARP approach has so far been widely used for the assessment of risks concerning health and safety within the company but not for the assessment of the financial risk related to civil projects and, specifically, to hydraulic works. Despite this, we believe that the ALARP criterion defines a 'general way of thinking' (Redmill 2010) and therefore can also find original application in the assessment of the riskiness of investments in the civil sector. Even in this case, in fact, the main objective is still the triangular balance between risk, mitigation costs, and achievable benefits. Thus, the aim of this research is to show how the integration of the ALARP principle with the traditional CBA can lead to a new economic approach, useful for verifying the investment risk and therefore to guarantee a more correct and transparent resource allocation process for projects of the water sector.

The Cost–Benefit Analysis for the evaluation of investment risk

The technique generally used to verify the economic performance of a project is the Cost–Benefit Analysis. This technique consists in forecasting the costs and benefits that the investment is able to generate in the analysis period; in the subsequent discounting of Cash Flows (CFs); and therefore in the estimate of the synthetic profitability indicators, in particular the Net Present Value (NPV), the Internal Rate of Return (IRR), the Benefits/Costs ratio, and the Payback Period.

If we consider the Net Present Value as an evaluation indicator, then a project is economically convenient when the sum of cash flows discounted to current events is positive and sufficiently large:

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} > 0 \quad (2)$$

where B_t and C_t are the benefits and costs generated by the project over time and r is the discount rate.

The Internal Rate of Return (IRR), on the other hand, can be defined as that specific discount rate for which the NPV is equal to zero:

$$\sum_{t=0}^{n} \frac{B_t - C_t}{(1+IRR)^t} = 0 \quad (3)$$

So an initiative is economically sustainable when the IRR is at least equal to the discount rate used to estimate the NPV.

However, for project initiatives whose risk of failure is considerable, the evaluation of economic performance indicators can take place through representations on a probabilistic basis. In other words, the riskiness of the investment is taken into account by treating the cash flows that can be generated by the project during the analysis period as stochastic variables. Therefore, it is possible to estimate the probability distribution of the profitability indicator using the Monte Carlo method. For this purpose, it is necessary to evaluate:

(a) the input, in terms of probability distributions to be associated with sensitive variables, i.e. those that most influence the outcome of a cost–benefit test;
(b) the output, in terms of the cumulative probability distribution of the economic performance indicator of the project.

The analysis of the frequency distribution of the evaluation index provides quantitative indications on the failure probability of the investment.

It should be noted that the CBA requires the transformation of all cash flows in monetary terms. On the one hand, this makes it possible to compare immediately the benefits and costs of the investment; on the other hand, however, it ends up neglecting the impacts difficult to express in quantitative terms.

Considering the specificities as well as the limits that characterize the ALARP principle and the CBA technique, it is shown that the joint use of the ALARP logic and the CBA quantitative assessment technique can lead to the characterization of an innovative approach for the evaluation of investment risk.

AN ECONOMIC MODEL FOR ACCEPTABILITY OF RESIDUAL RISK FOR PROJECTS IN THE WATER SECTORS

The proposed model introduces the risk acceptability and tolerability thresholds of the ALARP principle in the CBA procedural schemes. This is with the aim of expressing an objective judgement on the acceptance of the residual investment risk for water projects. The evaluation protocol is embodied in the logical-operative phases described below:

1. *Definition of the objectives of the risk management activity*. The main goal to be pursued is to avoid the failure of the intervention. This translates into the definition of actions and design choices that can positively influence the profitability of the investment.
2. *Identification of the risk components of the project*. This is expressed in the forecast of the costs and benefits that the investment generates during its useful life and in the consequent search for the sensitive variables of the system. A variable is said to be 'sensitive' when even its contained variation significantly influences the outcome of a cost–benefit test.
3. *Risk analysis*, which is explicit in the
   - estimate of the probability distribution of risk variables (input);
   - generation of the cumulative frequency distribution of the performance indicator and subsequent evaluation of the profitability of the project in stochastic terms (output).
4. *Risk assessment,* by comparing the risk of project failure, which can be read from the cumulative frequency distribution of the output (for example the NPV or IRR) estimated in step 3, and the thresholds of acceptability (T_a) and tolerability (T_t) as defined by the ALARP logic. If the risk falls: (a) in the broadly acceptable region, therefore below the threshold of acceptability, then the intervention is feasible; (b) in the unacceptable area because it is above the tolerability threshold, then the risk is to be considered too high and therefore it is necessary to provide for risk mitigation measures; (c) in the region between the acceptability threshold and the tolerability threshold, then the risk is ALARP – or tolerable – only if the costs of the envisaged mitigation options are disproportionate to the achievable benefits.
5. *Definition of risk mitigation measures* and subsequent estimate of the values of economic performance indicators considering the changes made with the defined mitigation measures.
6. *Evaluation of residual risk*, in order to express a judgement on the acceptability/tolerability/intolerability of the risk that remains despite the mitigation measures undertaken. If C_m are the risk mitigation costs, R_1 the risk of failure prior to the mitigation intervention, and R_2 the risk of failure after the mitigation intervention, then:
   - if $R_2 > T_t$, then the risk R_2 is still intolerable. Further mitigation measures should be envisaged, otherwise the project cannot be undertaken;
   - if $T_a < R_2 < T_t$, then the risk R_2 is tolerable as ALARP, or because further interventions cannot be contemplated or because they would entail excessive costs C_m in relation to the risk mitigation effects obtainable;
   - if $R_2 < T_a$, then the risk R_2 is broadly acceptable and it is not necessary to foresee further mitigation measures.

Figure 1 explains the phases of the defined economic evaluation protocol, which is validated on a case study in the following section.

CASE STUDY: RESULTS AND DISCUSSION

The protocol for accepting the investment risk, summarized in Figure 1, is applied with the aim of assessing the economic sustainability of a restructuring of the irrigation network in the Province of Salerno (Italy). In fact, the current network is no longer able to guarantee the competitiveness of the agricultural businesses served as it is obsolete and inefficient.

Description of the project

The interventions concern the works listed below.

- Restructuring and monitoring of the water intake structure. The intake structure consists of a channel of reinforced concrete with a rectangular section, of dimensions 1.20 × 0.80 m to be located in the bed of the Calore River, in a direction transverse to the direction of the water current. The water captured by this channel is fed to the existing collection tank, equipped with automatic mobile gates to ensure that the maximum flow rate granted by the concession is not exceeded (Fr_{max} = 1.250 l/s). Furthermore, systems to prevent the occlusion

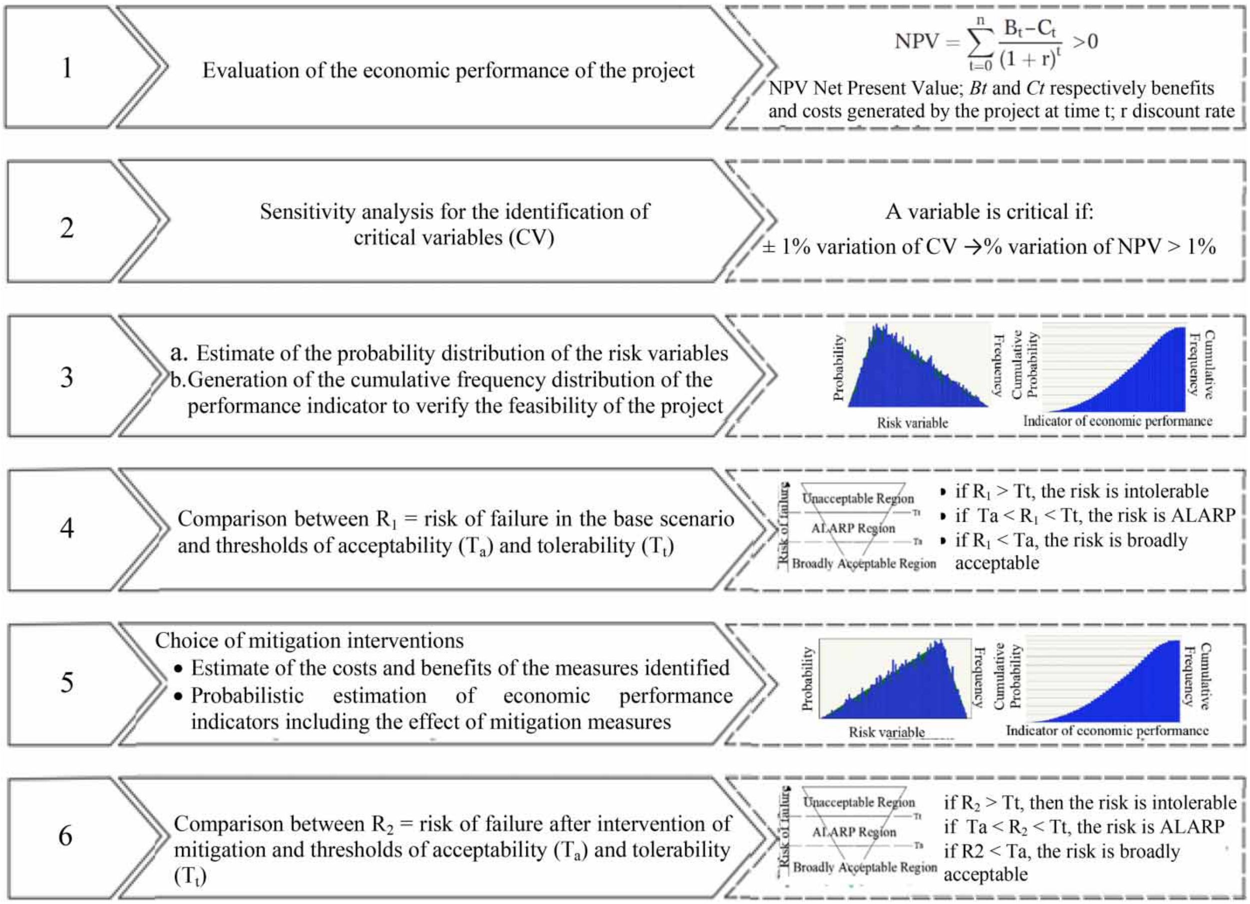

Figure 1 | The phases of the protocol for accepting investment risk.

of the channel by the material carried by the current are provided.

In order to ensure effective control of the flow rates derived from the Ponte Calore intake works, it is assumed that a measuring station of the Calore River water level with its data transmission system will be built.

- Restructuring and remote control of the lifting plant. The lifting plant, after dismantling the electrical equipment and the existing electric pumps, has a total flow rate within the limits of the concession, divided into two electric pumps each with a capacity of 625 l/s and a total head sufficient for the introduction of the water withdrawn in the main irrigation channel. A further electric pump, located in a well made with micro-piles, with a capacity of 150 l/ s, provides for the lifting of the flow taken from the river (at an altitude of 28.0 m asl) to supply the tank (at maximum altitude 81.7 m asl) for irrigated areas.

Auxiliary works are also envisaged: positioning of a bridge crane for the installation and maintenance of the aforementioned equipment; arrangement of the access road to the plant through road paving and curbs; consolidation of masonry works; installation of a video surveillance system; installation of a shielded fibre optic cable, for direct connection between the lifting system and the storage tank for the remote control of the pumps serving the irrigation utilities, with a length of 2,000 m, in direct relation to the level of the tub.

- Hydroelectric control unit. The plant for the production of energy from Renewable Energy Sources (RES) is located within the areas of the existing lifting system. This uses the flow derived from the Sele River exceeding that required for the irrigation supply of the consortium district in the non-irrigated months to return it, then, to the Calore River using an appropriate existing discharge artefact. The system is able to cover a rate equal to 57% of the costs for the operation of the adjacent lifting system.

- Adduction and distribution network. The net is composed of a supply line in steel (diameter F500 and length of approx. 1.975 m) which feeds a tank, an exhaust pipe (F 500 in steel) and the adduction pipe to the irrigated areas (partly in steel of diameter between 600 and 400 mm and partly in PEAD of diameter between 355 and 250 mm). In correspondence with the 26 subdepartments in which the irrigation area is subdivided, the 'hydrants' are located, equipped with sectioning, water measuring and monitoring devices. The distribution network (with pipelines in PEAD DE 160) originates from these to serve all the users of the area involved in the intervention.
- Storage tank. The accumulation tank (equal to about 80.50 m asl) is sized for night filling and for any lifting interruption. The following are the main dimensions of the work: base area $A = 12.20 \times 8.40\ \mathrm{m}^2$, height $h = 5.25$ m; foundation bed thickness $s_1 = 0.40$ m; wall thickness $s_2 = 0.30$ m.

The purpose of the intervention is to offer a sustainable and economically advantageous irrigation service to the greatest number of users. The replacement of the current plant with an improved technology allows both a reduction of dispersions along the network and a guarantee of better quality of the water resource. In fact, it will suffer considerably fewer contamination phenomena than in the case of free contact with the outside. Moreover, the greater control of consumption connected to the installation of instruments for detecting the flow rates supplied by the individual users and the introduction of the new tax pay system mean that each farmer is induced to withdraw what is strictly necessary, thus favouring the safeguarding of levels of groundwater.

From the estimate of the reduction both of localized losses connected to the state of degradation of the current network and of those distributed by surface runoff and evaporation, there is a reduction in water waste of about 50%. Specifically, referring to maize cultivation, both because it is more practiced in the area and because it requires a high water demand, it is estimated that the real need is approximately 4,000 m^3 for each hectare cultivated, while at present it is satisfied with a provision of 7,000 m^3.

Table 1 shows an excerpt from the estimates of *ex ante* and *ex post* water consumption for each user in the intervention area, considering the relative Utilized Agricultural Area (UAA) and Total Agricultural Area (TAA): *Ex ante* water consumption $= 7{,}000\ \frac{\mathrm{m}^3}{\mathrm{ha}} \times \mathrm{UAA}$, with $7{,}000\ \frac{\mathrm{m}^3}{\mathrm{ha}}$ volume per hectare of water resource supplied for *pre*–intervention irrigation. *Ex post* water consumption $= 4{,}000\ \frac{\mathrm{m}^3}{\mathrm{ha}} \times \mathrm{UAA}$, with $4{,}000\ \frac{\mathrm{m}^3}{\mathrm{ha}}$ volume per hectare of water resource that can be supplied for *post*-intervention irrigation.

In the following sections, the economic feasibility study of the intervention is conducted. In other terms, we draw up the business plan from the community points of view.

Definition of the objectives of the risk management activity

The objective of the risk management process is to assess the economic sustainability of the investment in order to avoid failure of the investor. The preparation of the business plan and the consequent estimate of the economic performance indicators are therefore preparatory operations for the assessment of the acceptability of the investment risk. The main assumptions used as the basis for the analysis carried out are specified below.

Economic analysis

This analysis is developed from the point of view of the community, with the aim of evaluating the main social and environmental benefits that the water system modernization project is able to generate in the area affected by the intervention. In this case, the following reference parameters are adopted:

- the analysis period is 30 years, as specified in Annex I to the Delegated Regulation (EU) n.480/2014 of the European Commission for projects in the sector 'Water supply/sanitation';
- the Social Discount Rate is 3.0%, as established by the *Guide to Cost–Benefit Analysis* of the European Commission for the 2014–2020 evaluation period.

Table 1 | Estimate of water consumption for users in the intervention area

Company no.	TAA [ha]	UAA [ha]	*Ex ante* water consumption [m^3]	*Ex post* water consumption [m^3]	Water resource saved [m^3]
1	0.43	0.41	2,781.86	1,648.51	1,133.35
2	0.43	0.41	2,799.36	1,658.88	1,140.48
3	0.44	0.42	2,804.10	1,661.69	1,142.41
4	0.45	0.42	2,851.30	1,689.66	1,161.64
5	0.45	0.43	2,908.22	1,723.39	1,184.83
6	0.45	0.43	2,913.12	1,726.30	1,186.83
7	0.45	0.44	2,941.92	1,743.36	1,198.56
8	0.45	0.44	2,941.92	1,743.36	1,198.56
9	0.47	0.44	2,983.30	1,767.88	1,215.42
10	0.47	0.45	3,048.19	1,806.34	1,241.86
11	0.48	0.46	3,123.14	1,850.75	1,272.39
…	…	…	…	…	…
170	2.86	2.71	18,275.54	10,829.95	7,445.59
171	3.33	3.18	21,445.50	12,708.44	8,737.06
172	3.81	3.66	24,686.21	14,628.86	10,057.34
173	4.20	4.03	27,201.35	16,119.32	11,082.03
174	4.20	4.03	27,233.69	16,138.48	11,095.21
175	4.51	4.29	28,936.41	17,147.50	11,788.91
176	4.78	4.54	30,644.06	18,159.44	12,484.62
177	7.42	6.97	47,052.62	27,883.03	19,169.58
178	15.37	14.65	98,899.67	58,607.21	40,292.46
179	22.94	21.86	147,554.59	87,439.76	60,114.83
180	31.77	30.34	204,809.72	121,368.72	83,441.00
Total	263.12	250.31	1,689,566.61	1,001,224.66	688,341.95

The costs coincide with those of construction of the works, supported by the Ministry of Agriculture. The revenues, on the other hand, include: the increase in tax collections related to the increase in Gross Saleable Production (GSP); the monetary quantization of water savings deriving from the modernization of the network, according to the shadow price; the monetization of the reduction of carbon dioxide emissions into the atmosphere. The individual items of the costs and revenues that contribute to defining the economic plan are detailed below.

Investment costs

The estimate of construction costs and the expenses that contribute to define the economic framework show that the amount of investment costs is equal to €12,459,722.41. These costs are entirely disbursed by the Ministry of Agriculture and it is assumed that they will be distributed equally during the construction phase of the intervention, estimated at two years. For details on investment costs, refer to Table A1 in the Supplementary Material.

Reduction of CO_2 emissions

The substitution of the gravity system with a pressure network involves centralizing the lifting of the resource and the consequent operation suspension of the motor pumps by the individual farmers. This entails a lower use of fossil fuels, with relative improvement in air and crop quality, due to the reduction of carbon emissions in the form of

CO_2 and pollutants from the combustion of hydrocarbons, such as PM_{10} particulates, hydrocarbons HC, nitrogen oxides NO_x, and sulphur dioxides SO_2.

The analysis of the literature and the study of the climatic and undeniable conditions of the area allow estimating: (a) a reduction in CO_2 emissions deriving from the modernization of the network of around 0.9 t/ha per year; (b) economic damage caused by a ton of CO_2 emitted into the atmosphere estimated at $220, or about €197.73. This takes into account not only the direct effects on the climate, but also the impact produced on national economies, quantifiable in the lower agricultural production and in the increase in social and health expenses. With reference to the characteristics of the analysis project, the following result is obtained:

$$\begin{aligned} B\left(R_{CO_2}\right) &= R_{CO_2} \cdot \mathrm{UAA} \cdot De_{CO_2} \\ &= 0.9\,\mathrm{t}/(\mathrm{ha} \cdot \mathrm{year}) \cdot 250.31\,\mathrm{ha} \cdot 197.73\,€/\mathrm{t} \\ &= 44{,}544.42\ €/\mathrm{year} \end{aligned}$$

where:

$B(R_{CO_2})$ = benefit deriving from the reduction of CO_2 emissions from the new plant [€/year];

R_{CO_2} = reduction of CO_2 emissions resulting from the modernization of the network [t/(ha·year)];

UAA = Utilized Agricultural Area [ha];

De_{CO_2} = economic damage caused by a ton of CO_2 emitted into the atmosphere [€/t].

Shadow price and value of water good

The main purpose of the modernization of the irrigation network concerns the optimization of water resource management. In this regard, the United Nations Environment Program UNEP report (Year Book 2010) notes that agriculture, together with forestry, fishing and aquaculture, is among the most important drivers of environmental pressure. Since in Italy agriculture has a particularly significant impact on the entire national territory, in recent years it has increasingly focused on initiatives to integrate agricultural dynamics and environmental sustainability, tending to favour a more rational and responsible use of natural resources. Moreover, the problem of water resource management is made even more relevant and topical by recent observations and theories on global climate change, which envisage future scenarios characterized by increasingly less water availability (Khalkhali et al. 2018; Mannan et al. 2018).

In order to consider the aforementioned issues in the Cost–Benefit Analysis, we estimate the shadow price of water for irrigation. Shadow price means the value attributed to the resource by the community in the context of free market bargaining, different from the administered tariff at which the good is ordinarily exchanged. The evaluation procedure that we follow is that of the Water Framework Directive 2000/60 EC, which specifies how the water good should be considered a natural resource to be protected and not a commercial good from which to profit. Elaborations on agronomic data allow us to estimate the shadow price of water at €0.042/m^3.

Increase in tax rates

The increment in tax collections related to the increase in gross saleable production is estimated in percentage terms with respect to the profit. The latter, in turn, is supposed to be equal to 25% of farm incomes, as can be seen from paragraph 1,094 of art. 1 of the 2007 financial law no. 296 of 27 December 2006.

The costs necessary for the construction of the works amount in total to €12,459,722. They are entirely disbursed by the Ministry of Agriculture and it is assumed that they will be distributed equally during the construction phase, estimated at two years. Among the benefits, on the other hand, are those deriving from lower CO_2 emissions, water savings based on the shadow price, the increase in tax rates, and the residual value of the works at the end of the analysis period (30 years). The negative net present value (€3,435,116) and the internal rate of return equal to 1% show that the intervention as assumed is not sufficiently profitable due to the high investment costs incurred by the Ministry of Agriculture. For a summary of the costs, benefits of the project and the business plan, see Tables A3 and A4 in the Supplementary Material.

Identification of the risk components of the project

'Critiques' are defined as those variables for which a variation of ±1% of the estimated value gives rise to a variation of over ±1% of the NPV. Thus, using the sensitivity analysis, the risky variables are sought, i.e. those that affect the performance of the investment. The elaborations lead to identification of the sensitive variables of the project:

- cost of investment C_i;
- gross saleable production GSP.

In detail, the ±1% variation of the variable 'cost of investment C_i' determines a change in the NPV value of 3%. The same percentage variation of the variable 'gross saleable production GSP' instead determines an increase/decrease of the NPV of 1.5%. The GSP variable in turn influences the increase in tax rates that represents a revenue item for the Ministry of Agriculture. Detail on sensitivity analysis is in Table A2 in the Supplementary Material.

Risk analysis

To assess the risk of investment failure in quantitative terms, it is necessary to estimate through Monte Carlo analysis how the values of the performance indicators change following the simultaneous variation of the project's sensitive variables. To this end, it is necessary:

- to estimate the probability distribution associated with each of the identified critical variables;
- to provide for the probability distribution of the economic performance indicator.

From the cumulative probability curve of the indicator, it is therefore possible to assess the project risk. This is by verifying whether, for a given NPV or IRR, the probability of it occurring is higher or lower than a reference value considered critical.

Table 2 summarizes the hypotheses assumed for the probability distribution of the critical variables detected.

For the 'construction cost' variable, a triangular probability distribution is assumed, where the total cost value of €12,439,819 is considered as the most probable, while considered possible is a variation of the same of ±5%.

For the gross saleable production, a probability distribution of the triangular type is still assumed. In this case, starting from agronomic analyses and market surveys, we estimate the gross saleable production values according to different climatic conditions. Thus, the most probable value of the variable is that estimated in conditions of average rainfall, while those less valued in conditions of drought and high rainfall are less likely. The results of the risk analysis are in the numerical values of Table 3. For details on the

Table 2 | Statistical indexes related to probability distributions of critical variables

	Investment costs		***Ex ante* saleable gross production**		***Ex post* saleable gross production**	
Variable statistics	**Hypothesis values**	**Triangular distribution**	**Hypothesis values**	**Triangular distribution**	**Hypothesis values**	**Triangular distribution**
Number of tests	10,000	–	10,000	–	10,000	–
Base case	12,459,722.41	12,459,722.41	1,505,913.19	1,505,913.19	1,958,956.10	1,958,956.10
Mean	12,457,030.81	12,459,722.41	1,331,271.78	1,330,771.87	1,906,688.80	1,904,488.29
Median	12,455,977.92	12,459,722.41	1,354,809.88	1,355,245.98	1,910,265.88	1,907,951.86
Mode	–	12,459,722.41	–	1,505,913.19	–	1,918,920.03
Standard deviation	253,678.54	254,333.02	146,773.93	146,435.51	161,445.60	161,347.96
Variance	64,352,801,619.56	64,685,284,389.27	21,542,587,652.81	21,443,358,640.59	26,064,683,168.52	26,033,162,645.26
Shift	−0.01	0.00	−0.54	−0.55	−0.07	−0.05
Kurtosis	2.40	5.40	2.40	5.40	2.41	5.40
Coeff. of variation	0.02	0.02	0.11	0.11	0.08	0.08
Minimum	11,845,697.01	11,836,736.29	919,997.17	918,156.15	1,509,796.26	1,502,249.93
Maximum	13,073,101.72	13,082,708.53	1,565,807.00	1,568,246.27	2,286,853.38	2,292,294.91
Mean standard error	2,536.79	–	1,467.74	–	1,614.46	–

Table 3 | Forecast values and statistical indices for NPV and IRR

Forecasting	NPV	IRR
Statistics	Forecast values	Forecast values
Evidence	10,000	10,000
Base case	– 3,435,116.82	0.01
Mean	– 3,603,934.43	0.01
Median	– 3,596,943.69	0.01
Mode	–	–
Standard deviation	460,575.80	0.00
Variance	212,130,065,031.27	0.00
Shift	−0.0212	−0.0215
Kurtosis	2.65	2.59
Coeff. of variation	−0.1278	0.2924
Minimum	– 5,111,191.05	0.00
Maximum	– 2,198,431.31	0.02
Mean standard error	4,605.76	0.00

results of pre-mitigation processing, see Figure A3 in the Supplementary Material.

The analysis shows that the probability of having a negative NPV is 100%. This proves that the intervention as it has been hypothesized up to now does not benefit the community and is not sustainable for the State. Hence the need to envisage risk mitigation actions.

Risk assessment

The application of the ALARP principle can be useful to express an objective judgement on the acceptability of the investment risk, making the decision-making process more rational and more transparent. Operationally, it is necessary to define two thresholds for investment risk, i.e.:

1. the *acceptability threshold*, understood as the limit value of the failure probability that the economic operator is willing to 'accept broadly';
2. the *tolerability threshold*, which represents the limit value of the probability failure that the investor tolerates, or because risk mitigation interventions are not predictable or because the planned mitigation measures would have disproportionate costs in relation to the benefits obtainable.

The values of the two thresholds depend on the investment sector, on the socio-economic characteristics of the area in which the project is located, but certainly also on the propensity to risk of the economic operator who intends to take charge of the execution and management of the works. In the case study, since the State that is a founder of the project does not intend so much to make profits from the investment as rather to generate socio-economic effects on the community, it is considered consistent to assume the following values:

- 30%, acceptability threshold;
- 60%, tolerability threshold.

Because of these values, it is clear that the risk level of the investment is unacceptable for the operator. In fact, the probability of failure is 100%, that is the probability for which $IRR \leq IRR_{lim} = 3.0\%$.

Selection of interventions for risk mitigation

Since the project risk is unacceptable for the investor, mitigation measures must be envisaged to increase the probability of success of the initiative. It has been said that the constant availability of water over time leads to an improvement in soil yield. In turn, this generates an increase in gross saleable production for companies in the transformed area and therefore greater tax revenues for the State. However, the intervention as planned is not feasible for the investor. This leads to envisaging the variation in crop quality as a risk mitigation measure, selecting crops that are more profitable. In fact, the modernization intervention makes it possible to have greater availability of the water resource, which can be redistributed on crops that require more water.

It is estimated that the cultivation of maize, which is taken as a reference both because it is more practiced in the area and because it needs high quantities of water, needs about 4,000 m^3/ha. This water requirement is currently largely satisfied, with a supply of 7,000 m^3/ha. Therefore, the resource savings deriving from the modernization intervention can be redistributed towards more profitable products, incompatible with the current condition. It is assumed to increase the supply to 5,000 m^3/ha, thus making it possible to cultivate vegetable plants such as cauliflower, fennel, lettuce, tomato, and courgette, already practiced in the area but negatively influenced by the scarcity of water. The decrease in benefit connected to the higher consumption of the water resource corresponds to €21,063. Table 4 summarizes the expected results with the mitigation intervention in terms of total GSP.

Assessment of residual risk

The ALARP principle requires evaluating the residual risk, which is the one that remains despite the action taken for its mitigation. To this end, the new probability distribution of the IRR is estimated, as follows from the increase in gross saleable production resulting from the change in crop quality and from the decrease in benefit in terms of lower water savings for irrigation purposes.

Table 5 summarizes the new hypotheses assumed for the probability distribution of the critical variable, 'gross saleable production', while the hypotheses for the 'construction cost' variable remain unchanged.

Table 6 summarizes the calculations results. From the probability distribution of IRR post-mitigation, a significant reduction in the level of risk is evident, which now falls within the ALARP area. The probability of failure, i.e. the one for which $IRR \leq IRR_{lim} = 3.0\%$, goes down to 56%. For details on the results of post-mitigation processing, refer to Figure A4 in the Supplementary Material.

This means that the risk is tolerable only because further mitigation measures would have costs disproportionate to the achievable benefits. The result is in line with the profitability indices of companies operating in the hydraulic works sector in the Campania Region. Specifically, a return of 3% is tolerable because it lies between the profitability of the first quartile company and the average company specialized in hydraulic works in the Campania Region (in Italy). This information derives from the analysis of official data from the AIDA database of the Bureau Van Dijk. This database contains financial and commercial information of more than 500,000 companies active on the national territory.

CONCLUSIONS

The concept of sustainability involves financial, environmental and socio-cultural aspects that it is increasingly important to take into account in economic evaluations. This

Table 4 | Value of the post-intervention mitigation GSP

	Average rainfall				
Crops	**Areas [ha]**	**Price [€/q]**	**Yield [q/ha]**	**Production [q]**	**GSP post-mitigation intervention [€]**
Artichoke	19.44	324.00	130	2,527.83	819,015.65
Cauliflower	12.42	48.81	400	4,967.76	242,476.33
Herbarium	157.70	12.63	300	47,308.70	597,508.83
Alfalfa (1st year)	7.19	166.67	116	834.50	139,086.39
Alfalfa (2nd and 3rd year)	14.39	166.67	180	2,589.83	431,647.43
Fennel	9.18	31.47	350	3,213.21	101,119.74
Lettuce	6.74	35.24	296	1,995.77	70,331.03
Silo-corn	157.70	4.54	505	79,636.30	361,548.82
Aubergine	2.71	42.93	293	793.75	34,075.51
Apple tree	6.62	38.11	340	2,251.51	85,804.86
Bell pepper	2.71	90.00	293	793.75	71,437.12
Tomato	4.06	53.79	559	2,271.52	122,185.15
Courgettes	7.01	51.38	296	2,075.96	106,662.82
Eggplant in the greenhouse	14.31	51.09	490	7,011.90	358,237.97
Bell pepper in the greenhouse	14.31	74.65	490	7,011.90	523,438.34
Total					4,064,575.98

Table 5 | Statistical indexes of the post-intervention mitigation GSP critical variable

Variable: post-mitigation intervention GSP

Statistics	Hypothesis values	Triangular distribution
Number of tests	10,000	–
Base case	4,064,575.98	4,064,575.98
Mean	3,849,268.79	3,851,913.38
Median	3,871,496.92	3,873,916.04
Mode	–	3,954,280.16
Standard deviation	306,911.99	306,772.81
Variance	94,194,967,852.77	94,109,554,491.16
Shift	−0.1705	−0.1965
Kurtosis	2.40	5.40
Coeff. of variation	0.0797	0.0796
Minimum	3,062,615.96	3,054,540.93
Maximum	4,540,883.51	4,546,919.05
Mean standard error	3,069.12	–

Table 6 | Forecasting values and statistical indices of the post-intervention risk mitigation IRR

Forecast: IRR post-mitigation intervention

Statistics	Forecast values
Number of tests	10,000
Base case	0.0318150
Mean	0.0293850
Median	0.0295470
Mode	–
Standard deviation	0.329%
Variance	0.0011%
Shift	−0.1431
Kurtosis	2.62
Coeff. of variation	0.1120
Minimum	0.0192040
Maximum	0.036932
Mean standard error	0.00003

is particularly true when investments in water resources are the object of analysis (Molinos-Senante *et al.* 2012). In fact, these interventions show a high degree of complexity; therefore, they are characterized by multiple risk components, including extra-financial ones, which significantly affect their concrete feasibility (Nesticò *et al.* 2018a, 2018b). For this reason, the risk assessment becomes essential to express judgements of economic convenience on such investments.

The reference literature suggests analysing and evaluating the risk in probabilistic terms. Generally, the risk assessment process is made explicit in the following phases: identification of sensitive variables; risk analysis; risk assessment; definition of mitigation measures. However, no criterion is established to determine whether the residual risk, i.e. the one that persists despite the envisaged mitigation actions, is acceptable to the investor. Moreover, in traditional economic feasibility studies, the benefits that have no market price, such as environmental benefits, are not considered and are therefore underestimated (Molinos-Senante *et al.* 2012).

In order to overcome these limitations, the paper proposes a model for the acceptability of investment risk with the aim of verifying the economic feasibility of water sector projects, taking into account the plurality of the effects that the investment generates on the community, including environmental externalities. The idea is to use jointly the traditional Cost–Benefit Analysis techniques and the ALARP logic, the latter widely used in highly risky sectors such as nuclear, energy, oil and gas. In particular, the ALARP principle leads to establishing whether a risk mitigation intervention has disproportionate costs compared with the benefits obtainable. The attempt to introduce thresholds of acceptability and tolerability to evaluate the residual investment risk makes it possible to define an evaluation protocol capable of supporting the investor in the decision-making process. This is by selecting risk mitigation interventions that maximize the investor's profit, without neglecting the environmental impacts of the investment.

The economic analysis model is tested on a project to restructure the irrigation network in the Province of Salerno (Italy). The purpose of the investment is to offer a sustainable and economically advantageous irrigation service for the greatest number of users. The replacement of the current plant with improved technology allows the reduction of water losses along the network, also reducing the phenomena of contamination of the water resource. The analyses conducted show that the intervention is not economically feasible for the State that financed the investment. In fact, the benefits that can be generated by the modernized plant, both in terms of higher tax rates on the increase in gross saleable production and in terms of saving water and reducing CO_2 emissions, are not sufficient to make the intervention economically sustainable. The analysis of the case study therefore leads to prefiguring a risk mitigation action, i.e. the introduction of new crop qualities able to increase the productive capacity of the companies falling in the transformed area thanks to the greater water supplies. In this way, the probability that the investor has a failure goes down to 56%, i.e. the investment risk becomes tolerable as ALARP. The calculations then show that further risk mitigation options are not foreseeable, since greater increases in the GSP can be obtained only at the expense of excessive consumption of the water resource.

The main limitation of the model concerns the definition of the thresholds of acceptability and tolerability of the investment risk. In the case study, these thresholds derive from qualitative analyses supported by judgements by industry experts. It follows that research prospects concern the quantitative assessment of risk thresholds based on official financial data, capable of expressing both the profitability of the investment sector and the socio-economic characteristics of the area in which the project is located.

The work demonstrates that the proposed innovative protocol for the economic evaluation of interventions in the water sector can be extremely useful in practice if the ALARP logic is integrated into the CBA schemes, so as to reconcile multiple effects, both financial and environmental. This methodological approach, allowing a consistent triangular balancing of risks, costs and benefits, including extra-financial ones, can become an essential tool to support environmental decision-making.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available online at https://dx.doi.org/10.2166/ws.2020.093.

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